The *Prosopis juliflora* - *Prosopis pallida* Complex: A Monograph

NM Pasiecznik

With contributions from

P Felker, PJC Harris, LN Harsh, G Cruz

JC Tewari, K Cadoret and LJ Maldonado

HDRA Coventry UK
2001

Correct citation

Pasiecznik, N.M., Felker, P., Harris, P.J.C., Harsh, L.N., Cruz, G., Tewari, J.C., Cadoret, K. and Maldonado, L.J. (2001) The *Prosopis juliflora - Prosopis pallida* Complex: A Monograph. HDRA, Coventry, UK. pp.172.

ISBN: 0 905343 30 1

Associated publications

Cadoret, K., Pasiecznik, N.M. and Harris, P.J.C. (2000) The Genus *Prosopis*: A Reference Database (Version 1.0): CD ROM. HDRA, Coventry, UK. ISBN 0 905343 28 X.

Tewari, J.C., Harris, P.J.C, Harsh, L.N., Cadoret, K. and Pasiecznik, N.M. (2000) Managing *Prosopis juliflora* (Vilayati babul): A Technical Manual. CAZRI, Jodhpur, India and HDRA, Coventry, UK. 96p. ISBN 0 905343 27 1.

This publication is an output from a research project funded by the United Kingdom Department for International Development (DFID) for the benefit of developing countries. The views expressed are not necessarily those of DFID. (R7295) Forestry Research Programme.

Copies of this, and associated publications are available free to people and organisations in countries eligible for UK aid, and at cost price to others. Copyright restrictions exist on the reproduction of all or part of the monograph. Requests for publications, reproduction and further information should be directed to the authors at the addresses below.

PJC Harris, NM Pasiecznik
HDRA
Coventry CV8 3LG, UK
Tel: + 44 (0) 24 7630 3517
Fax: + 44 (0) 24 7663 9229
Email: pharris@hdra.org.uk npasiecznik@hdra.org.uk

Front cover photographs: NM Pasiecznik, PJC Harris, G Cruz and LN Harsh

Typesetting by Chris Brooke-Harris, Steve Wills & Steve Hammett
Printed and bound by Emmerson Press, Farmer Ward Road, Kenilworth, UK

The Authors

NM Pasiecznik
Senior Research Associate (Agroforestry)
HDRA
Ryton Organic Gardens
Coventry CV8 3LG
UK
Fax: +44 (0) 24 7663 9229
Email: npasiecznik@hdra.org.uk

P Felker
Scientific Advisor
Facultad de Agronomia y Agroindustrias,
University Nacional de Santiago del Estero
Av. Belgrano
CP 4200 Santiago del Estero
Argentina
Fax: +54 385 4212131
Email: peter_felker@hotmail.com

PJC Harris
International Research Consultant
HDRA
Ryton Organic Gardens
Coventry CV8 3LG
UK
Fax: +44 (0) 24 7663 9229
Email: pharris@hdra.org.uk

LN Harsh
Principal Scientist (Silviculture)
Central Arid Zone Research Institute (CAZRI)
Jodhpur 342003
Rajasthan
India
Fax: +91 291740706
Email: lnharsh@cazri.raj.nic.in

G Cruz
Principal Scientist
Universidad de Piura
Ave. Ramon Mugica, Apdo. 353
Piura
Peru
Fax: +51 74 308888
Email: gcruz@udep.edu.pe

JC Tewari
Senior Scientist (Silviculture)
Central Arid Zone Research Institute (CAZRI)
Jodhpur 342003
Rajasthan
India
Fax: +91 291740706
Email: jctewari@cazri.raj.nic.in

K Cadoret
Overseas Research Coordinator
HDRA
Ryton Organic Gardens
Coventry CV8 3LG
UK
Fax: +44 7663 9229
Email: kcadoret@hdra.org.uk

LJ Maldonado
Regional Coordinator
Fundación Produce Nuevo León AC
Av. Constitución 4101, Ote. Col. Fierro
CP 64690
Monterrey, Nuevo León
Mexico
Email: lmaldona@prodigy.net.mx

Acknowledgements

The authors wish to thank those who have supported this project from conception and literature gathering, to reviewing, publishing and dissemination. Thanks are due to the Department for International Development (DFID) of the UK government for funding the production of this and associated publications, through the Forestry Research Programme.

This publication would not have been possible without the support of fellow research and development workers around the world, who freely supplied information, literature and reference lists for inclusion in the monograph and the database. Special thanks are due to those who provided large amounts of literature or information, including: Rieks van Klinken (CSIRO, Australia), Paulo Cesar Lima (EMBRAPA, Brazil), John Beer (CATIE, Costa Rica), Vesa Kaarakka (University of Helsinki, Finland), Yves Dommergues (CIRAD, France), Pierre Sigaud (FAO, Italy), Tony Simons (ICRAF, Kenya), Ousman Diagne (ISRA-DRPF, Senegal), Carl Stoltz (PPRI, South Africa), Rod Dutton (CORD, UK), Hew Prendegast (RBG Kew, UK), Colin Hughes (OFI, UK) and Mark Powell (Winrock, USA).

Many others assisted with provision of literature, information in response to specific questions, or reviews at various stages of the project. Thanks are offered to you all, including: Betánia Amador, Mario Antonino, Hari Behl, Ronald Bellefontaine, Peter Bezkorowajnyj, Eduardo Bonkoungou, Steve Bristow, Willemine Brinkman, Yahya Bukhari, Jeff Burley, Mariano Cony, Pascal Danthu, Ian Dawson, Prabhaker Dubey, Paul Earl, Mohammed El Fadl, Henri Esbenshade, Michael Farrar, Nicanor Herrera, Soren Hald, John Hall, Henry Le Houérou, Mario Lira, Alan Pottinger, Lucy Ramírez, Gurbachan Singh, Zwege Teklehaimanot, Ray Ward, Peter Wood, Sarah Workman, Noel Wright and Helmut Zimmermann. Sincere apologies to others who have helped but who we have not acknowledged.

Thanks to support staff in all collaborating institutes for their involvement. At HDRA, special thanks are due to computer resources, finance and publishing departments. At CAZRI, we would like to offer thanks to the Director Dr Pratap Narain, ex-Director Dr AS Faroda and to the many staff who assisted with the workshop, technical manual and subsequent training. Thanks to Luis Alban and Nora Grados at the University of Piura, Peru, and Carlos Rodriguez Franco, Director of the Forestry Section at INIFAP, Mexico, and also John Palmer and Duncan Macqueen at NRIL, UK and Dr JS Samra, Dr GB Singh and Dr PS Pathak at ICAR, India for facilitating project activities.

Foreword

There is a long list of tropical tree species that have, over the last 30 years or so, appeared to offer outstanding solutions to the land use problems of the tropical and the developing world. Various eucalyptus, tropical and subtropical pines, *Leucaena leucocephala* ('ipil-ipil') are just a few that have captured the stage at different times. The enormous impacts on human food security that resulted from the green revolution suggested to non-foresters and foresters alike that there must be potentially similar increases in yield available from the identification and cultivation of hitherto little-known trees. A major difference between plantation and agroforestry and irrigated agriculture, of course, was that there were many more species of tree than of staple food crops. A result of this has been a concentration of research effort on provenance or land race selection rather than genetic improvement, with some notable exceptions. But 'miracle' trees, as the authors of this monograph remind us, have remained elusive. And introductions and trials of exotic species and provenances have not only provided evidence of rapid growth but have also highlighted risks of them becoming noxious weeds. There is thus a conflict between a tree producing biomass quickly and its potential impact on other species in the farming system and in the rural landscape.

The genus *Prosopis* epitomises this dilemma. Not only does it include species which grow where virtually nothing else will, it also produces food and a high quality wood for fuel and many other purposes. On the other hand its very vigour and competitiveness makes it a formidable invader of other land use systems, such as grazing lands. Furthermore, movement of germplasm between countries in the past has not always been well-documented, so there is often some doubt about the original source and sometimes even about the identity of the species concerned.

The authors of this exhaustive text on the *Prosopis juliflora - Prosopis pallida* complex have produced an information source which is a landmark in the clarification of many of these issues. No book is the final word on its subject but this one should last a long time and provide a vital and accessible source of information for scientists, managers, farmers, foresters and students. As for the future of the genus and this particular species complex, its continuing contribution to human welfare will depend on usable knowledge and its application, which is the basis of wise management. In my view, informed managers will be wise to have this book at their elbow.

Peter Wood
March 2000

Preface

Prosopis juliflora and *Prosopis pallida* are two of the most economically and ecologically important tree species in arid and semi-arid zones of the world. Considerable literature on these species exists in various languages, as scientific and popular papers, books and as 'grey literature', published in regional or less well known journals. The most complete sources of information on the *P. juliflora - P. pallida* complex are the published proceedings of several national and international conferences, comprising carefully selected collections of papers on research and development topics. However, few attempts have been made to synthesise this information into comprehensive, concise and authoritative reviews. This monograph draws on all the above sources, with approximately 650 bibliographic references included.

Finally, it is possible to gain a deep understanding of the *P. juliflora - P. pallida* complex from a single comprehensive synthesis. Along with the associated outputs of a reference database (on CD ROM) and a technical manual aimed at the Indian context, this publication provides information which aims to improve the management and utilisation of this valuable natural resource, thereby improving the well-being of those people whose livelihoods depend to some extent, on these most resilient of trees. *P. juliflora* and *P. pallida* have similar morphology, are known to hybridise, and, due to the uncertainty of seed origin of introduced species, it appeared prudent to cover the entire complex in this publication. These species are truly tropical, and have consistently out-performed other *Prosopis* species in growth trials in the hot, arid tropics. Further comprehensive reviews are also required on other important *Prosopis*, notably the many sub-tropical species, such as *P. glandulosa* and *P. velutina* from North America and *P. chilensis* and *P. alba* in South America. Three other distinct species, *P. africana*, *P. cineraria* and *P. tamarugo*, are important in their native ranges and are also worthy of detailed publications.

The book is divided into four chapters, each intended to be free-standing. They can be read in any order, and thus some repetition of information is inevitable. While dealing principally with the *P. juliflora - P. pallida* complex, this monograph also describes aspects of the entire genus for clarity, and characteristics of other closely related species where deemed appropriate. The first chapter opens by stating the importance of the *P. juliflora - P. pallida* complex and how and why these species were selected for special attention, before describing the genus *Prosopis* in general and its relationship to humankind. Chapter two covers the complicated area of *Prosopis* taxonomy, also species descriptions, biology and ecology, giving a clearer understanding of what the species are, where they are found and how they function and interact with the environment. Chapter three describes in detail the *P. juliflora - P. pallida* complex as a human resource, the composition, roles and production of tree products. The final chapter then covers the management of the trees as resources, including nursery production, establishment, managing native stands and weedy invasions, and processing tree products. A concluding section identifies areas for future research and development.

The *P. juliflora - P. pallida* complex already provides many of the needs of populations living in tropical dry zones the world over but has great potential to provide much more, with the application of knowledge contained herein. However, this monograph does not aim to promote *Prosopis* as 'miracle trees for the future' or 'Cinderella species'. Complex problems require complex solutions, and a better understanding of the species can only help in identifying possible development pathways. No single species should ever be seen as the sole answer but rather as a tool in the continuing fight against poverty, desertification, land degradation and resource depletion. Government officials, administrators, researchers, development workers, charity and aid workers, all need to take newly obtained knowledge on board and see that it reaches those who most need it, for 'development' to occur. This is, however, so often the missing link in the chain of development. It is not the lack of knowledge *per se*, but the lack of knowledge of how to apply it that prevents uptake and subsequent development. For this to occur, more subtle changes are required, best summarised by the late Lawrence Roche; "A direct attack on rural poverty through a widespread revolution, green or red, is improbable, and would as in the past have mixed effects. A better life for disadvantaged rural people may be more feasibly sought through a different sort of change: through quiet personal revolutions in the perceptions, values and choices of professionals concerned with research technology and action for rural development" (Roche 1986).

Nick Pasiecznik

Contents

Chapter 1 People and *Prosopis*

Chapter 2 The species

Chapter 3 The complex as a resource

Chapter 4 Husbandry and management

Chapter 5 Recommendations

Chapter 1

People and *Prosopis*

1.1 Introduction

1.1.1 The place of *Prosopis* in rural development

> *"The rebellious sands are subdued and the inhospitable soils are colonised. The dreary scene of dry districts is changed to that of green belts. The bleak tree-less landscape is painted with splashes of brown, green and yellow. The monotony is broken for the traveller and the sheep and goats munch and crunch happily on the proteinous pods. The rural folk, whose lands were getting buried under drifting sands are grateful to the Forester and Prosopis, and the poor folk who had no fuel to burn in their hearths now have Prosopis. They collect the fuel in their leisure and sell in towns for a decent price" (Reddy 1978).*

So wrote CV Konda Reddy in 1978, on the introduction of *P. juliflora* into Andhra Pradesh, India a century earlier, and the effects this had had on the local people and environment. The main present use of *Prosopis* is as a source of fuel, often the major source of firewood and charcoal in areas where these trees are found. Pods of *Prosopis* species are a valuable source of carbohydrates, sugars and protein for livestock and, occasionally, human populations, and the timber still has a minor use in construction and furniture manufacture. In their native range, and occasionally where introduced, these uses for *Prosopis* have often arisen because they are the only, or the dominant, tree species. Their multi-purpose nature, with the potential to provide a wide range of products is advantageous, as is their ability to grow on the poorest of soils where few other useful species can survive. They can reclaim such sites allowing for removal after a single rotation and replacement with a more profitable crop. Their importance is positive, in terms of the provision of raw materials, but also negative, in terms of weediness reducing agricultural productivity.

The historical context of *Prosopis* and different opinions have led to the present position with two widely held points of view. There is one argument for further planting and improved management and another for eradication and control. An important factor is whether trees are native or introduced. In native ranges, there is often a respect for the tree and products, over-exploitation and stand depletion. This has stemmed from a knowledge of the value of tree products, unsustainable harvesting and land clearance which have led to the loss of large areas of *Prosopis* native range in recorded history. Where it is an exotic on the other hand, there is often a lack of trust, under-exploitation and resource wastage, resulting from a contrasting lack of knowledge of the potential of these species, poor management and natural and man-induced spread. There are, however, sustainable or at least durable systems in native and exotic ranges, that include *Prosopis* species as a main component. Trees are harvested for pods, fuel or timber and incidentally for many other products, and continue to be planted by national forestry departments and international organisations. They are seen to fulfil roles in both production and protection. There have been substantial areas of plantations established and many farmers and foresters report only positive qualities of *Prosopis* trees. They continue to be promoted as valuable multi-purpose species for dry zones.

There are many who dislike the genus as a whole because of problems of *Prosopis* species as invasive, thorny weeds. Common views on *Prosopis* species include their effects in denuding grassland ranges, invasion of water courses and drying up rivers and water tables. These views are common both where they have spread in native ranges and where they have been introduced. Some species are valued where they are exotic and cultivated and some are well utilised even where they are invasive. The opinions of ranchers and land-owners in Texas following heavy invasion by *P. glandulosa* ('mesquite') were summed up by a comment on *Prosopis* invaded grassland in Texas, USA, "mesquite is something more than a tree, it is almost an elemental force, comparable to fire - too valuable to extinguish completely and too dangerous to trust unwatched" (Peattie 1953).

Several *Prosopis* species that are very important in their native ranges are rarely, if ever, seen as weedy species but also have not successfully been introduced into other parts of the world (Pasiecznik 1999). Such species include *P. africana*, *P. cineraria* and *P. tamarugo* which are from sections of the genus other than the section Algarobia, which contains most species of economic importance (see 1.2.1, 2.1.1). Remaining tree species of section Algarobia are all closely related and most hybridise readily. It is only species from this section that have been successfully introduced, and it is only these that have become invasive weeds. However, these are the same species that have been noted as producers of large quantities of raw materials required by local populations. There are still species of this section that remain untested outside of their respective native ranges but are regarded as having potential in sub-tropical regions.

The value of *P. juliflora* and *P. pallida* for providing many much needed resources for the poor is generally accepted, with views for and against *Prosopis* coming from different quarters. The popularity of *P. juliflora* is income related, those that can afford bottled gas for cooking and do not have to raise livestock quickly forget its value as a fuel and fodder tree. Comments concerning its monoculture, lack of aesthetic value and unconfirmed beliefs on the lowering of water tables come only from the more affluent. Rural farmers are invariably aware of its importance (Pasiecznik 1998). *Prosopis* is generally the scourge of ranchers and pastoralists but a boon to the rural poor. There are concerns over the weediness, effects on grass growth and level of water tables, presence of long thorns and allergic pollen in several regions. However, the poorest of farmers acknowledge these trees for their benefits. In contrast to negative views of *Prosopis* as a weed, *Prosopis* provides up to 70% of the firewood needs of rural populations in dry regions in India. It was declared a 'Royal Plant' in Rajasthan in 1940, being promoted as a useful and productive species for the arid zone (Muthana and Arora 1983).

In Brazil, Silva (1990b) details many accounts of the desirable attributes of *P. juliflora* and the benefits for the North-East region following introduction. "Upon the understanding that only when a certain species has proven its economic value, confirmed by public acceptance, an objective and realistic forest policy can be undertaken.... (and) that *P. juliflora* ought to be made the basis of that policy" (Borba 1970, in Silva 1990b). "Although we always regard with great reservations the urgency with which attempts are made to introduce certain plant species in the country, we must state that, in the present case of *P. juliflora*, there is no qualm regarding the government's intentions with respect to the spreading of this valuable plant in regions with xerophytic vegetation in the semi-arid Northeastern region" (Guerra Filho 1963). "Every city ought to have a mixed municipal forest where *P. juliflora* were numerous. Under their canopy temperature becomes less hot and more pleasant" (Carvalho 1963).

Elsewhere, *Prosopis*, and particularly species of the *P. juliflora - P. pallida* complex, have also been welcomed as introduced species and their various virtues have been expounded. In Hawaii, Colonel L.W. Bryan stated that, "the kiawe (*P. pallida*) is still the most valuable tree ever introduced to the Hawaiian Islands" (Esbenshade 1980). In Africa, "*P. juliflora* has proved extremely useful in the arid zones of Sudan" (Wunder 1966), while its roles as a sand dune stabiliser and fuelwood tree in West Africa, as a shelterbelt and living fence in the Sahelian zone, and as a shade and fodder tree in southern Africa are well noted.

1.1.2 Introducing the *P. juliflora - P. pallida* complex

The genera *Prosopis* and *Acacia* contain some of the most widespread and important tree species in the arid and semi-arid zones of the tropical and sub-tropical world. Species of these two genera were estimated to occupy some 3.1 million square kilometres (Griffith 1961). Of the 44 *Prosopis* species recognised by Burkart (1976) (see 2.1.1), not all are of economic importance. Many are shrub species of limited value. Of the tree species (see Table 1, 1.2.1), half have small native ranges and have not been widely introduced, and less than ten have received considerable attention. Of these introduced and well-researched species, most are more sub-tropical with only two being truly tropical and frost sensitive. The truly tropical *P. juliflora* and *P. pallida* can be treated together for several reasons. They are mostly geographically distinct from other *Prosopis* species in regards to their native ranges (see 2.4.1). Neotropical and sub-tropical species such as *P. alba*, *P. chilensis* and *P. glandulosa* are frost tolerant and often deciduous in winter months. *P. juliflora* and *P. pallida* are killed to the ground without any resprouts at temperatures of only -6°C, while this temperature causes virtually no damage to *P. alba, P. chilensis and P. glandulosa* (see 2.4.3). *P. juliflora* and *P. pallida* are considerably more frost sensitive than even *Leucaena leucocephala*. Secondly, these species have their origins in frost free tropical regions of Peru and/or Central America with the result that their genetic affinities and environmental tolerances are very similar. Following introduction and spread, the *P. juliflora - P. pallida* complex occupy a far greater area than any other *Prosopis* taxa in frost-free regions (see 2.4.1).

P. juliflora and *P. pallida* are generally similar in terms of flower, pod and leaf morphology as well as tree form. They are, however, distinct from most other species in terms of these characteristics and can be generally differentiated on these grounds. With naturally occurring hybridisation, which is thought to occurs in the overlapping ranges of *P. pallida* and *P. juliflora*, and the great variation within and between varieties, forms and land races, few taxonomists world-wide could claim to be able to differentiate between these two species. Burkart (1976) provided the most comprehensive taxonomic treatment of the genus to date, describing these two species and varieties, forms and hybrids, subsequently described by Ferreyra (1987) and Díaz Celis (1995) with some variations. Differences in leaf shape between common *Prosopis* species are shown in Figure 2 (see 2.2.1). Keys to the tropical *Prosopis* of Peru that distinguish *P. pallida* from *P. juliflora* on the basis of morphological characteristics are presented in 2.2.3.

As with all *Prosopis*, it is possible to find individuals that perfectly fit the species description, but with the extensive interspecific hybridisation that occurs, a substantial percentage of the population often cannot be assigned to a single species. Introductions of germplasm of unknown or poorly documented provenances and crossing with subsequent introductions has resulted in exotic populations with characteristics of both of these species and their varieties. This justifies dealing with both species, and all references and literature pertaining to either species, as the *P. juliflora - P. pallida* complex. Other *Prosopis* species may also be conveniently grouped into 'complexes' or 'species groups' based on molecular similarities, bio-geography and resource character. For example, the '*P. glandulosa* complex' could be used to describe all *Prosopis* species of section Algarobia north of the Tropic of Cancer, while in South America, sympatric and closely related species could be grouped. For example the '*P. alba - P. chilensis* complex'.

The *P. juliflora - P. pallida* complex has attracted much attention from researchers, development workers and policy makers for the reasons previously discussed. These species have been the subject of three major international symposia on *Prosopis* (Habit and Saavedra 1990, Dutton 1992, Felker and Moss 1996) and numerous national conferences. The complex is both highly regarded, for providing fuelwood to rural populations such as in India (Muthana and Arora 1983), and the subject of eradication campaigns such as in Sudan where it is declared a noxious weed. It is, however, one of the most resilient species for use in Sahelian Africa, occurring from Senegal (Diagne 1996) through Niger (Butterfield 1996) and Sudan (Bristow 1996) to Somalia (Zollner 1986). It is the major charcoal species in Haiti (Lee *et al* 1992) and in Gujarat, India (Varshney 1996).

It is used to reclaim high pH (10.4) soils on mismanaged irrigated land in India (Singh 1995) and for sand dune control in Pakistan (Ahmad *et al* 1996) and Sudan (Bristow 1996). In Peru, the long sweet pods have been used for human foodstuffs for centuries. Current research in Peru is being directed at more efficient preparation and utilisation for human food (Grados and Cruz 1996). The recent demonstration of fast-growing, erect, thornless individuals with sweet pods of the same Peruvian *Prosopis* families in Haiti (Wojtusik *et al* 1993), Cape Verde (Harris *et al* 1996a) and India suggest much promise for development. Elite trees from the Haitian and Indian trials have been cloned for further use, and work is continuing on the cloning of superior wild trees, assumed to be *P. pallida*, in northern Peru.

Lastly, from an economic development perspective, trees referred to as *P. juliflora*, where introduced, for example in Haiti, India and Sudan, have problems with thorniness, weediness and pods with low-sugar and low palatability. In contrast, seeds taken directly from Peruvian *Prosopis*, possibly *P. pallida*, have produced erect, thornless individuals with faster biomass production in tropical regions of Haiti, Cape Verde and India than other '*P. juliflora*' or other subtropical species such as *P. alba* and *P. glandulosa*. Many of the problems faced where *Prosopis* has been introduced may be due to the introduction of poor genetic material of *P. juliflora*. Seed from Peruvian material assumed to be *P. pallida* is less likely than *P. juliflora* to be thorny, shrubby or invasive when introduced. A solution to many of the problems with exotic *P. juliflora* in tropical regions may be to use seed or clonal material where possible, from Peruvian and Ecuadorian *P. pallida*.

1.2 *Prosopis* species as a resource

1.2.1 Species choice

Of the many *Prosopis* species, only a few are of major economic importance. *Prosopis* species vary widely in their productivity and their relative use and utilisation by humans, primarily pods for food and fodder, and wood for fuel and timber. Characteristics preferred by humans are the production of large amounts of sweet pods, and rapid growth of erect trees with an ability to survive and thrive in poor soils and under drought conditions. In general, it is only the tree rather than shrub that have gained importance and more so those which dominate wide native ranges and produce the sweetest pods. General characteristics of all *Prosopis* tree species in relation to their use by man are given in Table 1. All species listed are utilised as a source of fuel, fodder and occasional timber to varying degrees. All are nitrogen fixing.

The species native to Africa and Asia, notably *P. africana* and *P. cineraria*, are less adaptable to other areas and do not establish well if introduced to different regions (e.g. Felker *et al* 1981a, Harris *et al* 1996a), probably due to specific environmental requirements which are not understood. Other species that have rarely been successfully introduced are those of section Strombocarpa, notably *P. tamarugo* and *P. pubescens*, again assumed because of the specific conditions found in their respective native ranges, particularly so for *P. tamarugo*. The four aforementioned species are important in their respective native ranges and are sufficiently distinct in terms of their characteristics to merit separate detailed studies. Thus, concentration is given in the following description of tree products to the *Prosopis* tree species of section Algarobia, being most widespread in the world and having the most attributes as a human resource.

No attempt will be made to distinguish between the many different uses and names given to a wide range of products made from various *Prosopis* species by a large number of tribes and cultures throughout the ages. Rather, the generic uses and names of *Prosopis* products are presented, principally from three main desert areas of the Americas, in the present day countries of USA/ Mexico, Peru/ Chile and Argentina/ Paraguay. These areas are those that have received the most relevant research and which contain widespread *Prosopis* forests. The following sections describe the products of many trees of the genus *Prosopis*, while specific knowledge of the *P. juliflora* - *P. pallida* complex as a resource is detailed in Chapter 3.

1.2.2 Tree products

Wood

The wood is probably the single most important natural resource from *Prosopis* species for use either as a fuel or for structural purposes (see 3.1). As a fuel it can be burnt directly or made into charcoal, and as a timber it can be used as poles or roundwood or cut into boards and cants. The use of the wood from *Prosopis* depends very much on the form of each *Prosopis* species, with shrubby species having limited value as a fuel and no value at all for structural purposes. Tree species with the potential of producing larger volumes of straighter branches and trunks have always had greater importance as sources of fuel and timber for local populations.

Prosopis species produce a wood which is a very high quality fuel, having a high calorific value of approximately 5000 kcal/kg (NAS 1980, FAO 1997). Fuel value varies between

Table 1. General characteristics of* Prosopis *species which can attain a height of over 7 m (adapted from Burkart 1976).

Species	Max height (m)	Native range (approx.) *	Section	Thorn length (mm)	Frost tolerance **	Salt tolerance	Weedy invader
P. alba	5-15	Argentina	Algarobia	0-40	some	some	some
P. africana	4-20	Africa	Anonychium	0	none	some	no
P. affinis	2-8	Argentina	Algarobia	3-25	some	some	some
P. caldenia	4-12	Argentina	Algarobia	5-25	yes	no	yes
P. chilensis	3-10	Argentina	Algarobia	0-60	yes	yes	yes
P. cineraria	-7	Asia	Prosopis	3-8	yes	yes	some
P. flexuosa	3-10	Argentina	Algarobia	0-40	some	some	some
P. fiebrigii	4-15	Argentina	Algarobia	2-10	some	some	no
P. glandulosa	3-9	N. America	Algarobia	10-45	yes	yes	yes
P. hassleri	6-10	Argentina	Algarobia	0	some	some	no
P. juliflora	3-12	C&S America	Algarobia	0-50	none	yes	yes
P. kuntzei	4-10	Argentina	Algarobia	80-500	some	some	some
P. laevigata	3-7	N. America	Algarobia	5-25	yes	yes	some
P. nigra	4-10	Argentina	Algarobia	0-35	some	yes	some
P. pallida	8-20	Pacific	Algarobia	0-40	none	yes	yes
P. pubescens	2-10	N. America	Strombocarpa	2-20	yes	some	some
P. pugionata	2-8	Argentina	Algarobia	20-95	some	some	some
P. ruscifolia	5-12	Argentina	Algarobia	10-330	some	yes	yes
P. tamarugo	-18	Pacific	Strombocarpa	5-38	some	yes	no
P. velutina	-15	N. America	Algarobia	10-20	yes	some	yes
P. vinalillo	3-10	Argentina	Algarobia	5-120	some	some	some

** - For more exact limits to native ranges see the distribution map (Figure 14, 2.4.1). North America signifies southern USA and Mexico; Central and South America denotes southern Mexico to northern Peru. The Pacific coast includes the tropical coastal and Andean region from northern Chile to Ecuador. The Argentinean region also includes parts of Uruguay, southern Brazil, Paraguay, Bolivia and northern Chile.*
*** - Absolute frost tolerance is dependent upon absolute minimum temperature, duration at this minimum, and length of time below freezing point. However, the frost tolerance can be approximated to: 'none' = killed at -5°C, 'some' = killed between -5°C to -15°C, and 'yes' = tolerates temperatures below -15°C.*

and within species, with calorific values from 4200 kcal/kg for *P. alba* to 5065 kcal/kg for *P. tamarugo* (Cuevas *et al* 1985) and 4200-4800 kcal/kg for *P. juliflora*. The wood does not spit, spark or emit much smoke, burns slowly with a hot and even heat, and is referred to as 'wooden anthracite' by some sources (NAS 1980). The wood contains aromatic hydrocarbons, and the smoke from some species is said to impart a pleasant flavour to food cooked over it (Maga 1986). Although the wood burns better when dry, a great advantage over some other species is an ability to burn well when freshly cut or 'green', although heat output is reduced as heat is needed to evaporate the moisture. Drying is thus not essential, reducing losses from theft or natural decay.

The charcoal obtained from the wood of *Prosopis* species is also of very high quality and can be produced as easily from green wood as from dried wood. Ten kg of green wood will make 1-2 kg of charcoal using traditional earth kilns, normally in 2-4 days (Lea 1996, Varshney 1996). Fuel from *Prosopis*, whether as fresh or dry wood or as charcoal is very often the preferred fuel of local populations (Vimal and Tyagi 1986). *Prosopis* species also have growth characteristics that make them very suitable as a source of fuel (NAS 1980). As well as growing quickly, and in dry or poor soils where little else may grow, they also coppice very well, resprouting rapidly following harsh and repeated cutting without showing any detrimental effects on plant health.

The heartwood of *Prosopis* species is strong and durable, hard and heavy. The specific gravity of wood of different species is given as 0.7-1.0 (NAS 1980), but wood density is in the range 700-1200 kg/m^3. The wood of *P. tamarugo* is generally the heaviest of common *Prosopis* species tested, followed by *P. chilensis*, *P. pallida*, *P. glandulosa* and *P. juliflora*. The wood has a relatively high dimensional stability over other timbers meaning less shrinkage and cracking, and abundant wood elements give a high tensile strength (Tortorelli 1956, Weldon 1986). Volumetric shrinkage varies from 3.3 to 3.4 for *P. alba* and *P. chilensis* (Turc and Cutter 1984, FAO 1997), to 4.7 for *P. glandulosa* (Rogers 1986), and to 8.6 for *P. tamarugo* (Cuevas *et al* 1985). Data for radial and tangential shrinkage differ similarly between species, ranging from 0.8 (radial) and 2.3 (tangential) in *P. chilensis* to 2.8 and 5.6 for *P. tamarugo* (Cuevas *et al* 1985). The heartwood is dark red to dark brown in colour, very distinct from the much lighter, often yellow-coloured sapwood, which is generally much more susceptible to attack from insects and is more quickly degraded. The colour of the heartwood tends to be lighter when freshly cut, taking on a darker, more intense colour after exposure to light.

Branches or coppice shoots of various dimensions serve as posts for fencing, chosen in preference to those of other species because of availability, suitable size and durability. For fence posts, relatively straight branches and shoots over 1.5 m long are required. They will often last at least ten years, with up 30-40 years recorded in some arid areas in Hawaii (Esbenshade 1980). Larger dimension roundwood is used in the construction of rustic housing, for pillars, supports, roof beams and as door and window frames, and also for pilings and ship building (Felger 1977, Díaz Celis 1995). The wood can be cut and worked for the production of household items and agricultural tools. It can also be cut into cants and boards for a variety of uses, the wood preferred over other species, again, for its strength and durability.

Although the wood is hard and heavy, it generally works well and takes a good finish (NAS 1980). Indigenous knowledge from North America states that wood is easier to cut in the summer months, when the moisture content is higher (Felger 1977). Summer cut wood is less durable, however, being readily attacked by wood boring beetles, and requires treating before structural use. This was traditionally carried out, by either scorching or drying around a fire, or soaking in water for a week and sun-drying. This latter method is said to produce wood that is lighter and easier to transport by pack animals (Felger 1977). For detailed descriptions of *P. juliflora* and *P. pallida* wood, see 3.1.

Pods

The fruit produced by *Prosopis* species are legume pods, high in sugars, carbohydrates and protein (see 3.2). Pods have been a historic source of food for human populations where *Prosopis* species are found, increasingly becoming less important as a human food and more important as a livestock feed during the last few centuries. Pods vary considerably in size between species and even between populations and individual trees of some species. Pods of Afro-Asiatic species tend to be 3-12 cm long, while the American species are generally divided into two groups. The smaller and spiralled pods, 2-10 cm long, belong to species of sections Strombocarpa and Monilicarpa (see 2.1.1), while the most commonly utilised longer and straighter pods, 10-45 cm long, belong to species of section Algarobia. All American species are heavily attacked by seed eating insects, mostly bruchid beetles, which can destroy over 25% of the seed produced, affecting most pods.

Pods of all *Prosopis* species are composed of an exocarp, a sometimes fleshy mesocarp, fibrous endocarps and hard seeds. The form and relative amounts of each varies widely between species, with several *Prosopis* species having a high percentage of mesocarp favoured as a source of food and feed. The mesocarp varies in taste from tart and bitter to the sweet pods preferred for human and animal consumption. Succulence also varies, from dry, fibrous pods to moist, sweeter pods. The chemical composition of the mesocarp varies widely between species and even between individual trees. For a single species, pod protein content tends to be consistent between sites and seasons, whereas sugar content exhibits some variation (Odoul *et al* 1986). There have been no anti-nutritional factors detected in the pods in regard to human consumption (Becker and Grosjean 1980, Grados and Cruz 1996).

Pods from species of section Algarobia contain 7-22% protein, 30-75% carbohydrates, 11-35% crude fibre, 1-6% fat and 3-6% ash (e.g. Odoul *et al* 1986, Galera *et al* 1992, Anttila *et al* 1993, FAO 1997). Large variations are observed between species, within species and between different trials. *P. juliflora* tends to show the largest variation in pod proximate composition of species in section Algarobia tested (see 3.2). Protein content is relatively consistent between all species, with *P. juliflora* recording the highest and lowest values. There are broad ranges in carbohydrate levels, which appear to vary more within a single species than between species indicating wide provenance variation. Differences in crude fibre observed may be because of different pod parts being analysed or different methods of analysis employed.

Prosopis trees produce high yields of fruit compared with fruit yields from other tree species growing in similar environments. *Prosopis* trees generally initiate flowering and fruiting in the third or fourth year after germination, much earlier under optimal conditions, but often considerably later under drought conditions or very poor soils. Fruit yields increase gradually up to 10-20 years and may be expected to continue at this high level for several decades (Lima 1990a). Fruit production is, in general, inversely correlated to rainfall and, in sub-tropical climates, also to minimum winter temperatures (Lee and Felker 1992). Yields as high as 100 kg/yr, and often 20-50 kg/yr have been recorded for single trees. Per hectare production is highly variable ranging from 1 to 8 t/ha/yr (see 3.2). This is a significant proportion of mean net annual biomass production estimated for some of the systems where *Prosopis* trees are found.

Prosopis species produce fruit every year and can be termed an ‘unfailing crop’ (Simpson 1977). They produce a greater yield of pods in years of below average rainfall but may produce low yields of pods in very wet years. Fruiting season varies, with one or two periods of main fruit production, or fruiting may be almost continuous. These are characteristics that make them very suitable as a source of food and/or fodder, also with deep roots accessing water tables making them less dependent on rainfall for the production of fruit. This is a very important attribute in arid and semi-arid zones, where the production of other food crops, whether wild or cultivated, is highly dependent on the rainfall. The need for alternative, unfailing crops, generally the fruit of mature savanna trees, is important for human populations living in desert regions. Pods have been an essential food source for indigenous peoples throughout the Americas (Felker 1979).

The fruit also helps sustain human life by providing a valuable source of food for animal species in most trophic levels of the ecosystems in which they are found. This supports biodiversity and system stability. Where *Prosopis* are common, pods are an invaluable source of food for wild animals which are hunted by man. Direct consumption by humans, even as a staple food, has not resulted in any recorded harmful effects on health. However, there are records of ill effects on livestock, particularly cattle when fed almost exclusively on pods of *Prosopis* species from section Algarobia (e.g. Silva 1990b). Symptoms such as facial contortions, an impacted rumen and constipation, occasionally resulting in death have been reported in the USA, Hawaii, Mexico, Brazil, Argentina, Sahelian Africa and India (see 3.2).

Leaves

Leaves of *Prosopis* species, although not eaten by man directly as a food source, are often consumed indirectly when used as a food for animals (see 3.3). The use of leaves varies widely between *Prosopis* species and between the different animals that may consume them. A minority of species are known to have leaves which are palatable to livestock and which are highly valued as a source of fodder or forage. All the Afro-Asiatic species have palatable foliage, while only a few of the American species have foliage that is readily consumed by all livestock. The three main fodder species are *P. africana*, *P. cineraria* and *P. tamarugo*. Tender green shoots and young leaves of all species are occasionally consumed by livestock, particularly when limited alternate forage is available. Leaves of all species are eaten only when no other fodder is available (Lee *et al* 1992).

Immature foliage and dry, fallen foliage both have higher palatability than mature, fresh foliage on the tree. Leaves of palatable species can be eaten directly off the plant or from lopped branches. Management systems including palatable *Prosopis* species generally involve lopping, up to three times per year with *P. cineraria* (ICFRE 1993), and the foliage is of greatest value at the end of the dry season when there is little other green forage available for livestock. There is also some seasonal variation in the relative chemical composition of *P. cineraria* leaves (Gupta and Mathur 1974, in Arya *et al* 1992). There are also reports of *Prosopis* leaves being used as a soil additive, composted, added directly as a mulch, or incorporated into the soil where they fall (Alzamora 1988). A large quantity of leaf material is produced and is known to have a major beneficial effect on soil quality (Singh 1996) (see also 3.3.2).

The chemical composition of leaves of common *Prosopis* does not vary greatly between species. The palatable *P. cineraria* has foliage with a crude protein content of 11-18%, crude fibre 13-22%, nitrogen free extract 43-59%, ash 6-12%, calcium 1.5-3.8% and phosphorus 0.3-1.8% (Arya *et al* 1995). The unpalatable *P. juliflora* has crude protein levels of 14-22%, crude fibre 21-23%, nitrogen free extract 43-50%, calcium 1.5% and phosphorus 0.2% (Bhandari and Govil 1978, Anttila *et al* 1993). *P. pallida* leaves were found to have a nitrogen content of 3.5-4.3%, phosphorus (P_2O_5) of 0.4-0.7% and potassium (K_2O) of 1.0-1.4% (Alzamora 1988). Mineral content in the foliage has also been observed to be directly related to the levels of minerals in the soil (Sharma 1968, Rhodes and Felker 1988), therefore site may be more important than species in determining leaf mineral content. Cline *et al* (1986) noted that levels of leaf phosphorus were proportional to levels of leaf nitrogen, and suggested the importance of soil phosphorus for nitrogen fixation. The concentration of sodium was also found to increase substantially on saline soils, with a subsequent reduction in phosphorus levels (see 3.3).

Honey and wax

Prosopis flowers are a valuable source of bee forage (see 3.4.1). Flowers are small, produced in inflorescences of various sizes and shapes but generally in spike-like racemes 5-15 cm long. The flowers produce copious quantities of pollen and nectar over relatively long periods of time, as a nutritive reward for potential insect pollinators. Larger bee species with longer flight ranges are thought to be the principal pollinating agents (Simpson *et al* 1977). *Prosopis* honey is light yellow in colour and generally of good quality with a pleasant taste and only a slight aroma.

Honey is still collected from wild colonies, but an increasing amount is produced in fixed or mobile hives in commercial apiculture. Traditional collection involves the location of wild colonies in the forest, smoking of the bees and removal of the comb and subsequent processing to separate the honey and the wax. Apiculture has been recorded from most regions where *Prosopis* species are native and widespread, and from several areas where introduced. Mexico is the world's largest exporter of honey, and much referred to as 'acacia' honey may actually derive from *Prosopis* flowers. Large amounts of top quality honey were exported from Hawaii for several decades, based on the large woodlands of introduced *P. pallida* (Esbenshade 1980). Wax is another important product of value for the production of candles and in pharmaceutical preparations (see also 3.4.1).

Exudate gums

Exudate gum is produced from natural wounds in the bark of plants as a defence mechanism but can be stimulated by artificial wounding (see 3.4.2). References to *Prosopis* 'gum' are sometimes ambiguous, as seed gums are also used. *Prosopis* exudate gums are water soluble, liquid and yellow when fresh, slowly hardening and darkening in colour. Old gum, as found in resin pockets in the wood can be very hard, crystalline in structure and almost black in colour. Water soluble gums have traditionally been produced from *Acacia* species, particularly A. *senegal*. This gum is of the highest quality and is the benchmark with which all other exudate gums are compared. Comparison of *Prosopis* gum with gums from traditional gum producing species show that *Prosopis* species produce gum of similar quality, with that of *P. juliflora* being almost identical in chemical composition to that of A. *senegal* (Anderson 1986).

Prosopis gums were chewed and eaten by some North American tribes and used in the manufacture of confectioneries. Gum, or bark covered with gum, was used in North America to produce a *Prosopis*-derived paint for skin, pottery and leather or as a basketry dye (Felger 1977). These uses have been replaced by the modern uses of gum, primarily as a food additive, emulsifier and thickener, as a raw material for making adhesives and sizing cloth, and in food and pharmaceutical preparations (e.g. Vimal and Tyagi 1986). In India, the gum is said to have a bitter taste and is used increasingly in the manufacture of textiles and adhesives. Collection of *P. juliflora* exudate gum is an important activity in Gujarat, India, where trees are harvested in the dry season (March-June). Approximately 1 kg of gum can be collected in a working day (Tewari 1998). A simple treatment has been developed in India that stimulates mean average production of exudate gum to over 0.5 kg/tree/year (Tewari *et al* 2000)(see also 3.4.2).

Tannins, dyes and fibres

The original name of *Prosopis* in North America is 'misquitl', from the use of tree bark as a tanning agent, with bark containing 14-16% catechol tannins (Doat 1978) (see 3.4.3). The tannin content of various plant parts from different species of *Prosopis* is 6-20%. Bark tannin along with that found in the wood and fruit extracts, is used in the tanning and curing of animal skin, particularly cattle hides in leather production. This generally involves the boiling of plant parts to extract the tannin. Fibres have also been made from some *Prosopis* species. Roots, with bark removed, were used in North America to make strong ropes, regarded as a valuable possession (Felger 1977). Fibres from the inner bark have also been used, and both have been employed in basketry (Felger 1977). A root extract was used to prepare a brown-purple colorant for the dyeing of cotton and other materials (Díaz Celis 1995). Bark and gum was used to produce paints, dyes, cosmetics and hair cleanser (Felger 1977), (see also 3.4.3).

Medicines

Many medicinal uses have been recorded for extracts from *Prosopis* plant parts from studies on the ethnobotany of populations in areas of the entire native range of the genus (see 3.4.4). Three main groups of ailments are treated with leaf and bark extracts: mouth and throat infections including ulcers and bronchitis; internal diseases including general pains, parasites and urinary disorders; and skin disorders, dermatitis and parasitic infections. In Asia, medicinal uses for native species include flowers for the prevention of miscarriage, bark extracts for the treatment of leprosy, dysentery, bronchitis, asthma, leucoderma, tremors and rheumatism. Leaf smoke is used to cure eye infections and extracts are recommended against snake-bites and scorpion stings (ICFRE 1993). In Africa, similar uses have been recorded where the native species is a valuable source of medicines (Neuwinger 1996).

In South America, preparations from fresh buds of various species are used to treat conjunctivitis. Leaf preparations are used to mend broken bones or cure didropesia, liver stones, dyspepsia and venereal disease, and are often mixed with other products (D'Antoni and Solbrig 1977). These preparations have also been recorded as treatments for mouth infections, ear ache, scorpion stings and snake bites (Pimentel 1960, in Díaz Celis 1995). In North America, medicines are commonly prepared as an aqueous solution or tea from most plant parts. Many tribes used infusions of leaves, buds and gums to treat eye ailments; leaves, bark and gum as laxatives, emetics, cathartics and purgatives; gum solutions to treat sore throats and respiratory afflictions; leaves, gums and bark for diarrhoea and other stomach disorders including indigestion and ulcers; and sap or gums as a disinfectant for open wounds and skin disorders (Felger 1977). *Prosopis*-based medicines were occasionally used in the Americas to treat the epidemic diseases of Old World origin.

Chemical compounds have been isolated, which contribute to the medical properties of *Prosopis*. The leaves of many species contain quantities of many different free amino acids and flavonoids (Carmen 1974), with alkaloids and diketones isolated as active ingredients. The concentration of alkaloids varies between species and within populations but is 0.4-3.6% of leaf dry weight. Concentrations were significantly higher in younger rather than in older leaves (Cates and Rhoades 1977). Of these alkaloids, two piperidine alkaloids have been studied (Neuwinger 1996). Prosopine is a weak excitant of the nervous system while prosopinine has a weak sedative effect but also has local anaesthetic effects three times stronger than cocaine. However, being strong irritants precludes their use in modern medicine. Aqueous and alcoholic extracts show some antibacterial activity (Siddiqui and Murthi 1948, in Ahmad and Sultana 1989), but the antibiotic and antifungal activity appears unimportant. A flavone glycoside, patutrim, has been isolated from the flowers (ICFRE 1993). Other studies have shown significant activity of plant extracts against lung carcinoma (Merzabani *et al* 1979) and against lymphocytic leukemia and other carcinomas (Ahmad and Sultana 1989) (see also 3.4.4).

Physical benefits

In hot, arid climates where few other trees are found, the shade provided by *Prosopis* tree species is welcomed by humans and livestock as well as by a wide range of other animals and insects (see 3.5). Trees are often favoured around houses and in urban areas in the dry tropics, for their shade, low maintenance, valuable products and their aesthetic qualities. Trees are also acknowledged as boundary markers. They provide shelter from the wind and reduce the movement of soil and sand, with material that is slowed and caught by the tree eventually building up around the base. Soil and sand are, in addition, fixed by roots giving *Prosopis* an important role in erosion control.

When planted in rows, tree species can serve as windbreaks and, if managed as a hedge, can protect dwellings and agricultural land from grazing livestock. This role is enhanced by the profusion of thorns on some species and unpalatability of most species. *Prosopis* woodlands are also known to provide shade, shelter and a valuable habitat for many wild animals that help to support human populations as a source of protein from hunted game. Bushes and shrubs provide a haven from attack by larger predators for small birds and mammals. All species support large insect populations that are a source of food for higher trophic levels (see also 2.4.5). *Prosopis* trees also have ameliorating effects on surrounding soil, increasing soil fertility and decreasing salinity and alkalinity, and their role in reclaiming otherwise unproductive sites has been noted (see 3.5).

1.3 History of *Prosopis* exploitation

1.3.1 Pre-history to the present day

There is a wealth of literature on indigenous uses of *Prosopis* species in their respective native ranges. Most of the historical literature relates to the widespread use of *Prosopis* forests in the American dry zones. While there are records relating to the early use of the Afro-Asiatic species, these will not be covered in any detail as they are quite distinct from the American species. In the Americas, records of human use come from archaeological evidence, the chronicles of early European soldiers, explorers and priests, and histories recorded from native populations. These records show that *Prosopis* was one of the most widespread and well utilised trees in the dry zones in the Americas. Some of the most complete descriptions of early uses and reviews of historical literature are by Felger (1977), Fisher (1977), D'Antoni and Solbrig (1977), Felker (1979) and Díaz Celis (1995).

There are several periods of exploitation that can be described and allow a good analysis of the evolution in utilisation of *Prosopis* products and reasons for changes in the distribution of species throughout the world. The first epoch described is prehistoric (Table 2). This is divided into the early, facultative period including the original uses of the tree by man, recently arrived in the ecosystems where *Prosopis* was prevalent, and the later, processing period where tree products underwent primitive processing. The second epoch is the colonial and post-colonial epoch and involved an early period of modified traditional utilisation and a later period of industrialisation. Finally, there is the modern epoch

Table 2. Classification of the history of exploitation and spread of* Prosopis *in the Americas.

Epoch	Period	Duration (approx.)	Characteristics
Prehistoric	Facultative	6500BC to 1000AD	Facultative use only as a source of food, fuel and basic raw materials.
	Processing	800AD to 1600AD	Development of utilisation with primary processing of tree products, on a sustainable basis.
Colonial & post-colonial	Transitional	1500 to 1800	Further development of product processing for the needs of the new colonials, involving land clearance for agriculture, on an unsustainable basis.
	Industrial	1750 to 1950	Use of products for industrial uses, as a fuel and for raw materials, for example in the expanding mining and railway operations. Massive over-exploitation of forest products in native range. *Prosopis* becomes a weed in native grassland. Introduction and spread of exotics.
Modern	Contemporary	1950 to 2000	Rates of deforestation declining. Some development of sustainable industries based on *Prosopis* tree products in native and exotic ranges. Further invasions of weedy species.

of developed, contemporary systems. There are, however, often extensive periods of overlap between these epochs and periods, with several continuing to the present day, and substantial regional differences.

1.3.2 Traditional uses

The names for *Prosopis* species in several North American Indian languages are unanalysable words and can be referred to linguistically as primary names, suggesting considerable cultural identity (Berlin 1973, in Felger 1977). This is repeated in South American Indian languages, with names such as 'the one' or 'the tree' given to some *Prosopis* species (D'Antoni and Solbrig 1977). However, it must be stressed that these names refer principally to tree species of section Algarobia, with sweet, edible fruit, distinct from those species producing dry or bitter fruits which were not consumed and often had different names. Seasons when *Prosopis* species fruited were times of plenty, characterised by many rituals and much population movement as work was transferred to areas of *Prosopis* forests. These months or seasons sometimes took a local name of *Prosopis* in their title, confirming their significance.

Prosopis pods were eaten by humans in the Tehuacan valley in Mexico as long ago as 6500 BC (Smith 1967, in Fagg and Stewart 1994), and there are other reports relating to the use of pods over one thousand years ago (Towle 1961). It can be assumed that the use of pods for food and wood for fuel was widespread amongst early man in the Americas. Roundwood was also already being used for the construction of housing early on in history. *Prosopis* wood has been found in tombs in many archaeological sites in Peru dating as far back as 2500 BC, to the earliest known site of the Upper Archaic Peruvian cultures (D'Antoni and Solbrig 1977).

As time progressed and societies and civilisations developed, so did the use of *Prosopis* products. Thus began the second period of exploitation in the prehistoric epoch, characterised by the processing of tree and pod products. With the development of more advanced metal tools, wood was cut for use in more detailed aspects of construction such as for making doors and windows. *Prosopis* wood was also fashioned into household and agricultural implements (Díaz Celis 1995). Sweet, fresh pods were commonly chewed in indigenous cultures, and are today still consumed raw by children and in rural areas. Pod processing techniques developed, with pods being dried in the sun and sometimes roasted on hot coals which also kill the bruchid beetles that otherwise damage the pods. They were pounded in pestles or ground with stones or rollers, into a flour of variable consistency. Seed and endocarps could be separated at any stage in the process or left and ground with the mesocarp.

The flour can be mixed with water to produce a refreshing and sweet drink ('añapa' or 'yupisin'), or fermented slightly ('aloja'). This liquid can be concentrated by evaporation into a very sweet syrup ('mel' or 'algarrobina'). Flour was mixed with water to make a gruel, or made into a dough which can be cooked into a bread ('patay') or eaten sun-dried ('atole') and these breads contain 1-5% protein and 45% sugars (Burkart 1952, Felker 1979) and can be stored for long periods. Many of these products are, however, still made today, and are produced commercially in several cases (see 3.2.2).

1.3.3 Conquest and industrialisation

Traditional uses of *Prosopis* products by native Indian cultures continued for centuries after colonisation, some still existing to the present day. Many were modified by new administrations or have lessened in their importance for many reasons. Processing technologies developed rapidly following the arrival of the Europeans in the Americas and the application of new techniques that they had brought with them. The early, predominantly Spanish chroniclers, recorded these uses of *Prosopis*, as did subsequent colonial administrations and several anthropologists during the last century. Early records following conquest all relate to the use of *Prosopis* pods and wood throughout the native range. The earliest records are from Cabeza de Vaca's journey through what is now the USA in 1528 to 1536 (Bandelier and Bandelier 1905), Alarcon's expedition in present day Mexico in 1540 (Bell and Castetter 1951), Almagro's journey across the Atacama in Chile (Oviedo and Valdés 1535, in D'Antoni and Solbrig 1977) and Cieza de León travels in Peru in 1547 (Díaz Celis 1995).

All early chronicles record the importance of *Prosopis* pods in the diet and tradition of indigenous cultures throughout the Americas, and the value given to pods as an animal feed, wood for fuel and construction, and a variety of plant parts for other uses. Fermentation and distillation of *Prosopis* pods became more common in the centuries following colonisation. However, human uses of processed pods as a source of food declined as alternative foods, primarily wheat and barley, became more widely available. This was mirrored by an increase in the use of pods as a feed for the rapidly increasing livestock numbers. Recently, pods have been seen as a cheap source of a variety of new products such as coffee substitute and also for chemical extracts.

Rough hewn timbers continued to be used in construction as door posts and roof beams, but their use was limited by the often short and crooked logs. Changes in architectural design and the preferences of colonists for high and broad ceilings required the use of long and straighter trunks. Large *Prosopis* trunks became less available over time following selective felling. A very wide range of small items, from tools to weapons, carvings to containers and cradles to coffins, in fact any item normally made of wood has been made from *Prosopis* wood. Detailed lists of manufactured artefacts are given by Felger (1997), D'Antoni and Solbrig (1977) and Díaz Celis (1995). These lists include many items that, following colonisation, were replaced by metal, such as shovels, ploughs, pulley blocks and weapons. The advent of saws and sawmilling technology, allowing the cutting of trunks led to the use of *Prosopis* for more accurate joinery such as improved furniture, window frames, boards and vehicle parts.

The demand for *Prosopis* timber increased dramatically during the colonial period with expansion in the number and size of ranches, railways, mining and manufacturing industries. Many species present in Argentina and the neighbouring countries of Bolivia, Paraguay and Uruguay were exploited for fuel and timber. The heavy demand for wood from the mines and railways led to large scale destruction of *Prosopis* forest cover, particularly near to such industrial centres. Such a hard wood in apparently endless supply led to uses even where stone would have been better employed, such as for making road cobbles for many Argentinean city streets. The massive deforestation that occurred during the World Wars led to the present great concern for the poor state of *Prosopis* woodland in Argentina and the need for conservation.

Large scale clearance of *Prosopis* forests on the Pacific coast of South America occurred soon after colonisation, with much land on the flat coastal belt and lowland valleys of Peru cleared to make way for the new plantations and ranches. This lead to recommendations as early as 1535 that ranch owners also plant trees, but this was over-ruled a few years later (Díaz Celis 1995). Charcoal was produced in very large amounts in areas where *Prosopis* was common, and was transported considerable distances. Fuel was also required for steam engines and metal smelters, and also for bread, pottery and gypsum ovens. Much of the forest cover in central Peru, near to centres of population and industry, was seriously depleted, with deforestation continuing until very recently. In northern Chile there was a massive clearance of similar woodland in the Atacama desert region, principally for firewood and charcoal for domestic and then industrial uses in mines and furnaces. This resulted in gross over-exploitation, to the point where there were fears of the possible extinction of *Prosopis* species in parts of their native range (Briones 1985).

In Mexico the story was very similar, with colonisation, industrialisation, land clearance, and the mining of gold and silver placing a great demand on the forested areas. Changes in land tenure following Mexican independence also permitted widespread and wholly unsustainable forestry practices, primarily felling for timber (Franco and Maldonado 1996). The revolution and civil war and the expanding railways saw the continuation of this trend. Large areas in central Mexico that were once extensive *Prosopis* woodlands were cleared. The land was converted to agriculture or pasture, and now only large, remnant trees remain.

In Africa and Asia, wood from *Prosopis* species is valued for similar qualities and characteristics, as a fuel of excellent quality and a fine timber. However, different tree characteristics and cultural issues mean that Afro-Asiatic species are prized primarily as a source of food and fodder. *P. africana* seeds are fermented into a food condiment in Nigeria ('okpiye') and other native range countries (Achi 1992). In India, immature pods of *P. cineraria* are dried ('sangri') and used in traditional dishes. Foliage of all Afro-Asiatic species is palatable to livestock and branches are lopped in times of shortage or to a prescribed management system. Because of their value, trees are encouraged and maintained in and around agricultural fields or on pasture. Conquest and industrialisation led to an increasing use of these trees as natural resources, particularly fuel and construction timber. There was subsequent deforestation, particularly in the Sahelian zone of Africa during droughts in the 1980s. In Asia, although the native *Prosopis* trees were over-exploited for firewood, the value of the trees in agricultural systems lead to their protection (Arya *et al* 1992, ICFRE 1993).

1.4 *Prosopis* in AD 2000

1.4.1 Deforestation to date

The areas that have suffered most deforestation in the Americas are those which once supported the largest *Prosopis* forests, located in three main regions, Mexico, Peru/Chile, and Argentina. This has been due primarily to land clearance for agriculture or ranching, and logging for a variety of wood uses (e.g. NAS 1980). Also, where forests were not completely destroyed, many have suffered from continuous selective felling and genetic depletion, with the best trees preferentially removed over time.

Management was minimal prior to colonisation, but exploitation was also at a very low level, with the large *Prosopis* forests able to support the local populations on a sustainable basis. It was the advent of major land clearance and industrialisation that led to over-exploitation for wood products and wood fuel and major deforestation throughout the native ranges. It is only more recently, with the availability of alternative fuel and raw materials that the rate of exploitation has declined.

In Argentina, it has been estimated that the natural coverage of *Prosopis* forests was reduced to between one quarter and one half of its original area between 1500 and 1975, due to the activities of man (D'Antoni and Solbrig 1977). In Africa, native *Prosopis* trees are rarely found in pure stands, but the savanna ecosystems in which they form a part have suffered encroachment (von Maydell 1986). From the north there has been a southward spread of desertic landforms, and from the south there is a northward pressure from agricultural and livestock rearing activities. Also, their value as a high quality timber and fuel has led to over-exploitation in some parts of the native range. Lowering of water tables due to water extraction by man has been blamed for the death of many mature trees in higher rainfall zones of central Africa (Bernard 1996). In Asia there has also been some destruction of native forests primarily for fuel (ICFRE 1993).

1.4.2 Weedy invasions

The invasion of woody weeds into range and agricultural land is becoming a problem of major importance in many regions world-wide. The issue of the value of *Prosopis* versus their status as a weed species is a contentious one. The specific problem of weedy invasions and their control and management merits special attention and prevention of further invasions is a part of overall management of the resource (see 4.3.3). Many other dry land trees have become invasive mostly where introduced, including *Acacia*, *Azadirachta* and *Leucaena* species. Several *Prosopis* species have been identified as being weedy. Invasions can be classified depending on whether they occur in the native range or where *Prosopis* has been introduced and whether they involve *P. juliflora* and *P. pallida*, or other *Prosopis* species. Areas of the world where *Prosopis* species are invasive weeds are shown in Figure 1.

The most studied weedy invasions have occurred within the native ranges of other *Prosopis* species. *P. glandulosa* in the USA, particularly Texas, and *P. ruscifolia* in northern Argentina and the Chaco region of Paraguay have spread dramatically since 1850. Other species have also spread in these regions to a lesser extent, including *P. velutina* in the USA and Mexico, and *P. campestris*, *P. hassleri*, *P. humilis*, *P. kuntzei* and *P. nigra* in northern Argentina and Paraguay, while *P. affinis* and *P. caldenia* have spread in parts of central-southern Argentina and Uruguay (e.g. Fisher 1977) (Table 3). While these invasions include many different species and environmental conditions, the history of land use is very similar and has led to very similar dynamics of invasion. In the transitional period of the colonial epoch, the regular burning of grasslands and harvesting of large trees for timber and fuel led to an increase of the area under pasture.

However, beginning in about 1850 in North America and somewhat later in South America, the industrial period changed the ecological balance. There was a massive increase in cattle numbers and also an increase in the frequency and severity of droughts. The loss of grass cover has the effect of reducing competition directly with seedlings of *Prosopis* and other species. With less ground cover there was also insufficient material to generate enough heat when burnt to kill the seedlings. This series of events differ in specific historic details, such as arrival of the railways, outbreak of war and the timing of droughts, but they all led to the increase in stand density in areas containing only wide-spaced *Prosopis* trees, and subsequent invasion of neighbouring grasslands. Native *Prosopis* species are declared noxious weeds in Argentina, Paraguay and the USA, where millions of hectares of rangeland have been made worthless and are now covered in dense, impenetrable thickets of *Prosopis*. Although *P. juliflora* exists in thickets in areas of central America and the Caribbean, it is not so often classified a weed in this part of the native range. Only in Colombia and Venezuela, where *P. juliflora* has invaded pasture, has it been declared a weed by ranchers. There are no records of *P. pallida* as a weed in its native range, though any spread may be balanced by the widespread exploitation of tree products there.

Several *Prosopis* species have been successfully introduced around the world in the last two centuries and have escaped

Table 3.* Prosopis *species classified as invasive or noxious weeds (adapted from Simpson 1977, Poynton 1990, Zimmerman 1991).

Species	Native range weeds	Introduced, exotic weeds
P. affinis	Argentina, Uruguay	-
P. caldenia	Argentina	-
P. campestris	Paraguay	-
P. cineraria	Pakistan	-
P. farcta	Israel, Jordan, Syria, Saudi Arabia, Iran, Trans-Caucasia, Turkey	-
P. glandulosa	USA, Mexico	Australia, South Africa, Namibia
P. hassleri	Argentina	-
P. humilis	Argentina	-
P. kuntzei	Argentina	-
P. juliflora	Venezuela, Colombia	Sudan, Eritrea, Iraq, Pakistan, India, Australia, South Africa, Caribbean and Atlantic islands
P. nigra	Argentina	-
P. pallida	-	Australia, Hawaii
P. pubescens	USA	-
P. ruscifolia	Argentina, Paraguay	-
P. velutina	USA	Australia, South Africa

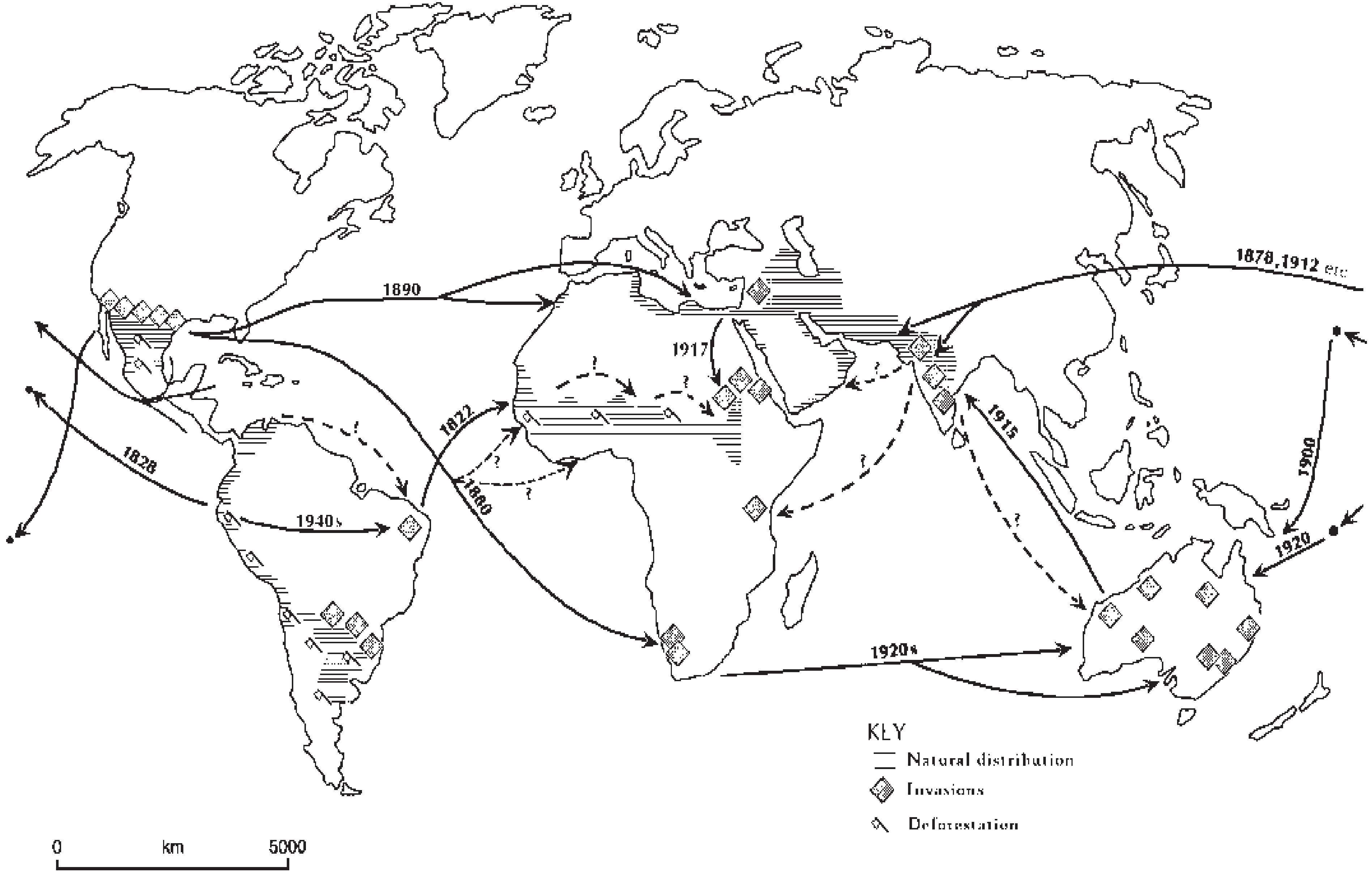


Figure 1. Approximate distribution of the genus Prosopis *in AD 2000, showing areas of deforestation in the native range, areas where* Prosopis *is an invasive weed. Possible routes of introduction with dates of introduction where known are presented.*

from cultivation and presented problems as weeds. The four main species are *P. glandulosa* and *P. velutina* in more sub-tropical regions and *P. juliflora* and *P. pallida* in the truly tropical zone. Other species such as *P. alba* and *P. chilensis* have been introduced less successfully and have not become weedy. *P. glandulosa*, *P. velutina* and their hybrids have become noxious weeds in South Africa and Australia and *P. juliflora* and *P. pallida* are classed as noxious weeds in Australia. *P. juliflora* in Pakistan and Sudan, and have weedy status in parts of other countries in southern and Sahelian Africa, Brazil and south Asia.

The ability of these trees to become established over a large area from a single introduction or a few scattered trees has been noted throughout semi-arid Africa and Asia. The stage of infestation varies between invasions, determining the form of weedy stands and thickets (see also 2.4.5). Native American invasions date from the 1800s and are in an advanced stage. *Prosopis* was introduced to southern hemisphere countries around 1900. In South Africa and Australia the spread was rapid and extensive stands now exist, albeit generally of young age. *Prosopis* is now a declared weed over millions of square kilometres of arid and semi-arid lands, where they drastically reduce the production of forage plants and threaten ranchers' livelihoods. It appears that some *Prosopis* species have a more aggressive nature than others and some have a broader ecological amplitude, making them better adapted to a wide variety of sites. However, man and livestock appear to have an over-riding effect on the environment into which invasions occur thus making it impossible to rank species for their weediness alone. While shrub species have little use other than occasional browse, tree species have shown the potential to yield large quantities of useful products from such stands if well managed.

Many control methods have been attempted (see 4.3.3). After decades of attempted eradication, particularly in the USA, Argentina, Australia and South Africa, the aim of total eradication has been seen to have failed, and even the reduced aim of control alone has been only partially achieved. The development of sustainable agroforestry systems has been suggested as the only method for increasing productivity of invaded areas (see 4.3.3).

1.4.3 Intentional introductions

Global spread

With introductions made before recorded history, known human population movements, changes in land use and the spread of other plants and animals can be used as indicators of possible spread of *Prosopis*. Several species from the Americas with useful attributes may have been introduced to neighbouring regions following the arrival of man in prehistory. Reddy (1978) suggested that *P. cineraria* may have been introduced to India by invading Aryan tribes from Iran and the Middle East, but pollen analysis has shown its abundance in north-western India for the last 10000 years (Singh 1970). *P. juliflora* is often quoted as native to the Caribbean where it is found often in coastal areas, but several authors have suggested that it was introduced (Johnston 1962, Little and Wadsworth 1964, Burkart 1976), possibly with the arrival of the first human settlers from Venezuela (circa 0-1000 AD) (Timyan 1996). The date of arrival of *P. pallida* in the Galapagos Islands is also unknown. Pollen analysis is required to clarify these situations.

Almost no records exist of early introductions of different *Prosopis* species within the natural range of the genus but it may be assumed that there were introductions of species and varieties with very sweet pods, made by early man during his journeys across the Americas or inadvertently by the domesticated animals which may have followed. Recent introductions, or re-introductions have occurred, if only on a limited scale in Argentina, Chile, Peru and Mexico. Very large plantations of *P. tamarugo* have been established in Chile, reforesting vast areas of the Atacama desert that had been deforested. Many other *Prosopis* species have been introduced to other parts of the Americas in recent times, including South American species into the USA as ornamental trees.

Prosopis trees have been introduced widely by man during the last 100-150 years. This is because of the perceived value of the trees' products, the multiple products obtained and the high yields under even the poorest conditions. Tolerance of drought and poor soils, and their value in agroforestry systems, including tolerance of repeated cutting and the amelioration of soils, have also been stated as reasons for introduction. The value of *Prosopis* as producing a quality timber, excellent fuel and sweet pods was well known by those who had seen trees in their native ranges, and there was a desire for selected species to fulfil similar roles in other countries. The demand for plants that could produce a large amount of dry season fodder came from some countries, a need for fuelwood producing trees from others (e.g. NAS 1980, Von Maydell 1986). As travellers and colonials reported wondrously about the growth and production of *Prosopis*, so seed of these species were often requested by land owners or colonial administrators. Some intentional introductions of *Prosopis* species to satisfy an observed need identified in the local community were well recorded. Many other introductions were not documented, however, and the species and date of introduction can only be assumed or ascertained from circumstantial evidence.

The majority of introductions of *Prosopis* species were of four species *P. juliflora*, *P. pallida*, *P. glandulosa* and *P. velutina*. The former two species are prevalent in tropical zones, while the latter two are found in more sub-tropical and zones. Species such as *P. alba* and *P. chilensis* have proved to be well adapted and are locally common in some regions. Other species such as *P. cineraria*, *P. pubescens* and *P. tamarugo* have also been widely introduced but have rarely survived. Mis-identification of *Prosopis* has lead to taxonomic confusion and so all records of introduction of *Prosopis* species by man will be detailed. The *P. juliflora - P. pallida* complex has been recorded as introduced and naturalised in a large number of countries. It is also expected that the complex is present in many other countries and there are records of introductions where it is assumed or known that the species died due to unsuitable climatic conditions, such as Spain (Hyde *et al* 1990). Distribution may be very limited in other areas such as the more humid Eastern Caribbean island states, where introductions have been reported.

Countries where the *P. juliflora - P. pallida* complex has been introduced can be derived from Burkart (1976), Habit and Saavedra (1990), Poynton (1990), Felker and Moss (1996) and Perry (1998). In the Americas, the complex has been introduced to Brazil, Hawaii (USA) and possibly some Caribbean islands if not naturalised in pre-history. In Oceania, the complex has been introduced to Australia, Papua New Guinea and the Marquesas islands. In Africa, the complex is recorded in Morocco, Algeria, Tunisia, Libya, Egypt, Cape Verde, Senegal, Gambia, Mauritania, Mali, Burkina Faso, Niger, Chad, Sudan, Ethiopia, Eritrea, Guinee-Bissau, Ghana, Nigeria, Kenya, Tanzania, Namibia, Zimbabwe, South Africa and Reunion. In Asia the complex has been observed in Jordan, Saudi Arabia, Bahrain, Qattar, United Arab Emirates, Iraq, Iran, Kuwait, India, Pakistan, Sri Lanka, Myanmar, Cambodia, Thailand, Vietnam, Brunei, Indonesia and the Philippines. It is certain that the complex also now exists in countries other than those listed above.

Exact details of introductions of correctly identified species are rare. Those that are known are described below, where possible with the probable course of events that have lead to the present distribution of *Prosopis* species. Quoted dates of first introductions are given but can be misleading, with older references to *Prosopis* species given in some colonial botanical surveys. A more complete picture could be made by extracting information from the 'floras' of most tropical countries over the last 200 years. Introductions of *Prosopis* species throughout the world with origins and dates of introduction where known are given in Figure 1, along with areas of deforestation.

The Americas

Within the natural range of the genus, *Prosopis* trees producing sweet pods were introduced to Baja California from mainland Mexico before Mexican independence (Felger 1977). Similar introductions of species and varieties with desirable characteristics are assumed to have occurred during the spread of human settlement across the American continent. Such routes of man-induced introductions may include the Pacific coast of Central America, Peru and Chile, and in the Caribbean. Later, with the advent of oceanic trade, there may have been exchange of material between Mexico and Cuba, and Texas and Jamaica. Many *Prosopis* species have been introduced in recent times, including South American species into the USA as ornamental trees. The major introduction of *Prosopis* species outside of its natural range to elsewhere in the Americas is to the semi-arid zones of north-east Brazil. The species present are under debate, with Burkart (1976) confirming that they were *P. juliflora*, though stating that *P. pallida* had also been introduced to Brazil without specifying where. There is much more morphological similarity between the Brazilian *Prosopis* and Peruvian *P. pallida* than with Central American *P. juliflora*.

The account of Azevedo (1982) is quoted in Silva (1989) and in many other papers presented at the FAO symposium 'The Current State of Knowledge on *Prosopis juliflora*' in 1986 (published 1990). This states that the first introduction of *Prosopis* into Brazil was by J.B. Griffing, who in 1942 introduced seed from New Mexico, USA (presumably therefore *P. glandulosa* var. *torreyana* and/or *P. velutina*) to the Sierra Talhada area of Pernambuco state. This was followed by a second introduction to Rio Grande do Norte by S.C. Harland in 1947 of seed from Peru, and in 1948 with seed from Sudan (e.g. Silva 1990b). Only two trees of each of these later two introductions are believed to have survived and it is stated that these provided the basis for the entire population of *P. juliflora* in the north-east of Brazil (e.g. Pires *et al* 1990, Silva 1990b). There are no records of either *P. glandulosa* or *P. velutina* existing today as naturalised species, so it can be assumed that the introductions from the USA did not survive. Other species have been noted in Brazil, such as *P. hassleri* or a hybrid of it (Burkart 1976), a disjunct population of *P. ruscifolia* near to Petrolina that was probably introduced, and another of *P. affinis* that may be a mis-identification (Lima and Silva 1991) (see 2.1.3).

The belief that *Prosopis* was first introduced into Brazil in the 1940s is commonly held but appears mistaken. *P. juliflora* is mentioned in the Flora Brasileira as long ago as 1879 (Bentham 1879, in Burkart 1976) and shows that the species was present at least locally before this. Also, Correa (1926, in Silva 1990b) states that *P. juliflora* was spreading on poor quality land from sea level to 100 m altitude in the 1920s. Silva (1990b) notes the existence of two 'forms' of *P. juliflora*, one a slow growing thorny tree with flexuous branches, while the other is fast growing with short thorns and erect branching. Several 'forms' are noted by Melo (1966, in Silva 1990b), not all of which are suited to local conditions.

These may be examples of the wide genetic diversity known to exist in *P. juliflora*, or they may have arisen from separate introductions. It is possible that trade between the Caribbean and Brazil may have led to the introduction of *P. juliflora* to the dry coastal areas of Ceará and Rio Grande do Norte from Venezuela or the Caribbean in the 1800s and this race may be the origin of the thorny slow growing form. Later introductions from the Peruvian-Ecuadorian race beginning in the 1940s appear to have resulted in the short thorned, fast growing and erect form, which has been widely planted in the region and is now the dominant type in the north-east of Brazil.

The Pacific and Australia

Pacific islands have naturalised populations of both *P. juliflora* and *P. pallida* recorded for the Hawaii islands and the Marquesa islands (Burkart 1976). It might be assumed that they were introduced from Pacific coastal areas of Peru and Central America where they are native. The first introduction into Hawaii is credited to the Catholic missionary Father Alexis Bachelot in 1828 (Perry 1998) or 1838 (Egler 1947, Esbenshade 1980). Seed came from a tree in Paris, France, which was thought to have originally come from Brazil (Esbenshade 1980) or South America (Perry 1998). *P. pallida* dominates coastal areas in Hawaii and has been revered as the most useful of all species ever introduced to those islands. It is from here that introductions to other Pacific islands such as the Marquesas were probably made. The distinction between *P. pallida* and *P. juliflora* is apparently clear in literature from Hawaii but much less so elsewhere in the Pacific.

Prosopis was introduced into Australia around 1900. Isoenzyme studies have shown that the *P. pallida* present there is identical except for one rare allele to the *P. pallida* in Hawaii, strongly suggesting that this species was introduced from here (Panetta and Carstairs 1989). The Hawaiian *P. pallida* may have been introduced to other Pacific islands before reaching Australia. Degener (1937, in Perry 1998) reported that Hawaiian seed (designated as *P. chilensis* (Molina) Stuntz) had been sent to Australia from Hawaii. No exact records of the first introductions exist, but *Prosopis* species were first introduced into Australia as a tree for shade, fodder and erosion control, with major planting and possibly further introductions in the 1920s and 1930s (Csurhes 1996). Several introductions were clearly made, with four species now naturalised in Australia (Perry 1998). Later introductions may have come from the Americas, or possibly from India or South Africa where *Prosopis* species had already become naturalised.

Of the *Prosopis* species present in Australia, *P. pallida* is widespread in the northern part of the continent, possibly due to earlier introduction, while *P. juliflora* var. *juliflora*, introduced from Mexico (Panetta and Carstairs 1989) is more limited in its range. Both of these species, being more frost sensitive, are restricted to the tropical zones. More widespread in southern areas are the species *P. glandulosa* var. *glandulosa*, *P. velutina* and a hybrid between the two. Some evidence of introgression with *P. glandulosa* var. *torreyana* has been noted (Perry 1998). A further hybrid contains genes from an as yet unknown species, thought to be a *P. glandulosa* X *P. laevigata* hybrid (Panetta and Carstairs 1989). *P. pallida* is also found in Papua New Guinea (Perry 1998), *P. juliflora* in Indonesia (Holm *et al* 1991 in Csurhes 1996), *P. juliflora* var. *juliflora* in the Philippines and Vietnam, and *P. glandulosa* in Burma (Burkart 1976). No further information on the dates and sources of introduced seed can be located, but it is assumed that seed was introduced from the Americas via Australia and the Pacific. South-east Asian *Prosopis* populations may also have been introduced from the Indian sub-continent.

India and Pakistan

There appear to be several competing histories as to the introduction of *Prosopis* into the Indian sub-continent, with no doubt that it first occurred in the 19th century. Luna (1996) uses the date of 1857 as that of first introduction of *P. juliflora* from Mexico, and Sindh province, now in Pakistan is also often given as the region of first introduction and Mexico the origin. However, Reddy (1978) gives a compelling account of the request for *Prosopis* seed made by Lt. Col. R.H. Bedome, Conservator of Forests of Northern Circle (Madras) to the Secretary of the Revenue Department of Madras in 1876; "The *Prosopis dulcis*, the *Prosopis pubescens* and *P. glandulosa* - are stated to grow best on dry arid soil. They yield hard and valuable timber and also an abundance of sweet succulent pods which are used for cattle feeding and also ground into meal. It is very desirable to introduce these trees into the fuel plantations in our dry districts; and I have the honour to suggest that the British Consuls at Galveston and San Francisco should be applied to for the seed. The *Prosopis juliflora* is a species growing in Jamaica which I should be very glad to get seed of". This was sent to the Secretary of State and seeds arrived and were sown that same year and outplanted in 1878 (Reddy 1978).

Thus seed was received and sown in Andhra Pradesh in 1877 (Reddy 1978). No further information was provided as to which species was planted out, but a reference to *P. juliflora* is given 7 years after this introduction (Mohan 1884, in Raizada and Chatterji 1954). This refers to 'cashaw', the common name for *P. juliflora* used only in Jamaica, and suggests that this may have been the origin of this introduction of *Prosopis* to India. Muthana and Arora (1983) and Dubey (1998) mix these two versions of events, placing the first introduction of *P. juliflora* in Sindh in 1877. Raizada and Chatterji (1954) state that the first introductions were of Mexican origin in 1877, with two further supplies of seed received through Kew Gardens and the India Office in 1878. Whichever account is preferred, *P. juliflora* was certainly widespread throughout India and also in Pakistan and Sri Lanka by the turn of the twentieth century.

Several accounts of introductions into other areas of India by Col. Corbyn and RN Parker are given variously from 1879 to 1909, assumed to have been of material already introduced. There was a second introduction of material from Mexico in 1912, via the Inspector of the Botanic Gardens in Darmstadt, Germany (Dubey 1998). *P. juliflora* was introduced into Rajasthan state in 1913 (Muthana and Arora 1983) and seed was supplied to neighbouring states. In 1915-16, several introductions of diverse seed material were made and trees planted in the Government Agriculture and Horticulture Garden, Lahore, Pakistan, including seed lots from the British Council in Peru, Mexico, Argentina and Uruguay (Dubey 1998). It is assumed that these may form the genetic base for many of the forms noted by Raizada and Chatterji (1954). In 1940, *P. juliflora* was declared a 'Royal Plant' in Jodhpur state and given special protection.

Mohan (1940, in Raizada and Chatterji 1954) reported the introduction of *P. velutina, P. glandulosa* var. *glandulosa, P. nigra, P. pubescens, P. strombulifera* and other forms of *P. juliflora*, but no records as to their performance are available (Raizada and Chatterji 1954). Subsequent introductions have obviously occurred, with Raizada and Chatterji (1954) noting five different forms of *P. juliflora* as well as *P. glandulosa*. The forms were differentiated by their supposed origins as the Peruvian, Australian, Argentine and Mexican forms as well as the geographically neutral Arid form. From pod and leaf form, it appears that Argentine form may be *P. alba* or a hybrid thereof, the Arid form may be *P. laevigata, P. velutina* or a hybrid form while the remaining three are from the *P. juliflora - P. pallida* complex. The Mexican form bears similarities to *P. juliflora* but has longer leaflets and may also be a hybrid form and the Peruvian and Australian forms possess characteristics of both *P. juliflora* and *P. pallida*.

Africa and the Middle East

P. africana is native to parts Africa, but other exotic *Prosopis* species are now widespread in many arid and semi-arid regions of Africa. While introductions into Senegal (1822), South Africa (c.1880) and Egypt (c.1900) are documented, earlier introductions may have occurred, and subsequent introductions of *Prosopis* into and around Africa are unclear. Seed may have entered Nigeria and Kenya from neighbouring African countries or from further afield. *P. juliflora* in Niger may have been introduced from Senegal or Sudan. *P. juliflora* and *P. pallida* are not thought to persist in areas of southern or Mediterranean Africa that receive frost. Differences in form are noticeable, and possibly have a genotypic basis arising from the different origins of the germplasm. However, Hughes (1991) considered most *P. juliflora* in the Sahel to have arisen from the original introduction of only a few individuals. These populations with a very small genetic base are termed 'genetic garbage' by some Sahelian foresters (Hughes 1991).

Baron Roger, governor of Senegal, is credited with the introduction of *P. juliflora* to the town of Richard Toll in the River Senegal estuary in 1822. This origin of this material is uncertain but thought to be of Mexican origin by Diagne (1992). *P. pallida* was introduced into Hawaii by a French missionary, from South American seed via Paris a few years earlier (Esbenshade 1980, Perry 1998), and it may be possible that some of this seed also came to Richard Toll. The similarity in leaf morphology between provenances from Hawaii and Senegal grown in a field trial in the USA further supports this (Felker *et al* 1983a). *P. juliflora* had been introduced from Senegal to Mauritania before 1960 (Diagne 1992) but had certainly been introduced elsewhere in the Sahel before this. *P. juliflora* was recorded in Senegal and Nigeria by Burkart (1976), and is now found in much of arid and semi-arid West and Sahelian Africa, referred to as *P. chilensis* by Delwaulle (1978). The very different form of seedlings suggests that there may have been at least two different introductions, one erect and more thornless type into Senegal and now in neighbouring countries, while there is a prostrate and thorny type present in Burkina Faso, Nigeria and Chad. In Senegal in the 1980s, *P. juliflora* plantations from Ecuadorian seed were established and seed from these have since been distributed. *P cineraria* has also survived and established well.

It appears that *Prosopis* was already present in Egypt by the early 1900s. Although identified as *P. juliflora* Swartz DC, winter frosts occur over much of Egypt making it unsuitable for the *P. juliflora - P. pallida* complex unless in sheltered or coastal locations. Much of the *Prosopis* in the Mediterranean zone of North Africa is much more likely to be *P. glandulosa, P. velutina, P. chilensis* (Burkart 1976) or hybrid forms including these species. Akrimi (1990) stated that cold-sensitive *P. juliflora* was killed outright in Tunisia, while other species survived. Reports of *P. juliflora* in North Africa may, however, be correct if they are present in favourable locations or in southern frost-free regions. *P. juliflora* was observed as planted and naturalised trees in occasional frost zones in Jordan, along with *P. glandulosa* and assumed spontaneous hybrids. *P. juliflora* from Mexico or hybrids with other sub-tropical species would possess more frost tolerance than more equatorial *P. juliflora* provenances, and the existence of frost tolerant hybrids cannot be discounted.

Prosopis was introduced into Sudan by RE Massey from the Egyptian Department of Agriculture at Giza and from South Africa both in 1917 (Broun and Massey 1929, in El Fadl 1997). Bukhari (1997) concluded from cytological studies that *P. chilensis* and *P. glandulosa* var. *torreyana* are the possible progenitors of *Prosopis* in Sudan. That the Sudanese *Prosopis* is *P. chilensis* or some other hybrid has been a continuous debate, but it is generally accepted that whatever the initial introductions may have been, subsequent introductions of *P. juliflora* from an unknown source are now the dominant 'common mesquite'. The binomial *P. chilensis* has been used to describe *P. juliflora* in much of Africa, from Senegal (Delwaulle 1978) to Sudan (Mustafa 1990), and Tunisia (Akrimi 1990) to Zimbabwe (White 1962). While this taxonomical error was corrected many decades ago in Hawaii and Peru, it appears to have persisted in Africa to this day (see 2.1). Wunder (1966) noted two different 'strains' of *Prosopis* growing in a plantation in Sudan, supporting the theory of several separate introductions.

The exact origins of *Prosopis* species and their subsequent introductions in East Africa remain unknown, as information regarding introductions in the 1980s are clearly not new. It may be that *P. juliflora* was introduced by livestock from Sudan or southern Africa, or by traders from India or southern Africa. *P. juliflora* could have been introduced from East Africa into other countries in southern Africa such as Zimbabwe. The existence of *P. juliflora* is southern Africa is confirmed with *P. chilensis* (syn. *P. juliflora*) recorded in present day Zimbabwe (White 1962), although of unknown origin. *P. pallida* is thought to be present in Kenya and may have been introduced into other parts of Africa, or could represent a mis-identification. Several species including *P. pallida* were introduced as fuelwood species in the 1980s.

Records of introductions into South Africa are more complete. *P. glandulosa* var. *torreyana* was introduced into South Africa no later than 1880 and several times since (Poynton 1990). *P. pubescens* was introduced as *P. dulcis* in 1880 by G. Alston with seed from J. Marquard (Zimmerman 1991). *P. chilensis* was first recorded in 1894 in the Cape of Good Hope, though this could possibly have been *P. juliflora* (Poynton 1987, in Zimmerman 1991), with another introduction from South America into Namibia in 1912 (Muller 1985, in Zimmerman 1991). There are also several large specimens of *P. alba* in South Africa, thought to have been introduced around 1900. Probably the source of much of the *Prosopis* to arrive in South Africa was the introduction of 23 seed lots from the USA/Hawaii and Mexico from 1897 to 1916 (Poynton 1990). Although they were all called *P. juliflora*, they almost certainly contained *P. velutina* and all varieties of *P. glandulosa*. Other more recent introductions include *P. tamarugo* from Chile in 1971 and *P. laevigata* from Honduras in 1985 (Poynton 1990).

P. juliflora and *P. glandulosa* were introduced into the Middle East in the 1950s, although there is one very large *P. juliflora* tree in Bahrain that is said to be 500 years old (Ahmad *et al* 1996). Although not possibly so old, it may show that there was some limited introduction of *Prosopis* by merchant and colonial traders long before the trees were intentionally introduced for other perceived benefits. There were introductions of several *Prosopis* species into Israel recorded in the 1970s (Pasternak *et al* 1986).

Chapter 2

The species

2.1 Systematics and nomenclature

2.1.1 Species classification

The genus *Prosopis* Linnaeus emend. Burkart is in the family Leguminosae (Fabaceae), sub-family Mimosoideae. The placing of *Prosopis* in the wider taxonomic classification system is given below, based on Elias (1981) and Lewis and Elias (1981). However, some reorganisation is expected following detailed molecular studies and the different phylogenetic importance being given to flowers, seed and wood. The phylogenetic origins of legumes are obscure, with the family Leguminosae (Fabaceae) generally accepted as being in the order Fabales, but also placed in the order Rosales, with possible links to the Sapindaceae.

Family:	Leguminosae	650 genera, 18,000 species
Sub-family:	Mimosoideae	50-60 genera, 650-725 species
Tribe:	Mimoseae	5 tribes
Group:	*Prosopis*	9 groups
Genus:	*Prosopis*	4 genera

The history of taxonomic confusion within the genus was largely settled with the authoritative monograph of Arturo Burkart (Burkart 1976), who defined the generic limits and divided the genus into five sections, based on floral characteristics, each also with marked vegetative differences in armature. Section Anonychium contains a solitary, unarmed species. The three species of section Prosopis all have internodal prickles, similar to those found on roses (*Rosa* spp.). The nine species of section Strombocarpa have spiny stipules, whereas the thirty species of section Algarobia have cauline, mostly axillary thorns. In between these latter two sections is the single member of section Monilicarpa. Section Strombocarpa is divided into two series, based on whether the seeds are positioned longitudinally or traversally within the pods. The discovery of a species with intermediate fruit fabric in section Prosopis reduced the systematic value of this difference in this section so that no series are distinguished. Burkart (1976) identified five series in section Algarobia, separated on vegetative grounds, but not all have been confirmed by more recent work (see 2.1.6).

Forty-four species and a number of varieties of *Prosopis* were described by Burkart (1976) (Table 4). The existence of populations of *Prosopis* with distinct characteristics led Burkart (1976) to describe many as separate species or varieties, even though several are known to hybridise. Johnston (1962) observed that areas of hybridisation between populations tended to be narrow, and each was readily distinguished. While the generic limits and division into sections is generally accepted, there is continuing debate as to the relative rank of species as defined by Burkart (1976). Being the most recent and complete taxonomical classification of the genus, this is taken as the basis of *Prosopis* taxonomy in this monograph. It is accepted, however, that this is likely to undergo substantial revision in the coming years. As no synthesis of the continuing taxonomic debate post-Burkart has been forthcoming, these are presented and discussed (see 2.1.6).

2.1.2 The genus *Prosopis*

The name *Prosopis* was selected by Linnaeus to describe the only species he was aware of, *P. spicigera*, in 1767. This is now synonymous with *P. cineraria*, the type species for the genus (Burkart 1976). Origins given for the name *Prosopis* vary but are all from ancient Greek. Burkart (1976) defined *Prosopis* as ‘a kind of prickly fruit’, while Allen and Allen (1981) gave the meaning as ‘bardane’, a type of thorny plant not related to *Prosopis*. The origin of *Prosopis* given by Perry (1998) was ‘towards abundance’, from the Greek word ‘pros’, meaning ‘towards’, and ‘Opis’, wife of Saturn, the Greek goddess of abundance and agriculture. This section deals with the genus *Prosopis* as a whole while specific descriptions of the systematics and nomenclature of the *P. juliflora - P. pallida* complex follow (see 2.1.3).

The history of nomenclature and synonymy in *Prosopis* is one of conflicting definitions and changing systematics leading to great confusion in the definition of species. Discrepancies concerning the generic limits of *Prosopis* and the movement of species from genus to genus were commonplace. Levels of generic and species rank altered as differences in vegetative characters were given different levels of importance from Linnaeus and the beginnings of plant taxonomy to Burkart (1976), whose lifetime’s study and eventual monograph remains the single most complete work on the genus. The taxonomy of Burkart (1976) has been generally accepted, and this is used as the benchmark with which other taxonomies are compared. There have been further regional studies and reviews of earlier literature during the last 20 years, which have suggested alterations to Burkart’s taxonomy (see 2.1.6), but have rarely been corroborated or globally accepted. With 40 American species, often with similar morphology and site requirements, closely related and with overlapping native ranges, botanists and taxonomists still continue to struggle to come to terms with workable species descriptions.

Many generic names have been applied since the first description of an American species *P. chilensis*, in 1782, then assigned the binomial *Ceratonia chilensis*. The description of *Mimosa juliflora* by Swartz in 1788 and *Mimosa strumbulifera* by Lamark in 1789 began the delimitation of species rank for *Prosopis*. However, the genus name given to these two species changed many times in the following two centuries. Similarities and differences between species were apparent and, as such, they were positioned into groups that today correspond accurately with the five accepted sections of the genus. These limits and subdivisions were first proposed by De Candolle in 1825, although many of these sections had earlier been given generic rank. When De Candolle incorporated the American species into the genus *Prosopis* in 1825, the Asian species that comprised the original genus *Prosopis* were assigned to a new section Adenopsis, later to become section Prosopis (Burkart 1976).

Following initial confusion, with species placed in existing genera such as *Ceratonia*, *Mimosa* and *Acacia*, new genera were composed. The genus *Spirolobium* of D'Orbigny in 1839 was renamed *Strombocarpa* by Englm and Gray in 1845, and

Table 4. The genus* Prosopis *Linnaeus emend. Burkart (from Burkart 1976).

I. Section PROSOPIS

- (1) *P. cineraria* (L.) Druce
- (2) *P. farcta* (Solander ex Russell) MacBride
  - var. *farcta*
  - var. *glabra* Burkart
- (3) *P. koelziana* Burkart

II. Section ANONYCHIUM

- (4) *P. africana* (Guill., Perr. & Rich.) Taubert

III. Section STROMBOCARPA

Series Strombocarpae

- (5) *P. strombulifera* (Lam.) Bentham
  - var. *strombulifera*
  - var. *ruiziana* Burkart
- (6) *P. reptans* Bentham
  - var. *reptans*
  - var. *cinerascens* (A. Gray) Bentham
- (7) *P. abbreviata* Bentham
- (8) *P. torquata* (Cavanilles ex Lagasca) DC.
- (9) *P. pubescens* Bentham
- (10) *P. palmeri* S.Watson
- (11) *P. burkartii* Muñoz

Series Cavenicarpae

- (12) *P. ferox* Grisebach
- (13) *P. tamarugo* F.Philippi

IV. Section MONILICARPA

- (14) *P. argentina* Burkart

V. Section ALGAROBIA

Series Sericanthae

- (15) *P. sericantha* Gillies ex Hooker & Arnott
- (16) *P. kuntzei* Harms

Series Ruscifoliae

- (17) *P. ruscifolia* Grisebach
- (18) *P. fiebrigii* Harms
- (19) *P. vinalillo* Stuckert
- (20) *P. hassleri* Harms
  - var. *hassleri*
  - var. *nigroides* Burkart

Series Denudantes

- (21) *P. denudans* Bentham
  - var. *denudans*
  - var. *patagonica* (Spegazzini) Burkart
  - var. *stenocarpa* Burkart
- (22) *P. ruizleali* Burkart
- (23) *P. castellanosii* Burkart
- (24) *P. calingastana* Burkart

Series Humiles

- (25) *P. humilis* Gillies ex Hooker & Arnott
- (26) *P. rojasiana* Burkart

Series Pallidae

- (27) *P. rubriflora* E.Hassler
- (28) *P. campestris* Grisebach
- (29) *P. pallida* (Humboldt & Bonpland ex Willd.) H.B.K.
- (30) *P. affinis* Sprengel
- (31) *P. articulata* S.Watson
- (32) *P. elata* (Burkart) Burkart
- (33) *P. tamaulipana* Burkart

Series Chilenses

- (34) *P. chilensis* (Molina) Stuntz emend. Burkart
  - var. *chilensis*
  - var. *riojana* Burkart
  - var. *catamarcana* Burkart
- (35) *P. juliflora* Swartz DC.
  - var. *juliflora*
  - var. *inermis* (H.B.K.) Burkart
  - var. *horrida* (Kunth) Burkart
- (36) *P. nigra* (Grisebach) Hieronymus
  - var. *nigra*
  - var. *ragonesei* Burkart
  - var. *longispina* Burkart
- (37) *P. caldenia* Burkart
- (38) *P. laevigata* (Humboldt & Bonpland ex Willd.) M.C.Johnston
  - var. *laevigata*
  - var. *andicola* Burkart
- (39) *P. flexuosa* DC.
  - forma *subinermis* Burkart
- (40) *P. glandulosa* Torrey
  - var. *glandulosa*
  - var. *torreyana* (Benson) Johnston
  - var. *prostrata* Burkart
- (41) *P. alpataco* R.A.Philippi
- (42) *P. alba* Grisebach
  - var. *alba*
  - var. *panta* Grisebach
- (43) *P. velutina* Wooton
- (44) *P. pugionata* Burkart

the genus *Neltuma* of Rafinesque in 1838 was renamed *Algarobia* by Bentham in 1839, before both were eventually given sub-generic rank and placed as sections in the genus *Prosopis*. Burkart (1940) suppressed section Circinaria (Bentham and Hooker 1867) and section Lomentaria described by Spegazzini in 1899 was also suppressed by Burkart (1976), and both are now excluded from the genus. The position of the closely related genus *Prosopidastrum* remains unclear. The African section Anonychium has remained unchallenged since 1842 (Bentham 1842) but its position in the genus may soon be questioned. In the Americas, section Monilicarpa was the last to be accepted, intermediate between the two large sections, Algarobia and Strombocarpa, where most taxonomic confusion has occurred. The generic limits of the genus and division into five distinct 'sections' are now generally accepted.

There have continued to be revisions of the genus since Burkart (1976), which have mostly involved the identification of new species and varieties. There is also an opposite view to reduce the rank and number of *Prosopis* species, and classification and ranking are of some debate (see 2.1.6). The ten species described by Bentham (1875) had increased to 44 in Burkart's classification a century later with Burkart personally responsible as the authority for a quarter of the species and half of the varieties in his monograph (Burkart 1976). Bentham's treatment incorporated many populations with semi-indistinct morphological traits as varieties or forms in a broader species concept. Burkart (1940, 1976) raised the rank of these varieties and a number of other noted forms to species rank. This trend continues with the identification of new species and varieties to the present day. A return to the treatment of Bentham, or grouping of species into broad 'clines' or 'complexes' is also put forward (see 2.1.6). The application of molecular techniques may clarify the taxonomic confusion in coming years, and further revision of the genus is to be expected. A list of the most frequently used synonyms of common *Prosopis* species is given in Table 5 (see 2.1.4).

2.1.3 The *P. juliflora* - *P. pallida* complex

The name *juliflora*, comes from *julus*, meaning 'whip-like', referring to the long inflorescences, and *flora* being the flower. The name *pallida*, meaning pallid or light in colour, refers to the greyish foliage, particularly when dry as in herbarium samples. The complex, as defined in this monograph, includes the two presently accepted species *P. juliflora* and *P. pallida* and their respective varieties and forms taken from Burkart (1976) and Díaz Celis (1995) (see below). The natural distributions of each, based on locations of herbarium and seed material, are given in Figure 16 (see 2.4.1), including the Caribbean, even though current thought suggests that these populations are naturalised to that region.

Prosopis juliflora (Sw.) DC.
var. *juliflora*
Prosopis juliflora (Sw.) DC.
var. *inermis* (H.B.K.) Burkart
Prosopis juliflora (Sw.) DC.
var. *horrida* (Kunth) Burkart
Prosopis pallida (H. & B. ex. Willd.) H.B.K.
forma *pallida* (Fosberg) Ferreyra
Prosopis pallida (H. & B. ex. Willd.) H.B.K.
forma *armata* (Fosberg) Ferreyra

Prosopis juliflora (Swartz) DC. has had an array of synonymy since the first description in 1788 (Table 6, see 2.1.4). Originally known as *Mimosa juliflora* Swartz, it became both *Algarobia juliflora* (Swartz) Bentham ex Heynh. and *Neltuma juliflora* (Swartz) Rafinesque during the last two centuries before both those genera were incorporated into the single, overarching genus *Prosopis*. *P. juliflora* is used here in its original, restricted and certainly biological sense, re-established by Burkart (1940) and accepted by Johnston (1962). The all-embracing, collective *P. juliflora* concept of Bentham (1875) was maintained by others such as Sargent (1902), Standley (1926), Benson (1941) and Standley and Steyermark (1946). Although the collective *P. juliflora* concept is currently rejected by most taxonomists and researchers, it is still used occasionally to this day (e.g. Dommergues *et al* 1999). Much confusion occurs when referring to old literature, because the binomial *P. juliflora* was used to describe species now generally accepted as separate taxa (Table 7, see 2.1.4).

Much literature from the USA has followed classification of North American species as varieties of *P. juliflora* (Bentham 1875, Benson 1941). The binomial *P. juliflora* was also used to describe some South American species, but only rarely. Therefore great care must be taken when referring to old literature on *P. juliflora*, with observation of authority but more importantly geographic origin required to ascertain the correct species being described. Taxonomical confusion in North America, particularly the USA, is probably the single largest cause of mis-identification involving the *P. juliflora* - *P. pallida* complex in its native range. It can be said with certainty that all references to *P. juliflora* from the USA and Mexico prior to Johnston (1962) and Burkart (1976) and many from after these dates refer to either *P. glandulosa* or *P. velutina*.

This has led to further problems when referring to literature on the *P. juliflora* - *P. pallida* complex, particularly where introduced, being caused by the simplification of binomials of introduced material by excluding the variety and authority. For example, when *P. juliflora* var. *glandulosa* (Torrey) Cockerell was introduced from the USA or Mexico before the 1970s, it often became simply *P. juliflora*, when it is actually *P. glandulosa* Torrey. Initial mis-identification without correction can be repeated continually leading to many foresters and researchers believing that a certain leaf and tree morphology is characteristic of one species when it can be seen by a trained eye to clearly belong to another. Several examples are widely quoted and have contributed to the confusion. In sub-tropical and Mediterranean zones where these species were introduced, particularly in South Africa, Southern Australia, northern Africa and the Middle East, the binomial *P. juliflora* is still often used. *P. juliflora* is generally frost sensitive and rarely survives prolonged cold periods found in such regions. The species present are likely to be of sub-tropical North American origin, possibly South American or hybrid forms, and the lack of common reference herbarium material means that the confusion has continued.

The reverse can also be true, where species identified as another *Prosopis* are actually *P. juliflora*. A classic example is the taxonomical mis-identification originating early this century in Sudan that has perpetuated to this day. The common species concerned is not *P. chilensis* (Molina) Stuntz but is clearly *P. juliflora* (Sw.) DC. from leaf morphology (e.g. El Amin 1990). Material was mis-identified as *P. chilensis* by experts in the herbarium at Kew, UK in 1966, furthering the problem, or maybe samples of a small population of *P. chilensis* was sent, not representative of the common *Prosopis*. Several other studies such as that by Bari (1986) noted that the original introduction in 1917 and subsequent naturalisations were of *P. chilensis*, continuing earlier false identifications. Although now positively accepted as *P. juliflora* in Sudan (e.g. Bristow 1996, El Fadl 1997), this problem has also spread throughout North, East and West Africa confusing foresters in many of these countries, and in other places where seed from Sudan has been planted. This includes seed from Sudan distributed as *P. chilensis* by the FAO and DANIDA from the 1970s to the present day, which is actually *P. juliflora*. *Prosopis* species in Israel have also been poorly identified in some cases and the labelling of seed of Israeli provenance is not always accurate.

Prosopis pallida has endured less taxonomical confusion than *P. juliflora*. It was originally placed in the genus *Acacia*, and was included in the genus *Mimosa* before being transferred to the genus *Prosopis*. It did not suffer the problems associated with the false classification of section Algarobia as a separate genus. Bentham (1875) notes *P. limensis* (sp. n., syn. *P. pallida*) from Peru as the only *Prosopis* species of section Algarobia he was aware of that was not sympatric with others in the section. This may assume that he was either unaware of *P. juliflora* and hybrids in southern Ecuador and northern Peru, or he treated them all as the same species, distinct from the *P. juliflora* of Central America, Colombia and the Caribbean. This may be important when comparing morphology within the complex (see 2.2.3) or when considering its origin and affinities (see 2.4.2). The species *P. limensis* was accepted for many years, but Burkart (1976) brought *P. limensis* into synonymy with *P. pallida* when no consistent differences could be found. Five species were recognised by Burkart and Simpson (1977) as native in Peru, while Ffolliot and Thames (1983) noted seven. There has been confusion as to the relative ranges of these species, where MacBride (1943) and Ferreyra (1979) noted *P. chilensis* as a species of the entire coastal zone, Weberbauer (1945) described *P. juliflora* for this whole region including inter-Andean valleys, and Ferreyra identified *P. affinis* in certain coastal localities. Present taxonomic thought states that *P. pallida* is the dominant species in Peru, *P. chilensis* is restricted to montane zones, particularly in the south, *P. juliflora* is restricted to the very northern coastal zone, while *P. affinis* is not present in Peru (Díaz Celis 1995).

Two forms of *P. pallida*, forma *pallida* and forma *armata* were described by Fosberg (1966) from introduced material in Hawaii, based primarily on differences in armature. Burkart (1976) noted these forms but failed to incorporate them into his monograph, although giving similar differences varietal status in *P. juliflora*. While the binomial *P. pallida* remains intact, further taxonomic confusion has involved the differentiation of the species into forms. Ferreyra (1987) confirmed the two forms of Fosberg (1966) but also described two new forms, forma *decumbens* and forma *annularis*. Ferreyra (1987) also gave the first description of *P. affinis* Sprengel in Peru, while noting that this species had previously been described only in Uruguay, Paraguay, southern Brazil and Argentina (e.g. Burkart 1976). While not referring directly to the work of Ferreyra, Díaz Celis (1995) accepts only the two forms of Fosberg, and by default brings *P. affinis* and *P. pallida* forma *decumbens* (Ferreyra 1987) back into synonymy with *P. pallida* forma *armata*, while *P. pallida* forma *annularis* (Ferreyra 1987) appears to be the same as the description of *P. juliflora* var. *juliflora* by Díaz Celis (1995). This confirms the existence of this variety in Peru made by Burkart (1976) but excluded by Ferreyra (1987). Further changes in nomenclature are expected, especially in northern Peru and southern Ecuador where all the varieties of *P. juliflora* and all forms of *P. pallida* are found.

The main taxonomic problem associated with *P. pallida* is the confusion with other *Prosopis* species from section Algarobia, mainly *P. juliflora*. For example in Hawaii, both the binomials *P. juliflora* and *P. chilensis* were used before the correct species, *P. pallida* was identified by Johnston (1962) although hybrids may exist. Similar problems have occurred in South Africa and Australia, and doubts still remain as to the taxonomy of *Prosopis* species in several regions where they have been introduced, in particular to tropical zones where the species present are *P. juliflora*, *P. pallida* or some hybrid between the two. In Brazil, Senegal and India, for example, it appears certain that some unrecorded introductions of *P. pallida* have taken place and are probably the principal species now present. Because of morphological similarity to the species already present, taken as *P. juliflora* due to the incorrect identification, the same binomial was used throughout.

In India, original introductions are thought to have been *P. juliflora* from Mexico or Jamaica (Reddy 1978, Muthana and Arora 1983). Differences in plant morphology may be due to further introductions of seed material of various origins and possible hybridisation between them. Five forms of *P. juliflora* were identified in India (Raizada and Chatterji 1954), and while the Mexican form is probably *P. juliflora*, the Peruvian form is likely to be *P. pallida*. Both *P. juliflora* and *P. pallida* have been positively identified in India (Burkart 1976). In the north-east of Brazil there is some confusion over species identification, the naturalised trees are generally assumed to be *P. juliflora* but with increasing belief that they may be *P. pallida* or originate from a hybrid mixture. Burkart (1976) states that *P. pallida* was introduced and cultivated in Brazil but fails to give locations. Several experts have noted the resemblance between the *Prosopis* in the north east of Brazil and the *Prosopis* from Peru accepted as *P. pallida*. Similar material exists in Cape Verde and also in Senegal, which may have been introduced from Brazil or directly from Peru. These examples confirm the need to deal with the complex as a single unit at the present time.

P. affinis was identified amongst populations of *P. juliflora* and *P. pallida* in Peru (Ferreyra 1987) and in the Serra Talhada mountains in Pernambuco, Brazil, close to where early introductions of *Prosopis* from Peru occurred (Lima and Silva 1991), and it was speculated that either there was mixed seed or that some hybrid material was sown. The descriptions note red-purple pods as the primary distinguishing feature based on the original identification of *P. affinis* in Peru (Ferreyra 1987). Burkart (1976) described the native range of *P. affinis* from the extreme south of Bolivia, Paraguay, north-east Argentina, western Uruguay and the extreme south-west of Brazil with no mention of the existence of a disjunct northern population in Peru. Comparison of the taxonomical descriptions between Burkart (1976) and Ferreyra (1987) show differences in leaf and flower morphology, and recent taxonomical descriptions of Peruvian *Prosopis* (Díaz Celis 1995) exclude *P. affinis*, with red-purple pod colour given as a variant of *P. juliflora* var. *juliflora*. On this basis it is assumed that *P. affinis* was incorrectly identified in Peru and northeast Brazil and it is not included in the complex.

2.1.4 Synonymy

Major confusion in the naming of *Prosopis* species arise from old literature, particularly from North America (see 2.1.3) but also from the entire native range of the genus (see 2.1.2) and this is common in poorly researched articles. A detailed classification of synonyms for *Prosopis* species is given in Burkart (1976) and Simpson (1977), and the most frequently used synonyms for common *Prosopis* species excluding *P. juliflora* and *P. pallida* are listed in Table 5. In Asia, the continuing use of the binomials *P. spicigera*, *P. stephaniana* and even *Lagonychium farctum*, over 20 years after accepted revision of the genus, shows the difficulties following the renaming of species. In Africa, *P. africana* is still occasionally referred to as *P. oblonga*, over a century after accepted revision. A full list of the binomials used for *P. juliflora* and *P. pallida* and their synonymity are presented in Tables 6 and 7. Problems of synonymy in the Americas originated initially from the re-naming of previously identified species, and the incorporation and separation of hybrids from species.

More confusion has occurred in areas where these species were introduced, due to the lack of information about the seed source and poor subsequent identification. This is far from being resolved, and in many cases incorrect binomials have been used for nearly a century. However, with continuing revision of the confusing taxonomy of the genus, a longer list of synonyms can be expected in the future.

2.1.5 Vernacular names

There are very many vernacular names of Old World *Prosopis*. *P. africana* has a multitude of names in various African languages (von Maydell 1986, Neuwinger 1996), and *P. cineraria* in many Asian languages where it is native (ICFRE 1993). Although there are over 40 *Prosopis* species in the Americas with many different names in indigenous Indian languages, two vernacular names and their variants are commonly used to describe tree species of section Algarobia. 'Mesquite' (English) and 'mezquite' (Spanish) are used in North America, and 'algarrobo' (Spanish) and 'algarobeira' (Portuguese) are used in South America. Species of section Strombocarpa have closed, spiralled legumes and are known in the Americas by different names, generally 'screwbeans' (English), 'tornillos' or 'mastuerzos' (Spanish).

The name 'mesquite' originates from the original Nahuatl Indian name from Mexico, 'misquitl' meaning 'bark that tans' (Maldonado 1990). Spanish variants are used in Latin America, although it is also the most common name for *Prosopis* in the English language, for example in many areas where introduced in Asia, Australia, and Africa. In South America, the first *Prosopis* seen by the invading Spaniards were called 'algarrobo', because of the observed similarity between these and the carob (*Ceratonia siliqua*) of the Mediterranean basin, both with similar, sweet edible pods (D'Antoni and Solbrig 1977, Cruz 1999). Thus the Spanish name for carob, 'algarrobo', became the most common name for South American *Prosopis* tree species of section Algarobia. *Prosopis*-dominated woodlands in parts of the Americas are subsequently referred to as 'mezquitales' or 'algarrobales'. It must be noted also that native species often have more exact names than above, e.g. 'honey mesquite' and 'velvet mesquite' or 'algarrobo negro' and 'algarrobo blanco'. This vernacular applies predominantly to tree species but also to shrubby species with straight or curved legumes. Some vernacular names used for *P. juliflora* and *P. pallida* around the world are presented below (Table 8), but because of taxonomic confusion within the complex, they are grouped together in a single list, divided only by country.

The vernacular names of the *P. juliflora* - *P. pallida* complex give some indication of the localities where the trees are found, or their uses or characteristics. In the Caribbean, the name 'bayahonde' and its variants has its origins either from the French 'baie-à-ondes' ('bay of waves'), being a coastal

Table 5. The most frequently used synonyms for common species of the genus* Prosopis *(from Burkart 1976, Simpson 1977), excluding* P. juliflora *and* P. pallida*, listed separately in Table 6 and 7.

Prosopis algarobilla Griseb.
Prosopis nandubey Griseb.
= *Prosopis affinis* Sprengel
Prosopis lanceolata Benth.
Prosopis oblonga Benth.
= *Prosopis africana* (Guill. Perr. & Rich.) Taubert
Prosopis atacamensis Phil.
= *Prosopis alba* Grisebach
Prosopis pazensis (Britt. & Rose) Wigg.
= *Prosopis articulata* S.Watson
Prosopis siliquastrum (Lag.) DC.
= *Prosopis chilensis* (Molina) Stuntz emend. Burkart
Prosopis spicata Burman
Prosopis spicigera L.
= *Prosopis cineraria* (L.) Druce
Lagonychium farctum (Solander ex Russell) EG. Bobrov
Prosopis stephaniana (M.Bieb.) Kunth ex Sprengel
= *Prosopis farcta* (Solander ex Russell) MacBride
Prosopis odorata Torrey & Fremont
= *Prosopis glandulosa* Torrey
Prosopis dulcis Kunth
= *Prosopis laevigata* (Humboldt & Bonpland ex Willd.) MC Johnston

Table 6. Synonyms of* P. juliflora, P. pallida *and their varieties, with year of first description where known. Confusion between* P. juliflora *and* P. pallida *particularly in Ecuador and Peru has led to several synonyms of* P. juliflora *being assigned also to* P. pallida *(e.g. FAO 1997), though not repeated here.

Mimosa juliflora Swartz (1788)
Acacia cumanensis (Humboldt & Bonpland ex. Willdenow) (1805)
Acacia juliflora (Swartz) Willdenow (1806)
Mimosa salinarum Vahl (1807)
Desmanthus salinarum (Vahl) Steud. (1821)
Prosopis cumanensis (Humboldt & Bonpland ex. Willdenow) H.B.K. (1823)
Acacia salinarum (Vahl) DC. (1825)
Prosopis bracteolata DC. (1825)
Prosopis dominguensis DC. (1825)
Neltuma juliflora (Swartz) Rafinesque (1838)
Algarobia juliflora (Swartz) Bentham ex Heynh (1840)
Prosopis dulcis var. *domingensis* (DC.) Bentham (1841)
Prosopis vidaliana A. Naves (1877)
Neltuma bakeri Britton & Rose (1928)
Neltuma occidentalis Britton & Rose (1928)
Neltuma pallescens Britton & Rose (1928)
Prosopis pallida forma *annularis* Ferreyra (1987)
= *Prosopis juliflora* (Swartz) DC. var. *juliflora* Burkart (1976)
Prosopis inermis H.B.K. (1825)
= *Prosopis juliflora* (Swartz) DC. var. *inermis* (H.B.K.) Burkart (1976)
Prosopis horrida Kunth (1822)
= *Prosopis juliflora* (Swartz) DC. var. *horrida* (Kunth) Burkart (1976)

Acacia pallida Humboldt & Bonpland ex Willdenow (1805)
Prosopis pallida (Humboldt & Bonpland ex Willdenow) H.B.K. (1805)
Mimosa pallida (Willdenow) Poiret (1810)
Prosopis limensis Bentham (1842)
= *Prosopis pallida* (Humboldt&Bonpland exWilldenow) H.B.K. forma *pallida* Fosberg (1966)
Prosopis pallida forma *decumbens* Ferreyra (1987)
Prosopis affinis (Sprengel) Ferreyra (1987)
= *Prosopis pallida* (Humboldt&Bonpland exWilldenow) H.B.K. forma *armata* Fosberg (1966)

Table 7. Synonyms where the binomial* P. juliflora *was used to describe other* Prosopis *species.

Prosopis juliflora (Sw) DC. var. *glandulosa* (Torrey) Cockerell (1895)
= *Prosopis glandulosa* Torrey
Prosopis juliflora (Sw) DC. var. *constricta* (Sargent) (1913)
= *Prosopis glandulosa* Torrey
Prosopis juliflora (Sw) DC. forma *arborea* L. Hauman (1913)
= *Prosopis flexuosa* DC.
Prosopis juliflora (Swartz) DC. forma *fruticosa* Hauan (1913)
= *Prosopis alpataco* R.A.Philippi
Prosopis juliflora (Sw.) DC. var. *velutina* (Wooton) Sargent (1941)
= *Prosopis velutina* Wooton
Prosopis juliflora (Sw.) DC. var. *torreyana* (Benson) (1941)
= *Prosopis glandulosa* var. *torreyana* (Benson) Johnston.
Prosopis juliflora (Swartz) DC. var. *articulata* (S. Watson)Wiggins (1950)
= *Prosopis articulata* (S.Watson)

Table 8. Vernacular names of* P. juliflora *and* P. pallida *throughout the world, whether native or introduced. Some names may not be specific to* P. juliflora *or* P. pallida*, and may also be used for other* Prosopis *species.

Country	Vernacular name (language)
Abu Dhabi	uweif (Arabic)
Ascension Island	Mexican thorn (English)
Australia	mesquite (English)
Bahamas	mesquite (English)
Brazil	algarobeira (Portuguese)
Cape Verde	espinheiro (Portuguese); spinho (Crioulu)
Colombia	algarrobo, cují, cují negro, cují yaque, trupillo, manca-caballo, trupi, algarrobo forragero, aroma, anchipia guaiva, mesquite (Spanish)
Costa Rica	arómo (Spanish)
Cuba	chachaca, guatapaná, plumo de oro, cambrón, algarrobo del Brasil (Spanish)
Curação	cojí wawalú, indjoe, wawahi, indju, qui, cuida, kuigi (Papiamento)
Dominican Republic	bayahonda, bayahonda blanca, bayahonde, bohahunda, bayahon, vallahonda, cambrón, mezquite (Spanish)
Ecuador	algarrobo (Spanish)
El Salvador	carbón (Spanish)
Guatemala	campeche, nacasol, nacascol, palo de campeche (Spanish)
Haiti	bayahonde, bayahonde française (French); bayarone, bayahon, bayawonn, bayawonn française, baron (Creole); chambron, guatapaná (Spanish)
Hawaii	kiawe, algaroba, mesquite (English)
Honduras	espino ruco, espino real, algarrobo (Spanish)
India	vilayati babul, vilayati babool, vilayati khejra (Hindi); gando baval (Gujrati); vilayati kikar (Marathi); angrezi bavaliya (Marwari); belari jari, velikaruvel, velimullu (Tamil)
Iraq	shouk shami (Arabic)
Jamaica	cashaw, cashew (English/ Patois)
Kenya	eterai , mathenge (Swahili)
Mali	gaudi maaka (Peulh)
Marquesas	carobier (French)
Mexico	mesquite, mezquite, algarroba, mareño, catzimec, chachaca (Spanish)
Middle East states	ghaf (Arabic)
Nicaragua	aguijote negro, acacia de Catarina, espino negro (Spanish)
Niger	shejain kawa, mugun kawa (Hausa)
Pakistan	vilayati babul, vilayati jand, vilayati kikar (Punjabi)
Panama	aromo, manca-caballo (Spanish)
Peru	algarrobo (Spanish); huarango, guarango, thacco, taco (Quechua)
Philippines	aroma (Spanish)
Puerto Rico	algarroba, aroma, aroma americana, bayahonde, mezquite, mesquite, cambrón, algarrobo americano (Spanish)
Senegal	dakkar toubab (Wolof)
Somalia	lebi (Somali)
South Africa	mesquite (English/ Africaans)
Sudan	mesquite (English)
Trinidad and Tobago	mesquit-tree (English)
Venezuela	cují, yaque, cují yaque, cují yague, yaque blanco, yaque negro, cují negro, cují amarillo, maíz criollo, caóbano gateado, cujicarora (Spanish)
Virgin Islands	algarroba (English)

species (Burkart 1976), or from the Spanish 'vaya hondo' ('to go deep') descriptive of the root system (Timyan 1996). In Cuba, 'plumo de oro' ('gold plume') refers to the long inflorescences, and 'algarrobo del Brasil' to its assumed origin. In Central America, 'mezquite' ('the bark that tans' or 'good wood') and carbón ('charcoal') refer to its desirable uses. However, 'espino negro' ('black thorn) in Nicaragua and 'espino ruco' ('tired thorn') and 'espino real' ('royal thorn') in Honduras relate to this undesirable character. These latter names may refer to a particularly thorny land race known to exist in Honduras (Stewart *et al* 1993) and elsewhere in Central America. 'Cuida' ('care' or 'caution') in Curaçāo also refers to large thorns.

In South America, 'algarrobo' and its variants are commonly used. In Colombia and Venezuela 'cují', 'yaque', 'trupillo' and variants are used, which are thought to be base names without specific meaning. Also used is 'maíz criollo' ('local maize') which refers to the consumption of the fruit by man or animal. In Peru, the names 'thacco' or 'taco' used in the Quechua language in the southern Andean provinces mean 'the tree' or 'the one' and refer to it being the most common or important species in that region. 'Guarango' and 'huarango' are also unanalysable words of Quechuan origin from the same area. Several specific epithets are occasionally used with 'algarrobo' in Peru to describe different land races or types. 'Sambito' or 'zambito' ('curled') describes trees with small leaflets and dense foliage; 'cholito' ('farmer') for more thornless trees with large leaflets; 'achaparrado' ('bush like') for more prostrate trees; 'cachito' ('small horn') for those with curved pods; and 'pava' ('female turkey') for those with red or purple coloured pods (Díaz Celis 1995, Cruz 1998).

Where it has been introduced, most vernacular names that differ from the above, include reference to the thorns. For example, it is called 'Mexican thorn' in Ascension Island, 'espinheiro' ('thorn tree') in Cape Verde, 'dakkar toubab' ('white man's thorn') in Senegal, 'shejain kawa' and 'mugun kawa' ('bastard thorn' and 'dangerous thorn') in Niger, 'shouk shami' ('Syrian thorn') in Iraq, 'vilayati babul' ('foreign thorn'), 'ganda babul' ('mad thorn') and variants in India. These references could be indicative of introductions of the relatively thorny provenances of the *P. juliflora - P. pallida* complex from Central America or the Caribbean, or just because of their relative thorniness and prominence in these countries. In the Arabian peninsula, the conspecific name 'ghaf' is used to refer to all *Prosopis* trees, belonging to both indigenous (*P. cineraria* and *P. farcta*) and introduced *Prosopis* species. The name 'carobier' used in the Marquesas in the Pacific, is the French name for the Mediterranean carob tree and is assumed to have had the same origin as the Spanish 'algarrobo'.

2.1.6 Taxonomic revisions?

Many suggestions have been proposed, changing the taxonomy of *Prosopis* from that described by Burkart (1976). Using Burkart (1976) as the most recent complete taxonomy, the following section presents and discusses the views of various *Prosopis* 'experts' and taxonomists as an aid to future revisions, but no new taxonomy is offered. There are two contrasting schools of thought. The taxonomy of Burkart has dominated, where observed morphological differences between *Prosopis* populations have been assigned the rank of species or variety. This had led to an increase in the number of species from Burkart (1940) to Burkart (1976), with several more having been suggested in the last 20 years. An alternative taxonomic view has become more prominent in the last 10 years, with the application of numeric taxonomy and molecular analysis, suggesting that several of the 'species' and 'varieties' of Burkart are genetically very similar and that their rank should be reduced to sub-species, geographic races or clines. These views are discussed in the light of research findings and the role of hybridisation in speciation (see 2.3.2).

Although large variations exist between American and Afro-Asiatic species in terms of plant characteristics, it appears that the genus will remain entire. Floral and leaf morphologies show similarities within the entire genus, but clear distinctions between different sections within the genus exist (e.g. Burkart 1976, Martínez 1984). Molecular studies have also confirmed overlapping characteristics (e.g. Burghardt and Palacios 1997, Ramírez *et al* 1999). If divided, the genus *Prosopis* would be reduced to only the Asiatic species (section Prosopis), with section Anonychium (*P. africana*) raised to generic rank and the American species into three separate genera based on the present sections Strombocarpa, Monilicarpa and Algarobia. As Burkart (1976) argued, "this would cause a total change in the nomenclature of many well known species, with no benefit to anyone". The only suggestion as to a possible alteration in generic limit is offered by Earl (1999), who recommends the inclusion of *Prosopidastrum* in the genus *Prosopis*. This closely related genus contains two defined species, *Prosopidastrum mexicanum* (Dressler) Burkart in Mexico and *P. globosum* (Gillies ex Hooker & Arnott) Burkart in Argentina (Burkart 1976). It is thought that they are reproductively isolated but this is not certain (Earl 1999). Burkart (1976) maintained separation on the grounds of dehiscent legumes and incurved thorns, absent in all other *Prosopis* species. However, additional information is required on these little studied species for clarification.

Several additional species have been described post-Burkart, but there is also an opposite move to reduce the rank of many previously described species and varieties. Taxonomic study has concentrated in the species rich regions in North and South America, but relatively little in the Asiatic, African and Central American centres. This has been aided by evidence from molecular studies, many of them very recent. Categories of sub-genus, section and series were developed for the purposes of sub-dividing genera, but many problems remain as to their respective levels, ranking and consistency with *Prosopis*. Hunziker *et al* (1986) proposed to elevate Burkart's sections to the rank of sub-genera, which has been supported by several studies in South America (e.g. Saidman and Vilardi 1993, Burghardt and Palacios 1997). While it is accepted that morphologically distinct 'species' of *Prosopis* exist within a 'section', distinctions are blurred by the presence of hybrid populations.

With the few Afro-Asiatic species, there has been relatively little post-Burkart debate over taxonomy. It is ambiguous, however, that section Prosopis is not divided into two series based on seed alignment in the pod as is section Strombocarpa, purely because an intermediate form, *P. koelziana* was discovered. A new species, *P. persica* has been described from Iran (Djavanshir 1993) and another variety of *P. koelziana* from the Middle East (Leonard 1986) which may be stable hybrid forms and require verification. *P. koelziana* was thought to be a hybrid by Burkart (1976). The reduction in the taxonomic value of pubescence in *Prosopis* suggested by Vilela and Palacios (1997) because of its noted variability and site specificity led to the questioning of the division of *P. farcta* into varieties based solely on pubescence as suggested by Burkart (1976). In Africa, the taxonomy of *P. africana* has been generally accepted, but two varieties have been noted by Neuwinger (1996) based on pod shape which require verification.

In the Americas, the debate as to the relative status of *Prosopis* species has continued and deepened, with extensive research undertaken in Argentina, and also in Mexico and the USA. Some revisions to the taxonomy have been suggested since 1976, involving new additions or exclusions from Burkart's classification, and re-classification of the 40 species described by Burkart (1976). Molecular studies have confirmed the division of American species into the three sections as described by Burkart (1976), though not necessarily the further sub-division into series, and occasionally not the division of species into varieties. It must be taken into account, however, that the material analysed may not have been from a pure specimen of the named species, as this is often difficult to ascertain in a genus where hybridisation is common and species identification from morphology can require considerable expertise.

Recent studies using protein electrophoresis (Burghardt and Palacios 1997) and randomly amplified polymorphic DNA (RAPDs) (Ramírez *et al* 1999), confirmed earlier work with leaf morphology (Martínez 1984), flavonoids (Solbrig *et al* 1977) and isoenzymes (Solbrig and Bawa 1975). These studies agreed with the division into 'sections', and placed *P. argentina* undisputedly in its own intermediate section, Monilicarpa. Its origin and affinities still remain unclear, however, with molecular as well as morphological similarities to species in both neighbouring sections. Section Strombocarpa is clearly distinct from section Algarobia in all molecular studies. There are differences in foliar architecture (Martínez 1984) and pollen grain morphology (Caccavari de Filice 1972). There are no known naturally occurring hybrids between species from these sections (Hunziker *et al* 1986), although they are graft compatible (Wojtusik and Felker 1993). The division between the African, Asiatic and two American sections is marked in all characters tested, expected with the absolute reproductive isolation observed between them.

The section Strombocarpa contains eight species described by Burkart (1976) in the disjunct ecosystems of North and South America. Within this section, there is some variation and overlap within and between the two series Strombocarpae and Cavenicarpae as seen with protein electrophoresis (Burghardt and Palacios 1997), and also but less so using RAPDs (Ramírez *et al* 1999). No difference in foliar architecture was observed (Martínez 1984). Re-definition or removal of series ranking in this section appears warranted, i.e. reducing the systematic value of seed alignment in the pod. Alternatively, a series rank should be introduced in section *Prosopis* for consistency within the genus, which appears unwarranted. Burkart (1976) noted that *P. tamarugo* and *P. ferox* were very similar, *P. burkartii* was thought to be a hybrid between *P. strombulifera* and *P. tamarugo*, and *P. strombulifera* and *P. reptans* appeared to be complexing species. Using isoenzymes, Saidman *et al* (1996) found that the genetic similarity between *P. strombulifera* and *P. reptans* is sufficient for the two to be considered sub-species or geographic races of *P. strombulifera* instead of good taxonomic species, while Earl (1999) includes all species of section Strombocarpa as a cline of a single species, *P. strombocarpa*.

The section Algarobia contains over half of the species described by Burkart (1976) and this is where much of the taxonomical debate centres. In North America, eight species were described by Burkart. In Mexico, several new species have been proposed. These include *P. bonplanda* (Earl and Lux 1991), *P. cuatzingoa* and *P. humbolta* (Earl 1999), and *P. bacharis* (Maldonado 1991). There is also the re-emergence of *P. microphylla* von Humboldt & Bonpland, *P. torreyana* Torrey (Earl 1998), *P. dulcis* Kunth (Earl 1999) and *P. pazensis* (Britt. & Rose) Wigg. (Maldonado 1991). In contrast, there appears to be a complex comprising the closely related species of *P. glandulosa*, *P. laevigata* and *P. velutina* in North America. Although they are morphologically different, Solbrig *et al* (1977) found no differences in the flavenoid contents between *P. velutina*, *P. glandulosa* var. *glandulosa* and *P. glandulosa* var. *torreyana*. Using isoenzymes, Solbrig and Bawa (1975) found that *P. velutina*, *P. glandulosa* var. *glandulosa* and *P. laevigata* were all alike. The main morphological character used by Hilu *et al* (1982) to separate *P. glandulosa* var. *torreyana* and *P. velutina* was leaf pubescence, the systematic value of which is now questioned following work by Vilela and Palacios (1997). These species were given only varietal rank by many taxonomists following Bentham (1875). Earl (1999) goes further, reducing the rank of all American species into a single cline incorporating all species of section Algarobia. However, several 'good' species are accepted in North

America, even if they are very closely related, and either their rank will be reduced or they could be grouped into a single complex.

Between the North and South American centres of polymorphism lie populations of *P. juliflora* and *P. pallida*. Observed differences, mainly in armature and form of *P. pallida* in Peru, led Ferreyra (1987) to distinguish three other forms, *annularis*, *armata* and *decumbens*. These are similar in distinction to the differences between the three varieties of *P. juliflora* described by Burkart (1976), which all occur in the same region. *P. juliflora* and *P. pallida* are in different series, but isoenzyme studies (Burghardt and Palacios 1997) do not support this. A disjunct population of *P. affinis* identified in Peru by Ferreyra (1987) is rejected in this monograph. Different races of *P. juliflora* were noted by Johnston (1962), who even proposed a possible division into separate species (see 2.4.2).

Remaining with section Algarobia, it is in South America, and particularly in Argentina and neighbouring countries, that the myriad of described species and widespread range has led to a continuing intensive study of native species and a re-examination of *Prosopis* taxonomy. Several new species and varieties have been described, including *P. nuda* from Bolivia (Schinini 1981). Species from section Algarobia show a strong degree of similarity in all studies undertaken, whether analysing foliar architecture (Martínez 1984), wood anatomy (Castro 1989), enzymatic properties (Saidman and Vilardi 1987, Saidman 1990), protein electrophoresis (Burghardt and Palacios 1997), leaf physiology (Vilela and Palacios 1997) or DNA samples (Ramírez *et al* 1999). The most radical view (Earl 1999) that all *Prosopis* within each section actually belong to a single species is not supported by these studies which identify distinct, 'good' species in the Americas, with morphological and molecular analyses (Martínez 1984, Burghardt and Palacios 1997, Ramírez *et al* 1999) and some observed reproductive isolation barriers (e.g. Saidman 1990) (see 2.3.2).

However, the distinctions between series as defined by Burkart (1976) were not often substantiated. Solbrig and Bawa (1975) supported the separation of *P. sericantha* in a separate section based on isoenzymes, not followed by Burkart (1976), who included it with *P. kuntzei* in the series Sericanthae within section Algarobia. Solbrig *et al* (1977), using flavonoids, found *P. sericantha* to be similar to North American species of section Algarobia while *P. kuntzei* was similar to species of section Strombocarpa. Ramírez *et al* (1999) found with RAPD markers that of all species tested from section Algarobia, only *P. kuntzei*, showed marked difference from species in series Ruscifoliae, Pallidae and Chilenses. The more recently described *P. nuda* (Schinini 1981) may be a stable hybrid form between *P. sericantha* and *P. kuntzei*. Obviously further work is required with these two species, though they are clearly distinct from other species in section Algarobia.

Species from within series Sericanthae and series Humiles appear to have stronger isolation barriers preventing hybridisation between species of these two series as there is limited geographical isolation. Some species from these two series are also sympatric with some species from the remaining series of section Chilenses, and with no known formation of hybrids this also suggests the existence of some inherent reproductive isolation. One or both of these series may have their rank raised following further research. It appears that the process of reproductive isolation is actively in progress amongst South American populations of *Prosopis* species particularly in the Chaco region. Identifying the reproductive barriers between species and groups of species, along with more detailed molecular analyses in progress should lead to a clearer picture of this most confusing taxonomy.

Solbrig *et al* (1977) found flavenoid differences between single species from series Denudantes, Humiles and Ruscifoliae, and also *P. alpataco* from series Chilenses, all of which were quite different from other species in section Chilenses, which were in two distinct groups from the North and South American centres. Martínez (1984) used leaf morphology to distinguish species from series Denudantes and Ruscifoliae from those in series Humiles, Pallidae and Chilenses although species from series Sericanthae were not included in the study. Protein electrophoresis by Burghardt and Palacios (1997) did not reveal any distinct differences between species in series Ruscifoliae, Pallidae and Chilenses, and all the putative South American hybrids identified by Hunziker *et al* (1986) were between species of these three series. No study has shown any morphological or molecular basis for division of species into the series Pallidae and Chilenses.

Using molecular markers, Ramírez *et al* (1999) identified differences between the species analysed, but the two recognised varieties of *P. alba* were not very closely related. Where varieties have disjunct ranges within similar ecosystems it may be questioned whether they are 'good' varieties or whether convergent evolution has occurred (Simpson 1977). Such may be the case with varieties of *P. laevigata* and *P. reptans*, native to both North and South America. Many other varieties distinguished by Burkart (1976) and subsequent division of species based purely on single morphological traits is questionable. That varieties of Bentham (1875) are now species of Burkart (1976), means that varieties of Burkart are equivalent to forms following Bentham's classification. The importance of ranking and consistency within the genus is clear, and further changes in varietal status of many taxa may be expected, dependent upon agreement as to the relative value of various taxonomic indicators.

Pubescence appears to be variable and site specific (Vilela and Palacios 1997) and of limited use in the separation of taxa when used alone. The presence of thorns is very variable within and between populations (Felker *et al* 1981a) and are generally absent on older branches, having being incorporated into the wood. Armature type was, however, used to separate the five sections by Burkart (1976) and has taxonomic significance. Quantitative floral characters are difficult to evaluate due to protygeny (Burkart 1940), with floral parts in many different stages of development on the same inflorescence. Changes in the relative importance and systematic value of characters including wood and seed anatomy will also affect the classification of species within the genus. Confusion arises as to the value and consistency in the use of habit and form in species classification (Johnston 1962). Quantitative foliar characters were significant and effective in distinguishing *Prosopis* species (Benson 1941, Johnston 1962, Martínez 1984, Earl 1998), and are recommended for use on the entire genus. If linked to molecular analysis on a range-wide level, quantitative foliar characters could provide a valuable field guide for species identification and some clarification of the confusing taxonomy.

The value of the effects of habit and form on species classification also merits specific attention. In sections Prosopis, Strombocarpa and Algarobia, two distinct 'forms', one erect and one prostrate sometimes exist in an otherwise morphologically similar population. While some observers suggest strong site influence, the occasional occurrence of both forms in the same area suggests genetic control. The relative taxonomic value of this character appears to differ between species in the three sections where it is observed. In section *Prosopis*, taxonomists recognise as species the erect *P. cineraria* and the prostrate *P. farcta*. They are thought to co-exist in some areas and to hybridise (Burkart 1976), and other 'species' and varieties described may be hybrid forms between the two. In section Strombocarpa, the South American *P. tamarugo* tree and prostrate *P. ferox* are given species rank by Burkart (1976), who notes their similarity. The erect *P. pubescens* is recognised while the prostrate form has been divided into a species complex in North America (Burkart (1976) and South America (Saidman *et al* 1996). It is known that all species within section Strombocarpa can hybridise and some putative hybrids have been suggested.

With the extensive range and variation in morphological traits observed in species of section Algarobia, the issue of habit and form is more complicated. In North America, the prostrate 'running mesquite' form of Johnston (1962) was given varietal rank *P. glandulosa* var. *prostrata* by Burkart (1976). The prostrate form was noted to occur particularly on clay soils, in height classes distinct from the erect form when also present. A similar prostrate form has been observed with *P. laevigata* but not given varietal rank (Johnston 1962, Burkart 1976). It is important to distinguish bushy forms from the truly prostrate forms. For example, bushy forms of *P. glandulosa* could be trained into tree forms by pruning, while the distinctive prostrate 'running mesquite' could not (Johnston 1962). Both forms appear to flower simultaneously in the USA, but other barriers to reproduction may well exist. In South America, the erect *P. flexuosa* is separated from the prostrate *P. alpataco* by species rank, and *P. pugionata* may be another hybrid form, while Burkart (1976) also notes variations in habit in some other species without giving them any rank. Ferreyra (1987) used habit to differentiate a newly described form of *P. pallida*, forma *decumbens*. Prostrate and tree forms can be distinct populations, but what rank they are given appears to vary widely between authors and regions.

The creation of new binomials for species that have already been named, the re-emergence of synonyms and the continued use of binomials from old literature has continued to confuse *Prosopis* taxonomy. Publications in press such as the new Flora Neotropica are expected to clarify the situation. However, it will be a theoretical taxonomical debate that has the last word in resolving *Prosopis* taxonomy. The differences between populations are accepted, and are being further quantified, from numeric taxonomy to DNA analysis, but the question remains, as to what rank these differences are given. Following Burkart's classification, which accepted that hybrids could be classified as distinctive species, other taxonomists have merely followed his lead. Further division of taxa based on minimal morphological differences between populations such as pubescence, habit or presence of thorns can only confuse the issue, leading to a potentially endless list of species. Some reduction in the rank of certain species and varieties appears warranted.

Molecular studies show that there are identifiable, 'good' species. While many can clearly hybridise and thus cannot be classified as true 'species' following certain theories of species classification, others are isolated by geographical or partial biological barriers to reproduction. Speciation appears to be actively in progress. Now it is up to biologists and taxonomists to clarify the position and ranking of species and hybrids. A way forward would be to first agree on a list of these 'good' species and group them into complexes based on agreed morphological characters, genetic similarities and geographic ranges, with site preference and resource character as additional characters making the new classification a useful tool for natural resource managers.

2.2 Description

2.2.1 Generic description

Prosopis species are all trees or shrubs of varying size (rarely sub-shrubs), predominantly xerophilous, aculeate, spiny or rarely unarmed (Burkart 1976). Leaves are bipinnate, often with few pairs of opposite pinnae. Only in a few sub-aphyllous species are they sometimes reduced, pinnate and paucifoliate. Petioles have circular, sessile, apical glands and sometimes smaller, similar ones on the rachis of the pinnae. Leaflets are small, rarely large, numerous, mostly opposite, linear, oblong, fusiform, entire and of the same colour on both sides. Venation is pinnate and not very prominent. Shoots in most species are dimorphic with long megablasts, flexuous and becoming knotty with age. Brachyblasts or short shoots emerge from multiple axillary buds, from which develop the cauline spines when extant, leaf fascicles and racemes.

The flowers are small, actinomorphic, pentamerous and hermaphroditic. Aestivation is valvate and the calyx is campanulate. The corolla has linear petals which are fused or more or less free, glabrous or pubescent, frequently villous or pilose inside the tip. The androecium is of 5+5 free stamens. Anthers are elliptic, dorsifixed, introrse, with an apical, pedicellate, globose or ovoid connectival gland. Pollen grains are simple, isopolar, tricolporate, sub-spheroidal to prolate. The exine is pertectate and baculate, and the sexine is bigger than the nexine. Pollen grains are large or small. The ovary is stipitate, villous or sometimes glabrous. Racemes are spike-like, amentiform, axillary, mostly densiflorous, but sometimes in globose heads (Burkart 1976). The fruit is a modified, indehiscent, fleshy legume called a 'dropaceous loment' (Burkart 1976). These are linear, straight, falcate, annular to spirally coiled with a fleshy mesocarp. The mesocarp is sugary or fibrous, containing endocarps, divided into one-seeded, coriaceous to bony segments. These are closed, sometimes opening easily, longitudinal or rarely biseriate and transverse. Seeds are ovoid, compressed, with a fissural line on the faces, known as a pleurogram. They are hard, brown, with a mucilaginous endosperm, typical of the Mimosoideae, surrounding the embryo. Cotyledons are flat, rounded and epigeous in germination.

Detailed descriptions of 44 *Prosopis* species and a number of varieties are given by Burkart (1976), which are accepted as the most recent complete taxonomy of the genus. Many of the species are clearly identifiable by leaf morphology and plant size and form, the most common methods of species identification in the field. While correct identification of species has been clarified within species' native ranges (e.g. Burkart and Simpson 1977), identification where introduced is often confused. It is not in the scope of this publication to provide detailed descriptions of all *Prosopis* species. However, of the most common *Prosopis* tree species, several have been incorrectly classified but are easily differentiable on the grounds of leaf morphology. Typical leaves of some common *Prosopis* species are shown in Figure 2a and 2b.

2.2.2 Description of the *P. juliflora - P. pallida* complex

Seedling

Seeds of *P. juliflora* and *P. pallida* are epigeous in germination. The fleshy cotyledons are the first seed leaves, persisting after the first true leaves have formed, being green or somewhat pale-green in colour. Once germinated, most energy is expended on rapidly developing a root system and locating a water source as soon as possible. In the first months, root length and biomass increases are much greater than shoot biomass leading to a high root: shoot ratio. Seedling development of *P. pallida* has been divided into distinct stages based on pairs of pinnae in leaves formed (Calderón 1989 in Díaz Celis 1995), shown diagramatically in Figure 3. Common features in the young branches of *P. pallida* are that the first leaves on each branch have only a single pinna, the following have two to three pairs, and some will have four pairs. A similar feature of young branches is that there is only one alternate leaf per node, increasing in number with maturity.

Tree size and form

Tree size and form vary considerably between species, populations and individuals, due to both genetic and environmental influences. On favourable sites with adequate moisture, *P. pallida* trees may attain a height of 20 m (Burkart 1976, Little and Skolmen 1989). While *P. juliflora* can normally only reach a maximum height of 12 m (Burkart 1976, Ferreyra 1987), trees of 20 m are also seen in favourable conditions (e.g. Singh and Singh 1993). Both species also exist as shrubs as low as 3 m high, while *P. juliflora* appears to have some land races that are very prostrate in form, at least in the early stages of growth (Stewart *et al* 1993). The trunk is short and often crooked or twisted, reaching a diameter of up to 65 cm. The bark is grey-brown, rough and fibrous, varying from finely fissured to furrowed. Under natural conditions, crowns are generally open, and broader than the tree is high.

Tree forms vary, including erect trees, flat-topped trees, and trees with decumbent branches touching the ground. The shrub form can also vary from erect sub-shrub to prostrate shrub form (Figure 4). Trees and shrubs are generally multi-stemmed, with much forking beginning low on the trunk, although more erect and less branched land races are known. In decumbent tree forms, branches are upright at first but take a horizontal form before becoming pendulous at distal ends, occasionally touching the ground. Prostrate forms are more common in younger trees, which can develop more upright stems as they mature. Smaller branches are green or green-brown and take on a zigzag appearance (Perry 1998). Provenances of the *P. juliflora - P. pallida* complex have significantly different tree forms (Harris *et al* 1996b) which appear to be genetically controlled (e.g. Lee *et al* 1992, Kumar *et al* 1998). However, environmental variables such as thin soils, presence of hard pan or persistent wind are also observed to induce the formation of smaller, more prostrate forms. Frost damage, browsing, insect infestations or cutting by man can all cause damage to the leader which breaks the dormancy of buds at the base of the stem and promotes a multi-stemmed form.

Root system

Roots develop rapidly following germination and can reach a depth of 40 cm in eight weeks (Figure 5). There are two distinct root systems which are formed under normal conditions of unimpeded root development. These are, characteristically, a deep root system, and a superficial root system, both having different functions during different seasons. The deep root system is made up of one, two or three (rarely more) main tap roots, which may divide at lower depths. They have the function of anchoring the tree but are primarily for sourcing ground water reserves, whether a water table or other subterranean supply. They can become very thick and tens of metres long until a permanent water source is found. *P. pallida* tap roots reach water tables 20-25 m deep (Díaz Celis 1995), while *P. velutina* has roots reaching over 53 m deep (Phillips 1963). Roots extend horizontally once a water source is reached and tend to grow following the direction of water flow (Tume *et al* 1989). Where there is an impermeable sub-surface layer, such as that formed by an iron pan or hardened calcareous pans, tap root extension is prevented and roots will extend laterally above this layer (Singh and Singh 1993). Impeded and unimpeded root systems of *P. pallida* are shown in Figure 6 and may be typical of the complex.

The lateral root systems of *P. glandulosa* have been studied in detail (e.g. Heitschmidt *et al* 1988, Gile *et al* 1997) and were found to consist of main lateral roots and two types of secondary root. Larger secondary roots (approximately 20 mm in diameter) grew vertically downwards from the laterals, while small, fibrous secondary roots (under 5 mm in diameter) extended and bifurcated vertically upward to within 4 cm of the soil surface (Heitschmidt *et al* 1988). The root system of *P. tamarugo* has also been studied in detail (e.g. Sudzuki 1985) but conditions in its native range are unusual and thought not to be applicable to other *Prosopis* species. Jones *et al* (1998) noted that root colour could be used to distinguish *P. juliflora* roots from other species, the young roots of *P. juliflora* were cream coloured with a translucent cortex, while old roots were pale brown with a semi-opaque cortex. Root density of *P. juliflora* was 3 cm of root/cm^3 of soil in the upper 15 cm of the soil profile, dropping to less than 0.5 cm root/cm^3 of soil at below 45 cm depth, and less than 0.2 cm root/cm^3 of soil at 1.8 m depth. This was approximately three times the root density found with *A. nilotica*, but *P. juliflora* roots had less effect on crop growth than *A. nilotica* per unit root length (Jones *et al* 1998).

Wood structure

The total volume of *P. juliflora* wood is divided between its microscopic constituents into: fibres 48%, vessels 18%, rays 18% and axial parenchyma 16%. The anatomical description of *P. juliflora* wood which follows, mostly comprises two descriptions which generally concur, by Gomes and de Muñiz (1990), based on samples from Brazil, and by Kazmi and Singh (1992), based on samples from India. The wood of *P. juliflora* is diffuse porous in its gross structure (Gomes and de Muñiz 1990, Kazmi and Singh 1992). The wood of *P. caldenia* and *P. chilensis*, however, was ring porous and semi-ring porous respectively, in a given growth ring, which Gomes and de Muñiz (1990) correlated with the lower rainfall prevailing where these species grew. In contrast, *P. juliflora* from a higher rainfall zone with higher mean temperatures and lower thermal amplitude than at the other sites was generally diffuse porous, with wider growth rings formed during rainy years. Porosity became semi-ring porous during drier years (Gomes and de Muñiz 1990). A magnified cross section of *P. juliflora* wood is shown in Figure 7.

Growth rings of *P. juliflora* are occasionally demarcated by darker and denser zones of fibrous tissues, visible to the naked eye, and also by a fine interrupted line of parenchyma cells visible only under a magnifying glass (Kazmi and Singh 1992). Medium sized vessels are formed at the beginning of the growth ring, coinciding with the beginning of the rainy season in Brazil (Gomes and de Muñiz 1990). Later in the growing season, high temperature and evapotranspiration do not favour the production of maximum diameter vessels, which are formed when water deficits are reversed. At the end of the growth ring, lower rainfall leads to the production of medium sized vessels and some small sized vessels (Gomes and de Muñiz 1990). Percentage of early wood is higher with increased water availability (Abohassan *et al* 1988).

Vessels are small to moderately large, visible to the naked eye or with a 10X lens. They are mostly solitary but sometimes in radial multiples of two to four vessels or in short clusters. Vessels are moderately few to numerous (2-12/mm^2), with vascular lines irregular to slightly tortuous in tangential view, somewhat unevenly distributed, and with a circular or oval cross section, polygonal in multiples, usually open and occasionally filled with organic deposits (Gomes and de Muñiz 1990, Kazmi and Singh 1992). Vessel elements are very short to short (approximately 0.2 mm long), small to large in diameter (0.1-0.2 mm wide), with or without short appendages. The perforation plate is exclusively simple, transverse in larger vessels to slightly oblique in smaller ones (Gomes and de Muñiz 1990). Intervascular pitting is alternate, circular to elliptic with a narrow aperture and distinctly vestured, similar to vessel-parenchyma pits and ray-parenchyma pits.

Parenchyma cells are often abundant, visible to the naked eye and distinct under a hand lens as lighter coloured patches or thick sheaths around vessels, sometimes connected obliquely or tangentially. They also appear as fine interrupted lines delimiting growth rings, either abundant and visible to the naked eye (Kazmi and Singh 1992), or not abundant and visible only with difficulty with a 10X lens (Gomes and de Muñiz 1990). Parenchyma cells are paratracheal, vasicentric and mostly aliform to fluent, enclosing several vessels, particularly in late wood and delimiting growth rings, also with apotracheal parenchyma present. Parenchyma cells are fusiform and seriate, in strands of 2-4 cells (0.2 mm long), frequent and often subdivided into locules with solitary rhomboidal crystals (Gomes and de Muñiz 1990, Kazmi and Singh 1992).

Rays are fine to moderately broad, homogenous, mostly normal, sometimes aggregated or fused, few to numerous (5-10 mm long) and distinct under a hand lens as lighter coloured, closely spaced lines. Rays vary in thickness from

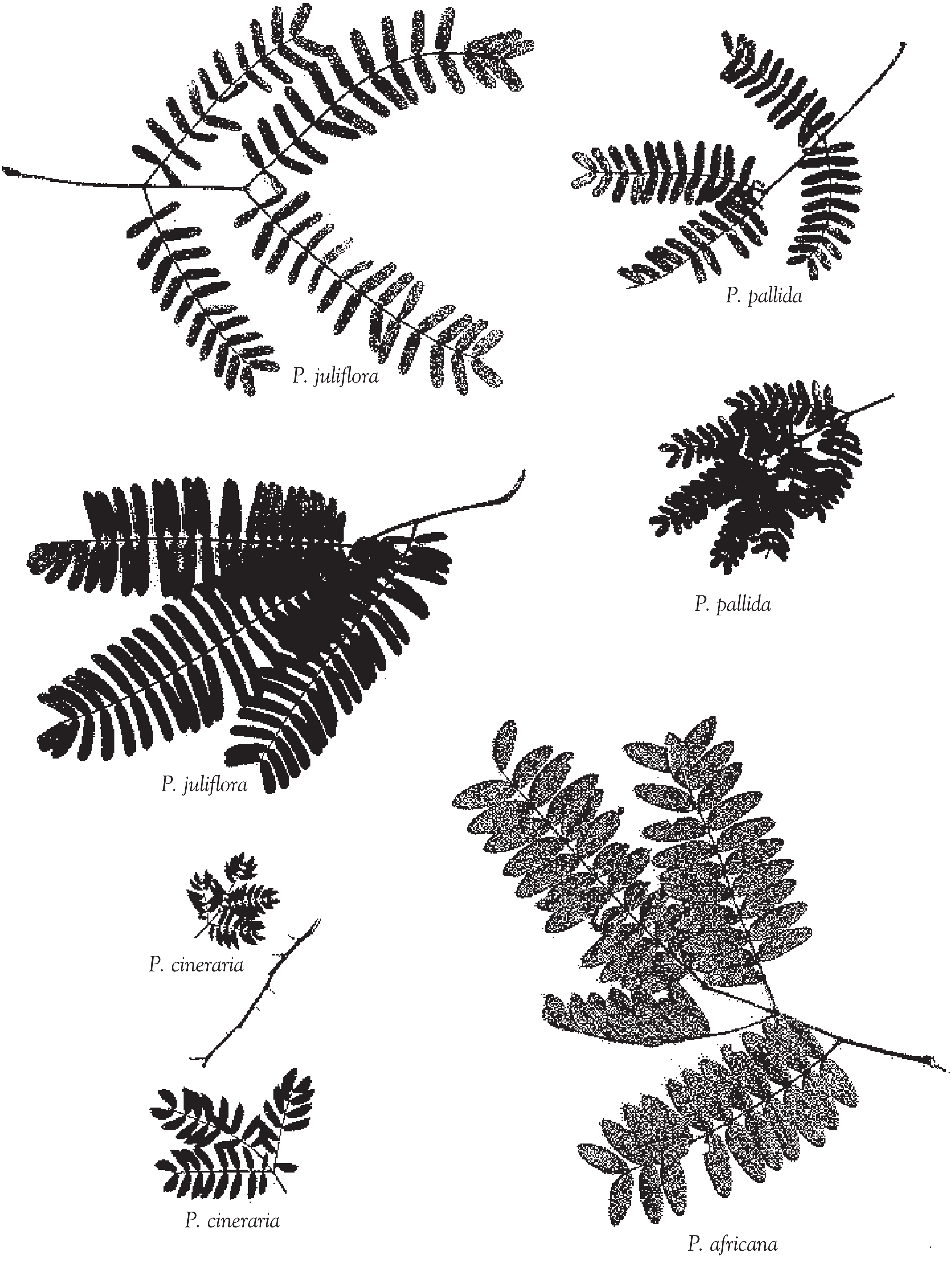


Figure 2a. Leaf shape of common* Prosopis *species (x 0.6).

Figure 2b. Leaf shape of common **Prosopis** ***species (x 0.6).***

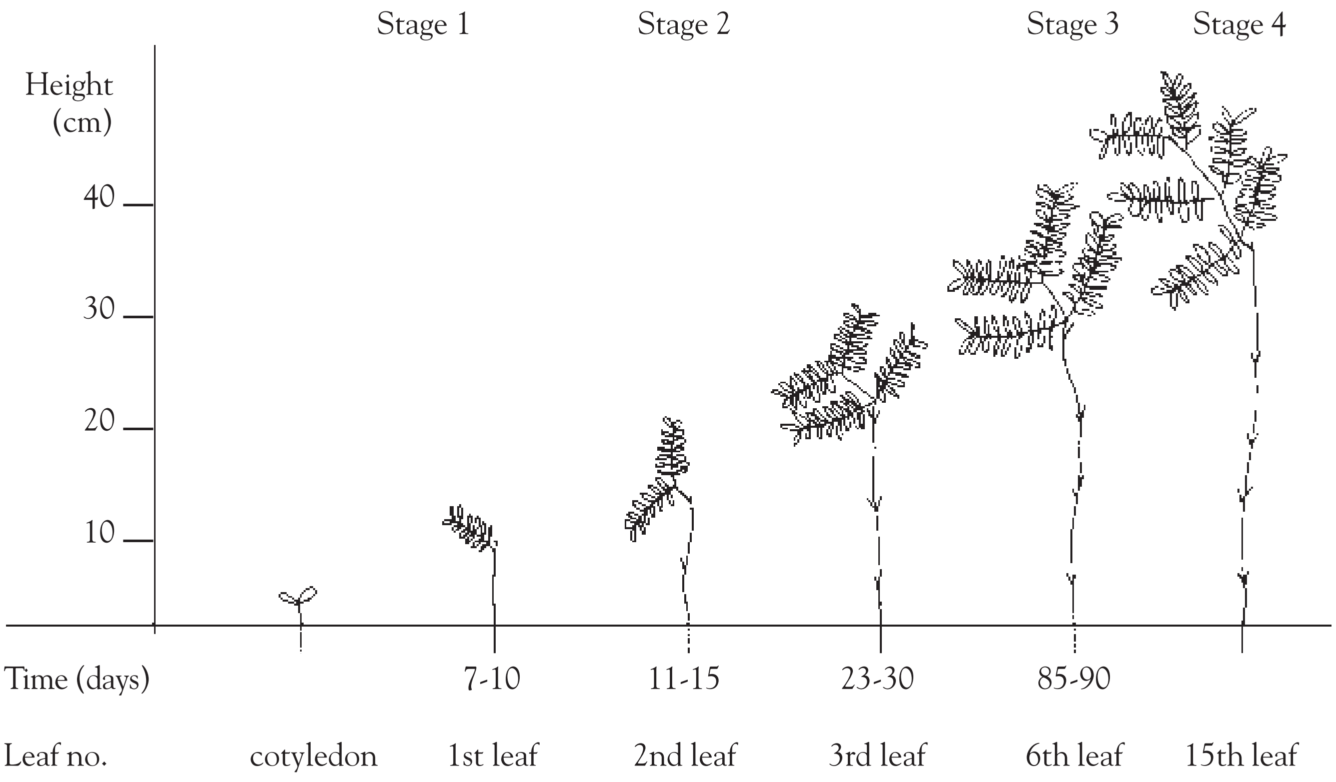
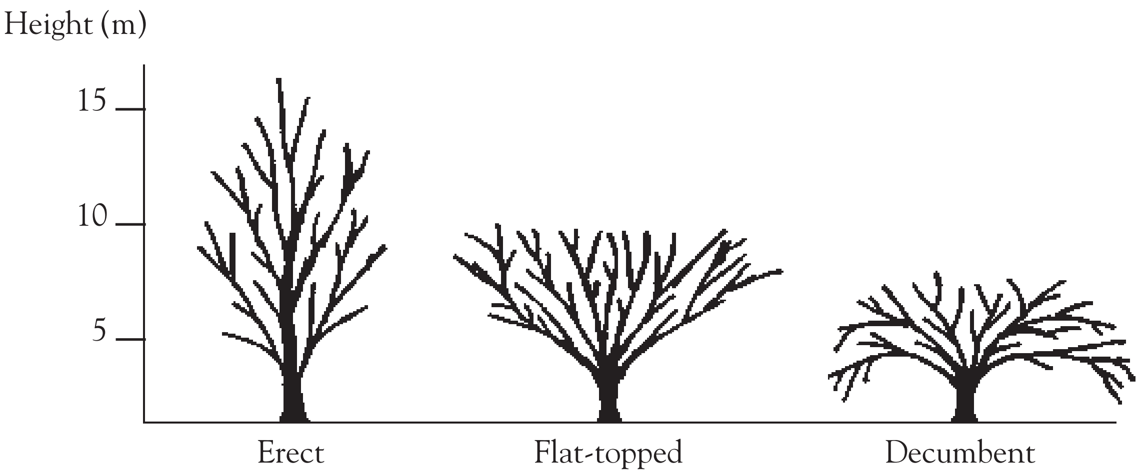


Figure 3. Stages of development of* P. pallida *leaflets in Peru (adapted from Calderón 1989, in Díaz Celis 1995).

Tree forms



Shrub forms

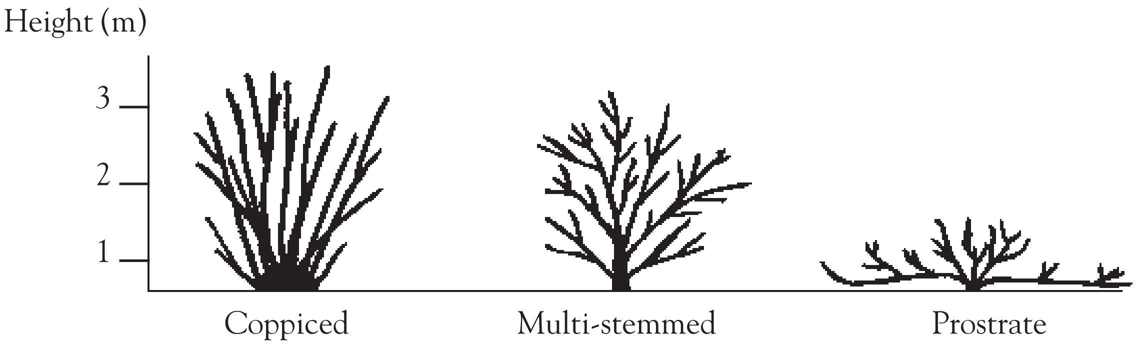


Figure 4. Tree and shrub forms observed in the* P. juliflora - P. pallida *complex.

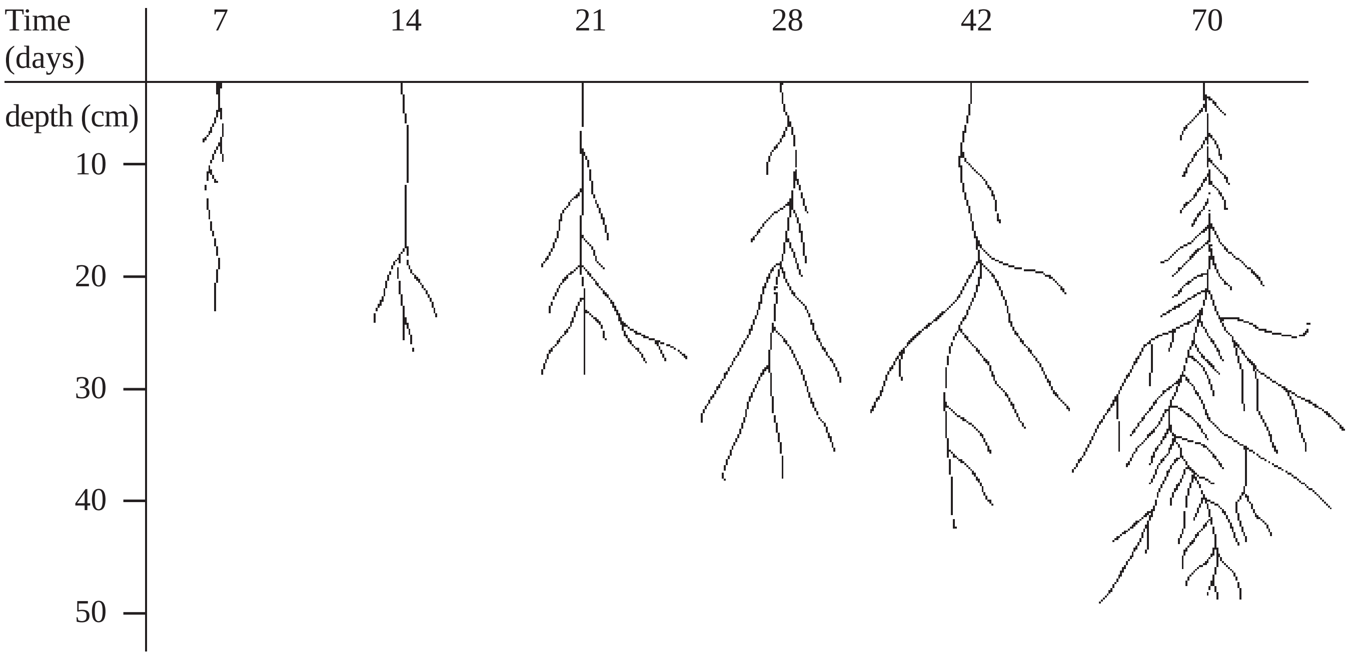


Figure 5. Development of root system in P. juliflora *seedlings in India (Gupta and Balara 1972).*

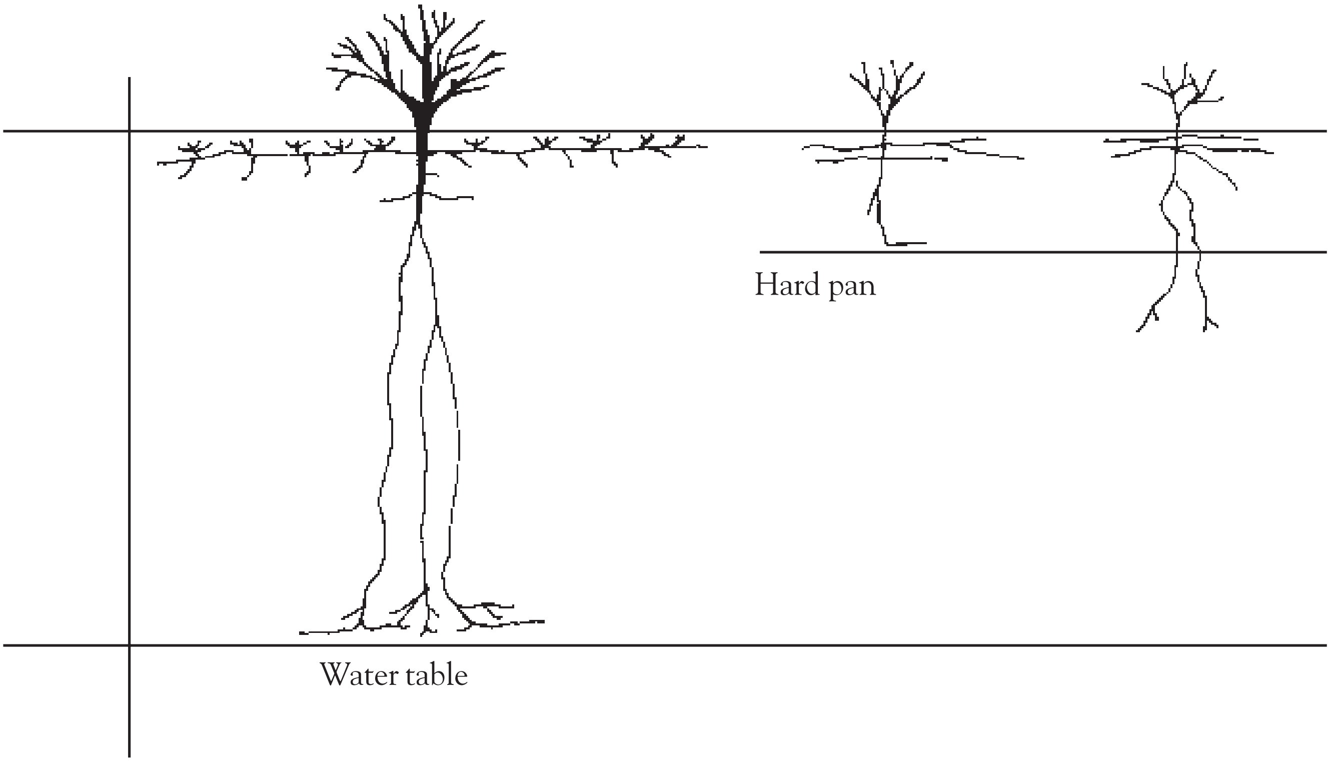


Figure 6. Root systems of P. pallida *with and without an impermeable layer in the soil profile (Roig, 1985 in Díaz Celis 1995, Aguirre, 1989 in Díaz Celis 1995).*

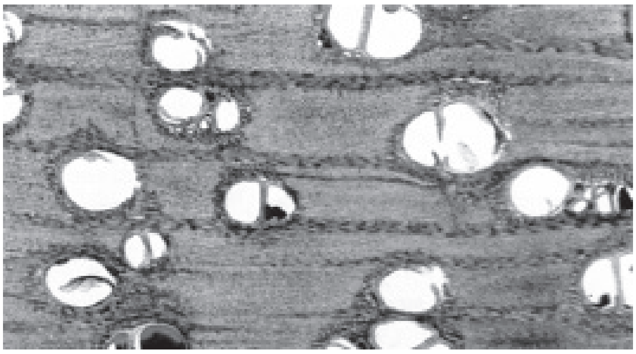


Figure 7. Section of* P. juliflora *wood (x30) (Gomes and de Muñiz 1990).

one to several cells wide, commonly 4-5 seriate. Uniseriate rays are very rare, extremely narrow and low (2-9 cells high). Multiseriate rays are extremely small (0.4 mm), up to 40 or 130 cells high and 2-8 cells wide. There are occasional crystals in procumbent cells.

Fibres are abundant in regular tangential bands. Fibres are 1.0-1.2 mm long and 0.014 mm in diameter (Rajput and Tewari 1986, Gomes and de Muñiz 1990, Kazmi and Singh 1992). They are very short and narrow, libriform, non-separate and often gelatinous with very thick walls (Gomes and de Muñiz 1990). Fibres are rather angular, aligned somewhat radially in transverse section, with pits on the walls which are distinct on radial walls (Kazmi and Singh 1992). A cytochemical study of normal and tension wood sides of cambium and xylary derivatives in stems of *P. juliflora* revealed marked differences in dimensions and composition of cambial cells and differentiation in cambial derivatives, leading to the formation of defining gelatinous fibres (Hariharan and Krishnamurthy 1998).

Thorns

Armature consists of cauline, axillary spines which are geminate and divergent. Spines are straight, multi- or uni-nodal, solitary, paired or solitary and paired on the same branch. Spines are produced on new growth, and tend to be largest on strong basal shoots and prominent on young branches. They become shorter on older stems due to incorporation of spines during wood growth and diameter increments in the stem and branches, and may become absent on older wood. Trees vary in the number and size of thorns, which may be absent or not on all branches. Thorns, when present, can be rare or profuse, long or short, thin or stout, 0.5-7.5 cm long and 2-5 mm in thorn base diameter.

Some completely thornless individuals and populations are known, due to suppression of the cauline spines. In Hawaii, the introduced *P. pallida* is estimated to include approximately 30% thornless trees (Esbenshade 1980). A small, truly thornless population from central and coastal Ecuador was called *P. juliflora* var. *inermis* by Burkart (1976), differentiated from *P. juliflora* var. *juliflora* by the total absence of thorns. *P. juliflora* var. *horrida* has longer and more profuse thorns, although some are thornless and there are other morphological differences (Burkart 1976). Burkart (1976) described *P. pallida* as thorny or thornless, whereas Fosberg (1966), Ferreyra (1987) and Díaz Celis (1995) differentiated the species into a truly thorny *P. pallida* forma *armata* and are generally thornless *P. pallida* forma *pallida*.

Foliage and flowers

Leaves are bipinnate, with 1-10 leaves per node, and petiole plus rachis 5-20 cm long (Díaz Celis 1995). For examples of leaf, pod and flower morphology, see Figures 8, 9, 10 and 11. Trees are aphyllous or sub-aphyllous, with a rapid turn-over of leaves. Pubescence varies from entirely glabrous or ciliolate to somewhat pubescent or pubescent (Burkart 1976, Perry 1998). Leaves have 1-4 pairs of pinnae per leaf (1-4 jugate), each pinna 1.5-14 cm long. There are 6-29 pairs of leaflets per pinna, with leaflets approximate on the rachis, slightly distant or conspicuously separate and up to 8 mm apart (Burkart 1976, Ferreyra 1987, Díaz Celis 1995).

Leaflets are linear-oblong, elliptic-oblong or ovate in shape, with an obtuse to mucronulate or minutely pointed apex, nerved below. Leaflets vary greatly in size, 2.5-23 mm long and 1-7 mm wide. Glands are cupuliform, sessile with an apical pore, present at the junction of the pinnae, sometimes also at the junction of the leaflets (Burkart 1976, Ferreyra 1987, Díaz Celis 1995). While trees are generally evergreen, *P. juliflora* is occasionally deciduous, possibly due to drought or cold temperature (e.g. Johnston 1962).

Flowers are small, 4-6 mm long, gathered densely together on cylindrical, spike-like inflorescences known as racemes. They are generally yellow, straw yellow or yellow-white in colour. Flowers are hermaphrodite, sometimes sterile, actinomorphic and pentamorous (Burkart 1976). The calyx is campanulate, green or greenish-yellow, bell-shaped and ciliolate outside, 0.5-1.5 mm long. The corolla is 3.0-3.2 mm long, styles 2.0-3.0 mm long, petals 2.5-3.0 mm long, free and villous within (Ferreyra 1987).The five stamens are 4-7 mm long, pistils 4-5 mm long, and the stipitate, villous ovaries are light green in colour and 1.5-1.8 mm long (Ferreyra 1987). Anthers have a glandular appendage (Chaudhry and Vijayaraghavan 1992). The pedicel is short, 0.5-3.0 mm long.

Racemes are 5-17 cm long and approximately 1.5 cm wide. The rachis, peduncle and acumen are glabrous or pubescent, the peduncle 4-20 mm long and the acumen 6-25 mm long. With *P. pallida* in Peru, Díaz Celis (1995) observed 237-366 flowers per inflorescence, while Alvarez Sanchez (1998) noted a mean flower number of only 228 and mean inflorescence length of 10.2 cm. With *P. juliflora* in Brazil, De Oliveira and Pires (1990) found 269-456 flowers per inflorescence (mean 344) and a mean inflorescence length of 11.5 cm. Flowering may commence in the first or second year under favourable conditions but 3-5 years is common in normal field conditions.

Fruit and seed

The fruit is an indehiscent legume, straight with an incurved apex, sometimes falcate or sub-falcate, with or without parallel margins. Pods are stipitate and acuminate, compressed to sub-compressed, and sub-moniliform. They are flattened, rectangular to sub-quadrate in section. Immature pods are green in colour, becoming commonly straw yellow when fully mature. Some pods are, however, brown or brownish, while red-tinged or purple pods are seen in northern Peru and Ecuador (Díaz Celis 1995). The number of pods produced per inflorescence varies greatly, with Goel and Behl (1996) noting 1-16 fruit per inflorescence. Pods also vary greatly in size, 8-40 cm long, 9-18 mm wide and 4-10 mm thick (Burkart 1976, Ferreyra 1987, Díaz Celis 1995).

Pods are made up of an exocarp, a fleshy mesocarp, and endocarp segments each containing a single seed, with up to 30 seeds per pod. Exocarps vary in their thickness, external colour and ease of separation from the mesocarp but are generally consistent. The relative proportion of mesocarp in the pod varies greatly, affecting pod thickness and chemical composition, of particular note being the content of sugars and proteins. The fibrous endocarps each contain a single compressed, ovoid or oblong seed. Seeds are brown in colour, shiny and with a horseshoe-shaped fissural line on both surfaces of the testa, with the arms pointing towards the hilar end. Seeds are up to 6.5 mm long and weigh approximately 0.25-0.30 g (25000-30000 seeds/kg). Inside the tegmen is the endosperm, which is hard, mucilaginous, corny or vitreous, which surrounds the yellow cotyledons. The cotyledons are round or elliptical, with a sagitate base and frequently do not cover the upper part of the radicle.

2.2.3 Comparative morphology within the *P. juliflora - P. pallida* complex

There is a lack of common herbarium material of species within the complex, which is true for section Algarobia as a whole (Burkart 1976), causing difficulties in the definition of the large variation in morphology observed. While the complex is dealt with as a whole with regards to ecology, biology, silviculture and management, this section attempts to analyse the noted differences between identified species and varieties in terms of traditional taxonomy. Leaves, fruit and flowers of *P. juliflora* and *P. pallida* are shown in Figures 8, 9, 10 and 11. A sample of leaves from the *P. juliflora - P. pallida* complex showing the wide variation in leaf morphology is presented in Figure 12. Table 9 and Figure 13 distinguish between species in Peru, and Tables 10, 11 and 12 detail taxonomical descriptions from native ranges and where introduced.

As well as differences between the species *P. juliflora* and *P. pallida*, three races are identified for the purpose of comparing morphology, adapted from Johnston (1962): the Peruvian-Ecuadorian 'southern' race, the Central American 'north-western' race and the Colombian-Caribbean 'north-eastern' race. The possible origin and affinities of these races is further discussed (see 2.4.2) and their estimated geographic range is mapped (Figure 17, see 2.4.2). From present taxonomic knowledge, only *P. juliflora* var. *juliflora* exists in the two northern races while all thorn varieties and forms of both *P. juliflora* and *P. pallida* are found in the southern race.

The tree form varies from erect with few branches to distinctly shrubby and multi-stemmed. Erect forms are more common in the southern race, including *P. juliflora, P. pallida* and hybrids in southern Ecuador and Peru, and also in inland sites throughout the native range. Therefore, while *P. pallida* appears somewhat more erect than *P. juliflora*, significant effects of site on phenotype blurs any distinction in this race. Variations in height and branch form are not consistent. The bark of *P. juliflora* is rough and fissured while that of *P. pallida* is noted as finely fissured, and the inner bark of *P. juliflora* becomes yellow after exposure and is slightly bitter to taste, while that of *P. pallida* is orange-brown and bitter (Little and Wadsworth 1964, Little and Skolmen 1989). There are large variations in the size and presence of thorns within and between races. *P. juliflora* var. *inermis* and *P. pallida* forma *pallida* are described only in the southern race and as completely thornless but are sympatric with other thorny forms and varieties, including *P. juliflora* var. *horrida* with the longest thorns of all. In the two northern races of *P. juliflora* var. *juliflora*, thornlessness is rare and the presence of longer, stouter thorns is common, particularly in coastal areas.

Leaflets of *P. juliflora* tend to be larger and further apart than those of *P. pallida*, and leaves also tend to be longer, given as a distinguishing feature by Díaz Celis (1995) between species in the southern race. Much larger leaflets are seen in some populations, particularly coastal areas in Central America and the Caribbean, possibly due to introgression by larger leaved temperate types such as *P. glandulosa*. Johnston (1962) observed that leaflets longer than 15 mm (15-20 mm) were observed only in the Central American race of *P. juliflora*, with 10-15 mm leaflet length seen in the Colombian-Caribbean race and leaflets less than 10 mm long (5-8 mm) in *P. limensis* (syn. *P. pallida*, of the southern, Peruvian-Ecuadorian race). Leaflet length of *P. juliflora* of the southern race is seen to be intermediate between *P. juliflora* of the Colombian-Caribbean race and *P. pallida* also of the southern race, using data from Johnston (1962) and Díaz Celis (1995). It thus appears possible to define trees of the complex simply by leaflet length, but the very wide variation observed in the field makes any form of classification difficult. Taxonomical confusion may be resolved by a range-wide study of the size, shape and number of leaflets, linked to molecular analysis assessing possible introgression of other species, such as *P. glandulosa* in the Central American race.

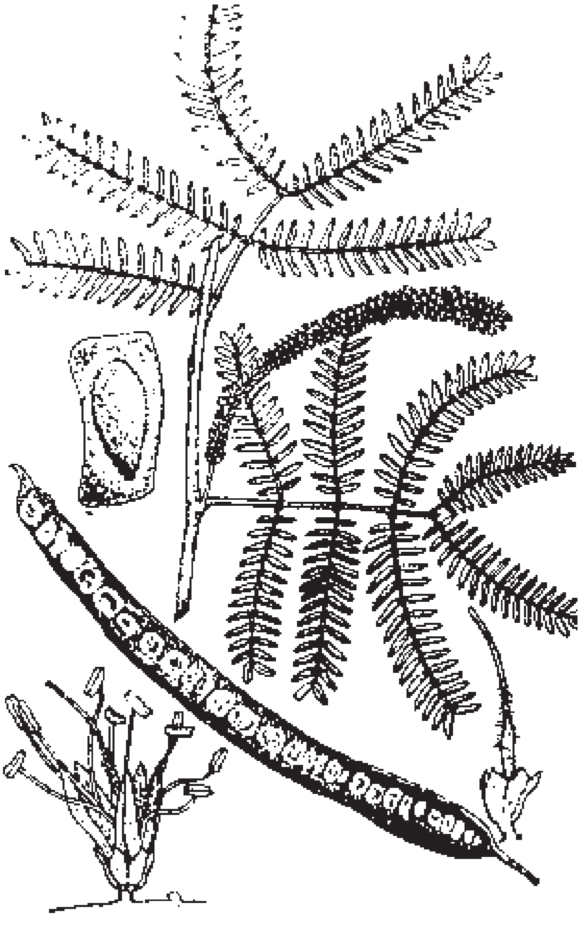


Figure 8. **Prosopis juliflora** ***(Peru). Branch with leaf and flower (x 0.5), fruit (x 0.5), seed case (x 2), flower (5), calyx and ovary (x 5) (Sanchez 1984, in Díaz Celis 1995).***

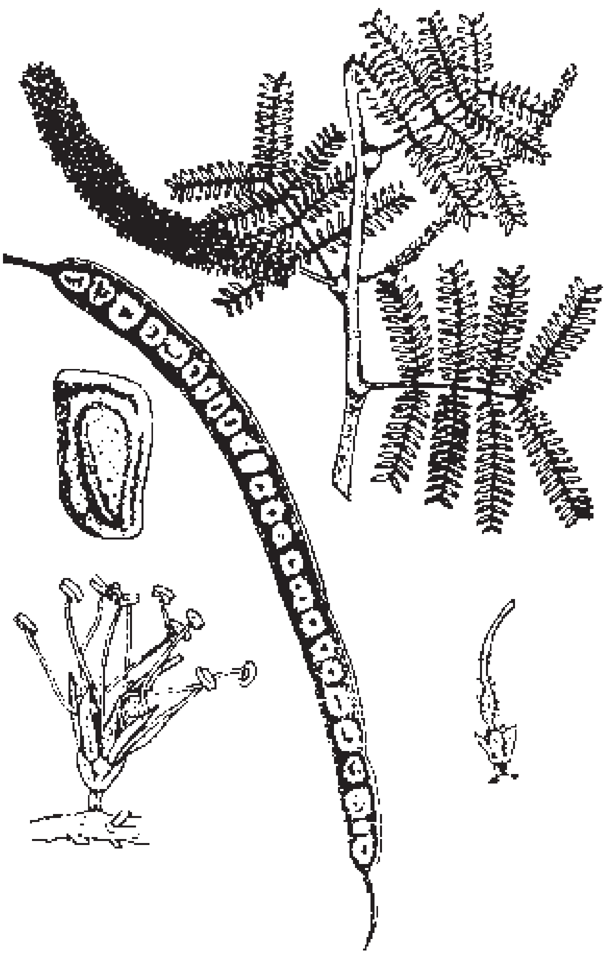


Figure 9. **Prosopis pallida** ***(Peru). Branch with leaf and flower (x 0.5), fruit (x 0.5), seed case (x 2), flower (5), calyx and ovary (x 5) (Sanchez 1984, in Díaz Celis 1995).***

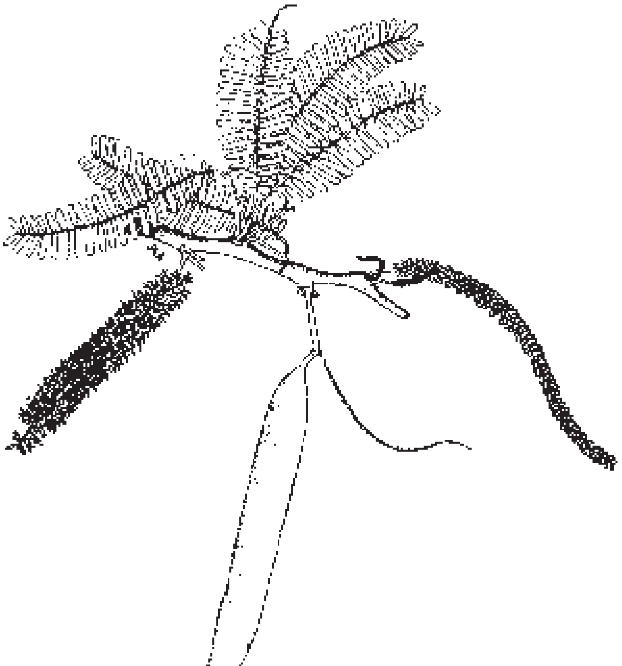


Figure 10. **Prosopis juliflora** ***(Puerto Rico). Branch with leaf, pod and flower (x 0.5) (Little and Wadsworth 1964).***

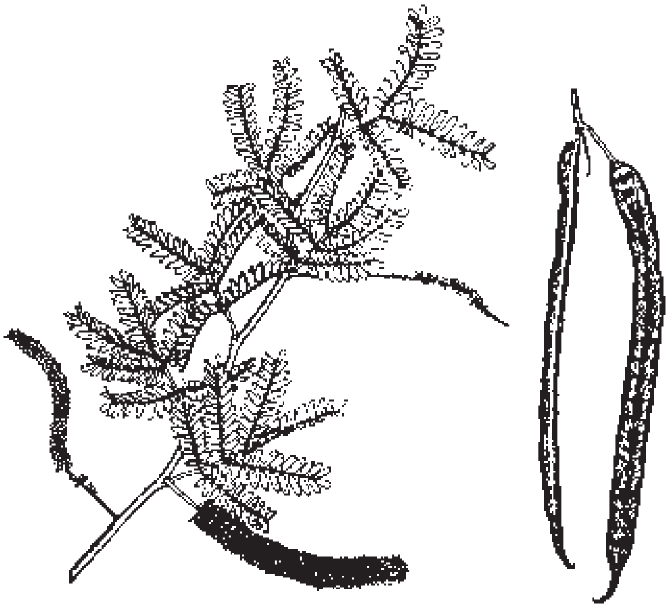


Figure 11. **Prosopis pallida** ***(Hawaii). Branch with leaf, pod and flower (x 0.5) (Little and Skolmen 1989).***

Figure 12. Range of leaf form in the P. juliflora - P. pallida *complex where introduced (x 0.5).*

Table 9. Organometric differences between* P. juliflora *and* P. pallida *where their native ranges overlap in northern Peru (adapted from Díaz Celis 1995).

Organ	Parameter	*Prosopis juliflora*	*Prosopis pallida*
Leaf	number per node	2-5	2-10
	length (cm)	10-20	5-8
Leaflet	pairs per pinna	9-17	8-14
	length (mm)	5-15	3-7
	width (mm)	2-6	1-3
	distance between leaflets (mm)	3-7	1-3
Inflorescence	length (cm)	9.5-16.5	8.5-14.5
	number of flowers	237-344	238-366
Fruit	length (cm)	16-28	9-23
	width (mm)	14-18	10-13
	thickness (mm)	6-10	5-7
	margins	without parallel margins	with parallel margins
Glands	presence	at junction of pinnae and of the leaflets	at junction of pinnae

A. Leaves small, 2-8 cm long. Leaflets 2-8 mm long. Inflorescences 3 times longer than the leaves. The edge of the fruit has parallel margins. 1. *Prosopis pallida*

B. Branches without thorns, small when present, 0.5-1.5 cm long. Leaflets pubescent, 3-6 mm long and 1.5-2 mm wide. Fruits large, 16-25 cm long. 2. *Prosopis pallida* forma *pallida*

BB. Branches with large thorns, 2-4 cm long. Leaflets sub-glabrous, 4-8 mm long and 2-3 mm wide. Fruits small, 14-20 cm long. 3. *Prosopis pallida* forma *armata*

AA. Leaves medium to large, 8-16 cm long. Leaflets 8-18 mm long. Inflorescences equal in length to the leaves, or slightly longer or slightly shorter. The edge of the fruit without parallel margins. 4. *Prosopis juliflora*

B. Branches without thorns. Leaflets oblong, apex obtuse, pubescent, 10-18 mm long and 4-5 mm wide. Fruits straw-yellow in colour. Interfoliar glands frequent. 5. *Prosopis juliflora* var. *inermis*

BB. Branches with thorns. Leaflets linear-oblong, apex sub-obtuse, mucronulate, sub-pubescent to sub-glabrous, 8-12 mm long and 3-4 mm wide. Fruit straw-yellow to chestnut-brown. Interfoliar glands frequent to occasional.

C. Thorns 0.5-1.5 cm long. Leaflets sub-linear and sub-glabrous. Fruit straw-yellow or chestnut-brown. Interfoliar glands occasional. 6. *Prosopis juliflora* var. *juliflora*

CC. Thorns 1.5-3 cm long. Leaflets oblong and sub-pubescent. Fruit straw-yellow. Interfoliar glands frequent. 7. *Prosopis juliflora* var. *horrida*

Figure 13. Key to identifying species, varieties and forms of* P. juliflora *and* P. pallida *in northern Peru (adapted from Díaz Celis 1995).

Table 10. Taxonomical descriptions of **Prosopis juliflora** ***and varieties from their native range.***

Species	***Prosopis juliflora*** **(Swartz) DC. var.** ***juliflora***	***Prosopis juliflora*** **(Swartz) DC. var.** ***inermis*** **(H.B.K.) Burkart**	***Prosopis juliflora*** **(Swartz) DC. var.** ***horrida***	***Prosopis juliflora*** **(Swartz) DC. var.** ***horrida*** **(Kunth) Burkart**
Source	Burkart (1976)	Burkart (1976)	Burkart (1976)	Ferreyra (1987)
location	world-wide	Ecuador	Peru	Peru
Form	sometimes shrubby, spreading branches, flat topped	-	flexuous branches	tree or shrub, multi-stemmed, trunk 40-50 cm in diameter, erect
height	3-12 m tall	-	3-8 m tall	3-7 m tall
Spines	0.5-5 cm long, not on all parts, solitary or paired	spineless	1.5-7.5 cm long, sometimes rare	1.5-3.0 cm long
Leaves	ample, glabrous or pubescent	-	-	-
pairs	1-3 (-4) jugate	-	2-4 jugate	(1-) 3-4 jugate
size	0.5-7.5 cm long (petiole + rachis)	-	2.5-7.0 cm long (petiole + rachis)	5-14 cm long (petiole 1.5-4.0 cm long)
pinnae	3-11 cm long	-	6-10 cm long	5-14 cm long
Leaflets	glabrous or ciliolate, rarely pubescent	finely pubescent	pubescent, pale	cinereo-villous
pairs	(6-) 11-15 (-29) per pinna	-	10-15 per pinna	12-16 per pinna
distance	approximate or distant a little more than own width	-	distant on the rachis	conspicuously separate, 5-8 mm apart
size	6-23 mm long	-	~15 mm long	8-19 mm long
	1.6-5.5 mm wide		~4 mm wide	2-7 mm wide
shape	elliptic-oblong, marginate or obtuse, mucronulate	-	elliptic, ovate to oblong, obtuse	elliptic, mucronulate
form	pinnate-reticulately nerved, herbaceous to sub-membranous, curved when dry	-	reticulately nerved	prominently reticulately-nerved below
Glands	-	-	-	interpetiolar, cupuliform, small, sessile, grey with apical pore
Racemes	rachis puberulent	-	-	peduncle and acumen glabrous
size	7-15 cm long	-	9-12 cm long	6-11 cm long (peduncle + acumen 10-22 mm long)
colour	light yellow	-	greenish white	yellowish
pedicel	-	-	-	8-25 mm long
calyx	-	-	-	1.0-1.2 mm long
stamens	-	-	-	4.0-4.5 mm long
others	-	-	-	corola 3.0-3.2 mm long style up to 3.0 mm long
Legume	straw-yellow to brown	-	brown	-
size	8-29 cm long	-	18-24 cm long	10-25 cm long
	9-17 mm wide		10-12 mm wide	10-16 mm wide
	4-8 mm thick		-	4-9 mm thick
	stipe to 2 cm long		stipe 1.5-2 cm long	
shape	straight with incurved apex, sometimes falcate, compressed, linear, parallel margins, stipitate, acuminate, rectangular to sub-quadrate	-	straight or sub-falcate, compressed, sub-moniliform	falcate, rarely straight, usually compressed, sub-moniliform
Seed	up to 25 per pod, oval, transverse	-	-	-

Table 11. Taxonomical descriptions of* Prosopis pallida *and forms from their native range.

Species	***Prosopis pallida* (Humboldt & Bonpland ex Willdenow) H.B.K.**	***Prosopis pallida* (Humboldt & Bonpland ex Willdenow) H.B.K. forma *pallida***	***Prosopis pallida* (Humboldt & Bonpland ex Willdenow) H.B.K. forma *armata***	***Prosopis limensis* Bentham (syn. *P. pallida*)**
Source	Burkart (1976)	Ferreyra (1987)	Ferreyra (1987)	Johnston (1962)
location	world-wide	Peru	Peru	Peru (Hawaii, Caribbean)
Form	trunk to 60 cm in diameter	tree or shrub, multi-stemmed, trunk 30-65 cm in diameter, erect	tree or shrub, multi-stemmed, trunk 20-60 cm in diameter, erect	-
height	8-20 m high	3-10 m tall	3-10 m tall	-
Spines	less than 4 cm long. unarmed or spiny	thornless	0.5-3.0 cm long, thorny	often unarmed
Leaves	pubescent, ciliolate to subglabrous, petiole short, pubescent	-	-	sordidly pubescent foliage
pairs	(1-) 2-4-jugate	2-3 jugate	2-4 jugate	(2-) 3 jugate
size	0.8-4.5 cm long (petiole + rachis)	6-12 cm long (petiole 1.1-3.0 cm long)	4-14 cm long (petiole 8-35 mm long)	-
pinnae	1.5-6 cm long	3-6 cm long	3-6 cm long	-
Leaflets	pubescent or at least ciliolate	cinereo-villous	cinereo-villous	pubescent
pairs	6-15 per pinna	12-15 per pinna	10-15 per pinna	11-14 per pinna
distance	approximate without touching or a little distant	-	-	-
size	2.5-8.3 mm long 1.4-4 mm wide.	7-12 mm long 3-4 mm wide	6-12.5 mm long 2-4 mm wide	5-8 mm long 2-2.5 mm wide
shape	oblong-elliptic to ovate, obtuse to mucronulate	elliptic, mucronulate	apex obtuse, mucronulate	-
form	pinnately nerved below, firm, pallid greyish-green when dry	reticulately nerved	nerved prominent below	-
Glands	sessile, cuplike gland at junction of pinnae	interpetiolar, cupuliform, sessile, dark greyish with apical pore	interpetiolar, cupuliform, sessile, dark greyish with apical pore	-
Racemes	rachis and the peduncle pubescent	peduncle and acumen glabrous	peduncle and acumen glabrous	-
size	8-15 cm long (2-3 times longer than the leaves)	6-17 cm long (peduncle 8-20 mm, acumen 6-21 mm)	5-14 cm long (peduncle 4-20 mm, acumen 8-25 mm)	very long, longer than the leaves
colour	greenish-yellow	yellow	yellowish	-
pedicel	short	5-30 mm long	8-22 mm long	-
calyx	0.5-1.5 mm long, ciliolate	1.0-1.2 mm long	1.0-1.2 mm long	-
stamens	5-7 mm long	4.0-4.5 mm long	4.0-4.5 mm long	-
others	ovary stipitate and villous petals 2.5-3.0 mm long and free, villous within	ovary 1.5-1.8 mm long corola 3.0-3.2 mm long style 2.0-2.5 mm long	ovary 1.5-1.8 mm long corola 3.0-3.2 mm long style 2.0-2.5 mm long	-
Legume	straw-yellow	yellow	yellow	-
size	(6-) 10-25 cm long 10-15 cm wide 5-9 mm thick	13.5-25 cm long 8-15 mm wide 4-9 mm thick	9-30 cm long 8-20 mm wide 4-10 mm thick	-
shape	straight or sub-falcate, sub-compressed, parallel margins, long or short stipitate with rounded base, acuminate, nearly sub-quadrate in section	straight to lightly falcate, semi-compressed, hand with 2-3 fruits	falcate, rarely straight, compressed, slightly sub-moniliform, hand with 3-8 fruits	narrow, rather depauperate, margins nearly parallel, thickness: breadth ratio about 5:10
Seed	up to 30 per pod oblong, 6.5 mm long	oblong, up to 6.5 mm long	-	-

Table 12. Taxonomical descriptions of **P. juliflora** *and* **P. pallida** *where introduced.*

Species	**Prosopis juliflora (Swartz) DC.**	**Prosopis juliflora (Swartz) DC. var. juliflora**	**Prosopis pallida (Humboldt & Bonpland ex Willdenow) H.B.K.**	**Prosopis pallida (Humboldt & Bonpland ex Willdenow) H.B.K.**
Source	Little and Wadsworth (1964)	Perry (1998)	Little and Skolmen (1989)	Perry (1998)
location	Puerto Rico	Australia	Hawaii	Australia
Form	short, to 45 cm diameter, bark rough and furrowed, inner bark yellowing	-	twisted, to 50 cm diameter, bark finely fissured, inner bark orange-brown	-
height	6-9 m tall	to 6 m tall	9-18 m tall	to 10 m tall
Spines	0.6-2.5 cm long, stout, brown	0.5 cm long, solitary or paired	to 2.5 cm long, single or in pairs	0.4-1.5 cm long, paired, sometimes absent
Leaves	-	glabrous or somewhat pubescent, ciliolate	finely hairy glabrous, ciliolate	moderately pubescent on both surfaces or almost
pairs	1-2 jugate	1-3 jugate	2-3 jugate	(1-) 2-4 jugate
size	7.5-15 cm long	-	to 7.5 cm long (including rachis <2.5 cm long)	-
pinnae	-	5.5-8 cm long	2.5-4 cm long	2-5 cm long
Leaflets	dull blue-green on both sides	green	dull light-green	pallid, grey green when dry
pairs	12-25 per pinna	(7-) 13-21 per pinna	8-11 per pinna	(7-) 9-15 per pinna
distance	-	internodes of pinnae axes 3-8 mm long	-	internodes of pinnae axes 2-3.5 mm long
size	6-15 mm long 1.5-3 mm wide	(5-) 10-16 mm long 1.5-3 mm wide	6 mm long <3 mm wide	-
shape	linear-oblong, rounded at both ends or minutely pointed at apex and slightly oblique at base	narrowly oblong, obtuse, apiculate, herbaceous, relatively soft and thin, 3 times as long as wide	narrowly oblong, rounded at apex, rounded and unequal sided at base	oblong-elliptic or ovate, obtuse, apiculate, 2-4 times as long as wide
form	-	curled or corrugated when dry	-	more or less flat when dry coriaceous, relatively rigid
Glands	-	-	glands on petiole between each pair of pinnae	-
Racemes	-	-	-	-
size	5-10 cm long (flower 4-5 mm long)	7-8 cm long (twice as long as leaves)	7.5-10 cm long, 1.5 cm wide (flower 6 mm long)	-
colour	yellow	-	light yellow	-
pedicel	pistil 4.5 mm long	-	-	-
calyx	<1.5 mm long, greenish-yellow, bell-shaped	scattered hairs outside, ciliolate	cupuliform, green	sometimes scattered hairs outside, usually ciliolate
stamens	<4.5 mm long	-	-	-
others	ovary hairy, light green petals 3 mm long, hairy inside	-	ovary hairy, petals narrow	-
Legume	yellowish-brown	straw-yellow to brown	yellowish	pale yellow, gold-brown size
	10-22 cm long 7.7-12.2 mm wide 4.5 mm thick	12-18 cm long ~12 mm wide -	7.5-20 cm long 10 mm wide 5 mm thick	7-16 cm long ~10 mm wide -
shape	slightly curved or straight, flattened	straight or slightly curved, parallel margins	narrow, slightly flattened	straight or curved, parallel margins or slightly undulate
Seed	brown, 6 mm long	-	10-20 per pod light brown, 6 mm long	-

P. juliflora has leaflets which tend to be spaced apart on the rachis a little more than their own width, while those of *P. pallida* are approximate (e.g. Díaz Celis 1995, Perry 1998). Burkart (1976) and Ferreyra (1987) also noted separated leaflets with *P. juliflora* var. *horrida*, but Burkart (1976) observed variation in this character with *P. juliflora* var. *juliflora*. Foliage of *P. pallida* tends to be more pubescent than that of northern races of *P. juliflora* which are commonly glabrous. Forms and varieties from the Peruvian-Ecuadorian race and introduced material tend to show intermediate characteristics (Burkart 1976, Perry 1998). Glands are present at the junction of the pinnae in both *P. juliflora* and *P. pallida* in Peru, but *P. juliflora* can be distinguished by the presence of glands also at the junction of the leaflets (Díaz Celis 1995).

Pod shape is used by Díaz Celis (1995) to differentiate between species, with *P. juliflora* having pods over 14 mm wide and without parallel margins, while *P. pallida* pods are less than 13 mm wide with parallel margins. However, parallel margins were observed in the pods of both species by Burkart (1976) and Perry (1998). Pod pubescence also varies, as does sweetness, with Lee *et al* (1992) suggesting that the southern race has distinctly sweeter pods than *P. juliflora* of the northern races. Length of inflorescence varies but has been used as a distinguishing feature in relation to leaf length. *P. pallida* has inflorescences generally longer than the leaves, while *P. juliflora* tends to have inflorescences equal to or shorter than leaf length.

While these characteristics described may be used to differentiate between the different species, varieties, forms and races within the *P. juliflora - P. pallida* complex, great variation means that conclusive distinctions are difficult to make. Where the complex has been introduced, it is rare that the exact origin of the seed can be ascertained, and material may possibly be from hybrid seed, or may have hybridised since introduction creating forms or land races that may bare little relation to individuals in the native range. With the strong likelihood that several separate introductions of *Prosopis* were made, several races may be present along with their hybrid forms. This again supports the need to deal with these tropical *Prosopis* species together in a single complex, particularly with introduced populations.

2.3 Biology

2.3.1 Chromosome number

Leguminosae have a base chromosome number of n=7, with n=14 established early in their evolutionary history, followed by descending aneuploidy to n=13 or lower (Goldblatt 1981). Only seven genera within the Mimosoideae, including *Prosopis*, were found to have n=14 showing their relative antiquity (Goldblatt 1981). However, Bukhari (1997) found no aneuploidy or B-chromosomes and concluded that the direction of chromosome evolution was towards increasing chromosome number. The chromosome numbers of most recognised species of *Prosopis* have been ascertained and all taxa are diploid with a haploid number of n=14 (2n=28), with the exception of *P. juliflora* which also has tetraploid forms (2n=56) (Hunziker *et al* 1975, Solbrig *et al* 1977). False tetraploidy interpretations have been explained by the fact that polysomaty is common in the root tip squashes used for analysis (Burkart 1976), or due to inaccurate counting procedures (Bukhari 1998).

Table 13. Chromosome numbers of various populations of the* P. juliflora - P. pallida *complex, both native and introduced, including assumed mis-identifications.

Species	Country	Chromosome number	Source
Native			
P. juliflora	Mexico	2n = 56	Bukhari (1997)
P. juliflora	Haiti	2n = 56 (ca. 112)	Hunziker *et al* (1975)
P. juliflora	Venezuela	2n = 56 (ca. 112)	Hunziker *et al* (1975)
P. juliflora	Colombia	2n = 56 (ca. 112)	Hunziker *et al* (1975)
P. juliflora	Colombia	2n = 28 (56, ca. 112)	Hunziker *et al* (1975)
P. pallida	Peru	2n = 28	Bukhari (1997)
Introduced			
P. juliflora *	Brazil	2n = 28 (56)	Hunziker *et al* (1975)
P. juliflora *	Senegal	2n = 28	Bukhari (1997)
P. chilensis **	Sudan	2n = 56	Bukhari (1997)
P. chilensis **	Kenya	2n = 56	Bukhari (1997)
P. juliflora	Pakistan	2n = 56	Bukhari (1997)
P. juliflora	India	2n = 56	Bandyopadhyay *et al* (1990)

* - Possibly *P. pallida*   ** - Almost certainly *P. juliflora*

Prosopis show a very low level of polyploidy when compared with the family Leguminosae as a whole, attributed to the fact that most species do not possess life history and genetic characteristics normally associated with polyploidy. These are long life combined with vegetative propagation, primary speciation followed by chromosome repatterning, and a high frequency of interspecific hybridisation (Grant 1971 in Solbrig *et al* 1977). Karyotype morphology of all species investigated was similar, with somatic chromosomes, which are very small (0.8-1.3 µm) showing slight variations in size within the complement. Chromosomes are only slightly differentiated, with median to subterminal centromeres, one pair of which displays a terminal microsatellite in most species (Hunziker *et al* 1975). Observation of regular meiosis shows 14 bivalents in metaphase 1, suggesting chromosomal homology between parental plants (Solbrig *et al* 1977). Chromosome counts for species of the *P. juliflora* - *P. pallida* complex are shown in Table 13.

Within the complex, *P. juliflora* has diploid and tetraploid forms (x=14, 28, 56, 2n=28, 56, 112) but are rarely diploid, whereas *P. pallida* appears entirely diploid (x=14, 2n=28) as are all other *Prosopis* species tested (Hunziker *et al* 1975). Hunziker *et al* (1975) found 100% of the cells were tetraploid in populations of *P. juliflora* from Haiti and Colombia. Amongst diploid forms, a population from Colombia had 90% of the cells tetraploid, while only 20% of cells were tetraploid in a population from Brazil. It can therefore be suggested that any species that are truly tetraploid are likely to be *P. juliflora*. Diploid material could be either *P. pallida*, *P. juliflora* or hybrid forms but may be more likely to be *P. pallida*.

The formation of polyploid forms tends to occur in rapidly expanding or hybridising populations, both of which are observed in *P. juliflora*. Stabilisation of tetraploid forms has been suggested as an evolutionary process increasing adaptability to new or changing environments. Chromosome numbers within various populations of the *P. juliflora* - *P. pallida* complex are generally consistent but tend to differ between regions (Table 13). The tetraploid nature of *P. chilensis* in Sudan and Kenya, found by Bukhari (1997), strongly suggests that this is actually *P. juliflora*. This is in contrast to the diploid nature of *P. chilensis* found in its native range (Hunziker *et al* 1975, Bukhari 1997), and confirms many observations made on the leaf morphology and tree form that state that the 'common mesquite' in Sudan and elsewhere in Africa is *P. juliflora* (e.g. El Fadl 1997) (see 2.1.3). The tetraploid material observed from India and Pakistan confirms that this is *P. juliflora*. However, the diploid forms seen in Brazil and Senegal by Hunziker *et al* (1975) and Bukhari (1997) suggests the presence of the diploid *P. pallida* or *P. juliflora*. Further analysis of polyploidy across the complex is required. If it is confirmed that polyploidy only occurs in populations of *P. juliflora*, chromosome number could be used in distinguishing the origins of introduced material.

2.3.2 Genetic variation and hybridisation

Variation can be of two forms, the cellular genetic differences and the observed phenotypic differences (see 2.3.3). Genetic variation was high for all characters tested in several *Prosopis* species including *P. juliflora* (Kumar *et al* 1998), *P. flexuosa* (Cony 1996) and *P. cineraria* (Jindal 1998). Felker *et al* (1981a) noted a hundred-fold difference in growth rates of *Prosopis* seedlings, with large variations also noted between progeny from a single parent tree. Thus, this variation exists at both provenance, family and individual level. In Argentina, Hunziker *et al* (1975) found that genetic variation based on the percentage of polymorphic loci and the expected mean of heterozygotes per locus, showed that species of section Algarobia possess more genetic variation than species of section Strombocarpa. Genetic variation can be introduced into a population by (i) outcrossing, thus maintaining genetic heterozygosity, (ii) hybridisation with subsequent backcrossing and, (iii) mutation of alleles in the duplicate set of chromosomes (Solbrig *et al* 1977). All species of section Algarobia are reported to be self-incompatible (Solbrig and Cantino 1975) (see 2.3.4). Solbrig and Bawa (1975) suggested that *P. juliflora* was a permanent heterozygote for all the four enzymes tested. Hunziker *et al* (1975) suggested that similar populations of *P. juliflora* were essentially tetraploid in nature.

Solbrig and Bawa (1975) attributed the low genetic variation found in some *Prosopis* species to: (i) partial self-compatibility, (ii) severe genetic depletion following extreme reduction in population, or (iii) extreme directional selection following population expansion. Genetic variation was low both within and between populations of *P. juliflora* in isolated valleys of Colombia and Venezuela. This was assumed to be due to recent establishment or isolation of the populations in the last 10000 years, no gene flow between populations and inbreeding within (Solbrig and Bawa 1975). Genetic variation based on phenological characteristics was also low in recently introduced (less than 50 years old) and expanding population in Brazil, assumed to be based on the initial introduction of only four trees by Pires and Kageyama (1990). Introductions of the *P. juliflora* - *P. pallida* complex to Africa are thought to have had a small genetic base (Hughes 1991). Other *Prosopis* populations arising from recent invasions such as *P. glandulosa* in the USA and *P. ruscifolia* in Argentina, were also found to have low genetic variation (Solbrig and Bawa 1975). Thus it is assumed that many introductions of *Prosopis* species have started with only a few seeds and thus a low genetic base, and rapid expansion reinforces this low variation.

Hybridisation is apparently possible between *Prosopis* species within any given section of the genus. Considerable efforts have been undertaken to resolve the identification of the parents in hybrid populations, particularly in Argentina and Mexico/USA where the ranges of many species overlap (Hunziker *et al* 1975, 1986, Burkart 1976, Palacios and Bravo 1981, Naranjo *et al* 1984, Almanza *et al* 1992, Earl 1998).

However, hybridisation has not been observed between species of different sections (Hunziker *et al* 1986) (see 2.1.6). Hybridisation is noted to occur between species of section Strombocarpa in both North and South America (Burkart 1976). Interspecific hybridisation is also common within section Algarobia, but research addressing this has been carried out almost entirely in the two centres of polymorphism in North and South America. There has been scant regard for the continuing taxonomic confusion in the intermediate zone with *P. juliflora* and *P. pallida*.

Within section Algarobia, a large number of two- and even three-way hybrids have been postulated and confirmed with a variety of morphometric, enzymic and molecular studies in Argentina (Palacios and Bravo 1981, Hunziker *et al* 1986) and Mexico (Almanza *et al* 1992). Some recognised species have been shown to have arisen from hybridisation, for example, *P. vinalillo* was observed to be a stable hybrid between *P. alba* var. *panta* and *P. ruscifolia* (Burkart 1976) (see also 2.1.6). Where there are sympatric populations, which are found particularly in Argentina, hybrid swarms are seen with intermediate characteristics that can be used to identify the parent species (Palacios and Bravo 1981, Hunziker *et al* 1986).

Within the series studied Ruscifoliae, Pallidae and Chilensis species show signs of variable barriers to hybridisation (Naranjo *et al* 1984, Hunziker *et al* 1986, Saidman 1986, 1990). These different barriers are most clearly classified by Palacios and Bravo (1981). Pre-zygotic factors include ecology and habit of different species and their amplitude, geographic and temporal isolation in flowering, mechanical isolation and use of different pollinators, with post-zygotic factors being flower sterility and pollen non-viability. These are seen to vary between species combinations, with no barriers observed between *P. glandulosa* and *P. laevigata* (Almanza *et al* 1992) and none between several Argentinean species (Palacios and Bravo 1981, Saidman 1986, Hunziker *et al* 1986).

Some reproductive isolation has, however, been observed in South American species. An incipient isolation mechanism was observed preventing the production and/or survival of hybrids between *P. caldenia* and either *P. alpataco* or *P. flexuosa* (Saidman 1990). The latter two hybridised more freely, and the similarity between *P. alpataco*, *P. flexuosa* and also *P. pugionata* noted by Burkart (1976) may suggest that these three are more closely related. In an area where ranges of *P. alba*, *P. nigra* and *P. ruscifolia* were sympatric, Palacios and Bravo (1981) noted that *P. alba* X *P. ruscifolia* hybrids were much more common than hybrids of the other two possible combinations. This might suggest that those two species are more closely related to each other than to *P. nigra*, even though they were placed in different series by Burkart (1976). However, Ramírez *et al* (1999) found *P. alba* and *P. nigra* to be very closely related when using molecular markers. In a very broad study, Hunziker *et al* (1986) found that inter-series hybrids, with species from the series Ruscifoliae, Pallidae and Chilenses, were more common than intra-series hybrids.

There appears to be very little chromosome repatterning accompanying speciation in the genus which has probably negated any effect that hybridisation might have otherwise had on polyploidy (Solbrig *et al* 1977). Hunziker *et al* (1975) found hybrids without evidence of chromosome interchange heterozygosity and also postulated that structural reorganisation of the chromosome has not played a major role in speciation. The speciation process was postulated to be caused mainly by gene mutations as suggested by karyogram uniformity (Burkart 1976). Bukhari (1997), however, noted structural and numerical chromosomal modifications and similar karyotypes, suggesting that short chromosomal rearrangements played a significant role in the evolution and reproductive isolation among taxa in the genus. However, the conclusions were based on incorrectly identified seed material and must be questioned. Thus it appears that mutation rather than chromosomal rearrangements is responsible for introducing genetic variation into an isolated population, which then undergoes niche-directed selection pressure.

How, and indeed if, a mutated gene enters the gene pool of the whole population depends on crossing and selection mediated by the environment. In *Prosopis* populations, outcrossing will produce offspring that contain the new genetic material, assuming that there are no fertility barriers. These offspring will be preferentially selected for if they have characters that are better suited to the niche environment. Repeated preferential selection will increase the frequency of the new gene in the population, enforced by backcrossing and introgression until the original population is made extinct (Rhymer and Simberloff 1996). Alternatively, a population with characters that are better suited to the environment is created, which then becomes separated by reproductive isolation barriers. Speciation and evolution can both be said to have occurred, but full stability requires the formation of some reproductive isolation barriers. The exact process of hybridisation, introgression, segregation and stabilisation (speciation) is especially complex with many sympatric *Prosopis* species in Argentina and Mexico and few apparent barriers to reproduction (Hunziker *et al* 1986, Earl 1998). Little is known about the sympatric populations of *P. juliflora* and *P. pallida* in Peru and Ecuador, and while it may be assumed that similar processes to those observed in the North and South American centres occur, detailed studies are required.

2.3.3 Physiology and phenology

Germination

Seeds are orthodox and possess an inherently high level of dormancy. The hard seed coat must be broken or weakened to allow water absorption by the seed and for germination to occur (e.g. Catalán and Balzarini 1992) (see 4.1.1). Hard seed coats will also degrade over time and older seed that is still viable tends to germinate without pre-treatment (Pasiecznik and Felker 1992). Fresh, just-harvested seeds gave germination rates of 90% (Ffolliot and Thames 1983), assumed to be because the seed coat has not yet hardened. The seed coat has been found to contain 'egg-timer' cells, whose function appears to be to allow water transfer as the seed matures, before closing up completely when the seed coat dries.

Seeds in their endocarp shells exhibit decreased germination, thought to be because the endocarp impedes water uptake by the seeds. Killian (1990) found no difference between closed and open endocarps of several *Prosopis* species, but a significant increase in germination with endocarps removed. Seeds are less likely to germinate if left in the entire pods, whether soaked or broken. An allelopathic chemical extract from pod pericarps decreased germination in *P. juliflora* (Warrag 1994). Passage through different animals has varying effects on seed germination, through the removal of the mesocarp or endocarp, or other mechanical or chemical factors (see 4.1.1).

Assuming seed dormancy has been broken, seed germination is then dependent on available soil moisture and water quality, available nutrients, temperature and the depth in the soil. Drought stress, nutrient supply and temperature affect the allocation of sugars and carbohydrates in germinating *P. juliflora* seed organs (El-Sharkawi *et al* 1997). Temperature and drought stress have a dominant role, while higher levels of nutrients increased translocation of sugars to the radicle, improving water uptake capacity through increased osmolarity (El-Sharkawi *et al* 1997). Available soil moisture has a strong effect on germination, emergence and seedling survival. Water quality is less important, but there are variations in the response of seeds from both within and between species and populations (Bazzaz 1973, Villagra and Galera 1992). *P. juliflora* seeds have relatively nutrient poor embryos but nutrient rich seed coats. It was suggested that leaching of nutrients from the seed coat aids seedling establishment by assisting rapid growth of the embryo following germination and the creation of a favourable micro-environment (El-Sharkawi *et al* 1997).

P. juliflora seeds showed no decrease in final germination with up to 30% added sea water, although the rate of germination was retarded (Khan *et al* 1987). Other species showed decreased germination with increasing salinity. Higher salt concentrations would be expected to reduce germination even in the most salt tolerant land races. With low osmotic potential from increasing salinity, Killian (1990) found no effects on the water uptake of seeds during the initial stages of germination, but there were effects later at higher concentrations. Increasing alkalinity markedly decreased the final germination and germination rate of *P. juliflora* seed above pH 9.0 (Srinivasu and Toky 1996).

The optimum temperature for germination of *P. juliflora* seeds is 30°C, with germination decreasing rapidly at temperatures below 20°C or above 40°C (Sundararaj et al 1966), or above 45°C and below 15°C (Perez and Moraes 1990). Optimum germination of *P. juliflora* was estimated at temperatures of 35°C (Nambiar 1946), 30-35°C (Perez and Moraes 1990), or when temperature alternates between 20°C and 30°C (Torres *et al* 1994). Dry heat plays a role in increasing germination but appears to have only a small role in breaking seed dormancy. Optimum sowing depth of seed is 10 mm for *P. juliflora*, with germination falling markedly when sown below 20-30 mm deep (Mutha and Burman 1998). Seeds on the soil surface germinate but rarely become established probably because of dehydration (Harris *et al* 1996a). Germination is followed by rapid establishment of root system and young shoots and leaves.

Root development

All *Prosopis* species are able to survive in areas with exceptionally low annual rainfall or very lengthy dry periods, but only if roots are able to tap ground water or another permanent water sources within the first few years. Being species adapted to arid and semi-arid climates, germination and establishment generally occurs during the brief rainy season and seedlings must be sufficiently well established to survive the first dry season. The existence of two root systems, a deep tap root to reach ground water and a mat of surface lateral roots to make use of infrequent rainfall events, puts *Prosopis* species firmly in the category of phreatophytes, but showing a variety of mesophytic and xerophytic characteristics depending on water availability (Mooney *et al* 1977).

The need for rain or a high water table is reduced in coastal areas, where there is sufficient atmospheric moisture. Tap roots are essential during long droughts when deep sources are the only available water, and this supply ensures tree survival. An extended dry period prior to tap roots reaching ground water may explain the mortality of young trees. Lateral roots are more important during periods of abundant water, such as during rainy seasons or periods of episodic flooding or irrigation, but are also able to absorb soil moisture resulting from light rains or even from dew, cloud or other forms of atmospheric moisture deposition. Roots at the limit of the lateral root system are thought to function only during very dry periods when all water reserves nearer to the tree are exhausted. Roots of *P. glandulosa* were able to absorb nutrients and fix nitrogen even with high levels of water stress (Felker and Clark 1982).

Leaf physiology

Prosopis leaves have many adaptations to drought, such as the bipinnate, compound leaves typical of the Mimosoideae. Possession of larger numbers of smaller leaflets is considered to be a response to high temperatures, being a means of dissipating increased heat loads. In the *P. juliflora - P. pallida* complex, the action of the pulvinus can cause the leaflets to fold, protecting stomata on the upper leaf surfaces from water loss during periods of high evapo-transpiration. Leaflets of *Prosopis* species possess specialised adaptations promoting efficient utilisation and retention of water such as sunken stomata, more stomata on adaxial than on abaxial surfaces, thick and waxy cuticles and the presence of mucilaginous cells (Vilela and Palacios 1997).

There are also metabolic changes within the leaf and the whole plant during periods of drought stress that better enable the plant to survive. Sen and Mehta (1998) found seasonal variations in *P. juliflora* leaf concentrations of proline, sugar and protein, assumed to be a response to drought. In natural stands of *P. juliflora* in Venezuela, osmotic adjustment was observed in the dry season, with an increase in leaf concentrations of all measured nutrients (Alarcón and Díaz 1993). Greater stomatal openings and transpiration was recorded in *P. chilensis* seedlings under drought conditions when fertilised (Imo and Timmer 1992).

There were marked growth flushes of new leaves during the year in sub-tropical species (Nilsen *et al* 1987), although some smaller periods of leaf senescence and replenishment were observed in *P. juliflora* (Goel and Behl 1996). The presence of chlorophyll in the green stems of *P. juliflora* is also a response to drought, allowing for leaf shedding during dry periods while still maintaining some photosynthetic potential (El Fadl 1997). Diurnal changes occur in photosynthetic rate and stomatal conductance, with a marked depression in both during the high temperatures found at midday (Sinha *et al* 1997). No changes in stomatal features or plant growth were observed with increases in carbon dioxide (Winter 1986, Malone *et al* 1993).

P. juliflora also exhibits physiological responses to other environmental variables, such as saline/ sodic conditions. Garcia-Carreño and Ochoa (1991) suggested that different plant strategies exist depending on ecotypic variation. Khan *et al* (1987) concluded that *P. juliflora* responded to salinity via potassium ion selectivity during ion influx, and exclusion of sodium ions from the leaves by retaining them in the root. Sharma (1984) indicated the capacity of *P. juliflora* to tolerate salinity by increasing sodium levels in the leaves, while Khan *et al* (1987) found calcium levels in the leaves decreased under saline conditions, while levels of magnesium increased in the leaves but declined in the roots.

Unpalatability of foliage and armature of various types have evolved to protect some *Prosopis* species from damage by herbivorous mammals. Herbivory is an important factor, with an estimated 40% of immature *P. glandulosa* leaves removed by insects and 35% of shoots removed by rodents or insects (Nilsen *et al* 1987). Leaf production in *P. glandulosa* was found to occur in two short, rapid bursts which was considered to be a response to insect herbivory, as growth was mostly independent of climatic variables (Nilsen *et al* 1987). The foliage of the *P. juliflora* - *P. pallida* complex, contains chemical defence systems against herbivory. A variety of unpalatable or poisonous chemicals including alkaloids and tannins are found in *P. juliflora* leaves (see 3.3.1). Allelopathic chemicals have been isolated from several species and shown to have a deleterious effect on the germination and growth of other plant species (see 3.3.2). Many such chemicals serve a variety of functions, and it is over-simplistic to describe their evolutionary functions simply as 'for defence' (Janzen 1981).

Phenological variation

Prosopis species exhibit high levels of variability in morphological characters. The reproductive self-incompatibility and obligate outcrossing observed in the *P. juliflora - P. pallida* complex tends to lead to large phenological variation, being a combination of both clinal (continuous) variation in response to broad climatic factors and ecotypic (discontinuous) variation in response to disjunct environmental factors (Burley *et al* 1986), both of which are seen in *Prosopis*. Such differences in continuous climatic clines such as temperature, rainfall and day length, and discrete differences in site such as soil type, salinity or depth combine to create a variety of phenological responses. Variations are observed principally in native populations. In invading populations, clinal variations are obscured because of the rapid and widespread dispersal of diverse genetic material by humans and animals over a range of site and climatic conditions.

The main climatic variables involved in phenological variation are temperature and rainfall. These have been shown to affect the leaf morphology of *Prosopis* species in Mexico and the USA (Graham 1960, Hilu *et al* 1982, Earl 1998), with a tendency for a larger numbers of smaller leaflets where heat intensity is greater (Earl 1998). Temperature and rainfall also affected the timing of bud break and dormancy in populations of *Prosopis* species collected from a wide range of sites in the USA (Graham 1960, Peacock and McMillan 1965, Lee and Felker 1992). Changes in stomatal density, pubescence, cuticular thickness and mesophyll structure were seen in several Argentinean *Prosopis* species in response to the external environment (Vilela and Palacios 1997). Sandy soils were observed to effect pubescence in two species and water deficit was seen to effect other leaf characters (Vilela and Palacios 1997). Rainfall and temperature both affected wood structure in three South American *Prosopis* species (Gomes and de Muñiz 1990) and sugar content in *Prosopis* pods was environmentally controlled (Lee and Felker 1992).

Flowering time has evolved variously, with legume production generally coinciding with the beginning of the wet season for improved water dispersal and seedling establishment, or the beginning of the dry season, ensuring increased pod consumption and seed dispersal by wild animals. Flowering times vary between species and sites and are genetically controlled. In North America, more temperate land races showed a delay in flowering compared with more sub-tropical races, even when planted at the same location, and each population had distinct, synchronised flowering

(Graham 1960). Lee and Felker (1992) also noted synchronised flowering of *P. glandulosa* over a 120 km rainfall gradient, also exhibiting increased nectar production and pod yields in drier years. The synchronised mass blooming of *Prosopis* species, irrespective of annual rainfall, was viewed as being due to their phreatophytic nature, with species able to produce flowers and seeds even during dry seasons (Simpson *et al* 1977).

Variation in the onset of flowering can be expected between populations of all species due to climatic variation within existing ranges. Flowering is also variable within and between trees of the same population. Almost continuous year-round flowering of *P. juliflora* is seen in Brazil (Silva 1990b), India (Goel and Behl 1995) and Haiti (Timyan 1996) but there is always a period of maximum fruit production. In parts of India, one or two fruiting periods occur, depending on site and the 'form' of *P. juliflora* present (Luna 1996), and in Brazil there is a principal fruiting period with a smaller, secondary season later in the year (Pasiecznik and Harris 1998). With continuous flowering, periods of major fruit production may correspond to periods of increased pollinator activity and not necessarily to genetic controls, particularly with introduced material. Some flowering and fruiting times from selected locations in the native range are shown in Table 14.

2.3.4 Reproductive biology

Breeding system

Floral evolution in legumes is characterised by clear trends towards maximising pollen and nectar economy, leading to the development of increasingly sophisticated pollinators (Arroyo 1981). In mimosoid legumes, a reduction in flower size was compensated for by compaction and transference of attraction to the entire inflorescence, with sterility and neutering playing an integral part in this process (Arroyo 1981). Flower biology is similar in all *Prosopis* species studied and is generally asynchronous. *Prosopis* flowers are produced in masses, mainly on spike-like racemes.

Anthesis is protogynous (Burkart 1976, Hunziker *et al* 1986, Goel and Behl 1996), although this is contested (Genise *et al* 1990, Hoc *et al* 1994). Styles emerge from most flowers prior to anthesis but they are probably not receptive at this stage and flowers remain in this state for some days. Anthesis occurs when the flowers are fully open. Flower maturation is often observed to begin at the proximal end while flowers at the distal end are still immature. However, Diaz Celis (1995) noted that this occurs simultaneously, in all the flowers of a single efflorescence. The stigma has a central depression into which pollen falls for fertilisation, assisted by a sugary secretion (Goel and Behl 1996).

Prosopis species are generally assumed to be self-incompatible (Solbrig and Cantino 1975, Simpson 1977, Felker and Clark 1981). This was confirmed with no successful pollination or fruit set recorded after bagging and selfing flowers in Brazil (de Oliveira and Pires 1990) or India (Goel and Behl 1996). Some limited self-compatibility (4%), however, has been observed in *P. juliflora* following bagging and hand pollination (Sareen and Yadav 1987), and is thought to occur more widely in some species of section Strombocarpa (Solbrig and Bawa 1975).

Self-incompatibility has probably been positively selected for in desert environments, with obligate outcrossing leading to high variability in progeny produced, both within and between natural populations (see 2.3.2). The maintenance of high genetic variability can be seen as a mechanism for survival in dry zones with a high variability in rainfall, temperature and soil types, and for continued evolutionary adaptations to a changing environment. The presence of peroxidase activity in the pollenkitt of *Prosopis* pollen, as well as in the stigma, style and ovary suggests that the Argentinean species studied by Hoc *et al* (1994) possess a gametophytic self-incompatibility system, assumed to extend to include the *P. juliflora* - *P. pallida* complex.

Table 14. Flowering and fruiting times of the* P. juliflora - P. pallida *complex from selected locations in its native range.

Species	Location	J	F	M	A	M	J	J	A	S	O	N	D	Source
P. juliflora	Honduras	*	* o	o	o								*	Hughes and Styles (1984)
P. juliflora	Colombia			* o	* o	o		*	*	* o	o	o		Rondón (1992)
P. pallida	Peru (north)	*	*				o	o	o				*	Díaz Celis (1995)
P. pallida	Peru (south)		o	o	o						*	*		Díaz Celis (1995)

* - flowering; o - fruiting

Pollination

Prosopis species are primarily insect pollinated, and this is facilitated by nutritional rewards. Flowers attract large numbers of potential pollinators with the production of copious amounts of pollen, and bees and legumes have been intimately associated throughout their evolutionary histories (Arroyo 1981). Insect pollination is supported by the fact that pollen grains are produced and released singly, rather than in polyads of 16 or 32 which is consistent with pollination by larger animals such as birds and bats (Elias 1981). Pollen contains starches and other food sources for insects (Hoc *et al* 1994). Anther glands in *P. juliflora* release a protein-carbohydrate exudate and the flower is pollinated while the insect eats the gland (Chaudhry and Vijayaraghavan 1992). Anther glands may exude a sticky substance to attach the pollen to the body of the insect, and to protect the anthers and ovaries. They may also exude an odorous chemical attractant (Luckow and Grimes 1997).

Percentage pollination in *P. juliflora* is always low, however (e.g. de Oliveira and Pires 1990), thought to be possibly due to; poor pollen viability, short periods of pollen release or stigma receptivity, lack of synchronisation between pollen release and pollen reception, few pollinating insects or too few at times of maximum receptivity, flower sterility or high rates of ovary abortion. Long periods of asynchronous flower production would assume a long period of pollen release and floral receptivity. Goel and Behl (1995) found *P. juliflora* pollen viability to be 79-96%, but maximum pollen production occurred at midday, and insects are less mobile during the high temperatures found at this time.

There appears to be sufficient numbers of pollinating insects with little host specificity (e.g. Kingsolver *et al* 1977). However, should climatic conditions stimulate heavy flowering over extensive ranges, it is possible that sufficient numbers of pollinating insects may not be available. A large number and variety of insects have been observed visiting *Prosopis* flowers, but bees are thought to be the main type of insect responsible for pollination. For extensive lists of the numerous species of insect visitors, pollinators or seed-eating beetles of *Prosopis* species, refer to Ward and Hudleston (1968), Schuster (1969), Kingsolver *et al* (1977), Ward *et al* (1977) and Johnson (1983) (see 2.4.5). Many oligolectic bees are small in size with small flight ranges, and cross pollination is thought to be by larger species of bee. Increased pollination is noted in honey producing areas and is seen to have positive effects on fruit production (Esbenshade 1980).

Although very large numbers of flowers are produced, not all are fertile (Solbrig and Cantino 1975) and high rates of ovary abortion are found. Stylar trimorphism was noted in four Argentinean species by Hoc *et al* (1994), with flowers having the shortest styles found to be unreceptive to pollination. Intra-populational dimorphism in nectar production was observed in *Prosopis* flowers in Mexico (López-Portillo *et al* 1993, Golubov *et al* 1999). That not all flowers are fertile or receptive and differences in nectar production may be due to resource limitation, with high energy demands made on plants for reproduction, and because few pollinator visits are required to set fruit (Simpson 1977, López-Portillo *et al* 1993).

Floral trimorphism in closely related genera, e.g. *Parkia*, *Dicrostachys* and *Newtonia*, with showy sterile flowers proximally, male nectar producing flowers in the middle and bisexual flowers at the apex, does not occur in *Prosopis*. However, the sterility of some flowers and variation in nectar production confirms that *Prosopis* species exhibit some 'division of labour', with sterile flowers serving the function of petals, attracting pollinators to the inflorescence where they will hopefully pollinate a fertile flower. Such a system is more energetically and reproductively efficient, with the plant then able to channel conserved energy into extra growth, defence systems or fruit and seed production (Elias 1981). Reproduction has been estimated to use up to 50% of the energy demands of a plant and in resource limiting environments this can be considerable.

Fruit production and seed dispersal

Very few legumes are produced compared with the large numbers of flowers produced per tree (Solbrig and Cantino 1975). Out of 10000 *P. juliflora* flowers, de Oliveira and Pires (1990) estimated that 129 mature fruits would be produced, an efficiency of 1.29%. This is high in comparison with estimates by Solbrig and Cantino (1975), that out of 10000 flowers, only one flower of *P. chilensis* developed into a mature fruit, while 26 *P. flexuosa* flowers initiated development into fruit but only seven reached maturity, with rarely more than two fruit per inflorescence. There is no regularity as to where on the inflorescence pods are more likely to be produced (Hoc *et al* 1994, Goel and Behl 1996). Not all seeds develop at the same rate and, at fruit maturation, some seeds remain undeveloped. An average of 17% of the total seed produced by 15 American species was estimated to be immature (Solbrig and Cantino 1975).

Prosopis pods ripen at different times of the year depending on species and climate. Fruit maturation causes an abscission layer to form at the base of the pedicel and the pods fall to the ground within 1-3 months in most species. After falling, the seeds become components of the seed bank and are subject to physical and environmental factors and dispersal. However, little is known about the seed bank of *Prosopis* species (Solbrig and Cantino 1975). Reports show that when collected and stored, seed of *Prosopis* species can remain viable for considerable periods of time, up to 50 years for *P. velutina* (Glendening and Paulsen 1955). Seeds of several species have maintained more than 50% viability over 10-15 years when stored in their pods (Pasiecznik and Felker 1992). Reports of conservation in the soil seed bank are variable with 2 and 10 years given for *P. velutina* (Glendening and Paulsen 1955).

Seedlings are rarely observed under the canopy of a mature tree, possibly because of shading, allelopathic effects, or the presence of seed-eating insects. Beetles of the family

Bruchidae are responsible for destroying a substantial percentage of seeds produced by *Prosopis* in their native range, and dispersal mechanisms may also be an evolutionary response to destruction by such insects. Where the seed comes to rest decides what set of physical and environmental factors will act upon the seed. In arid and semi-arid zones it is particularly important that seeds be dispersed to sites with sufficient moisture for seedling establishment. Water is an important dispersal agent in desert ecosystems. Water dispersal ensures widespread dissemination of seed during flooding or other high rainfall events when seedling establishment is favoured.

Prosopis species are often found colonising ephemeral water courses and dispersal is aided by water flow in the rainy season, particularly during very wet years (Solbrig and Cantino 1975). Oceanic dispersal is important for coastal species, and for crossing large bodies of water such as in the Caribbean. Pods and endocarps float and are impervious to water infiltration, protecting the seed from the harmful effects of extended periods in sea water. However, there is no certainty with water dispersal that pods will be broken up or the seed scarified. The seed may also be destroyed completely or deposited too deep in the soil.

Pods have a high sugar content, are low in anti-feedants, and are widely sought after by a variety of animals. Disjunct stands of trees near to ancient centres of population suggest that man has also been a dispersal agent in historic and prehistoric times. Birds, bats, reptiles and ants also feed on *Prosopis* fruits and are potential, if only minor, agents of dispersal. Livestock are now the primary dispersal agents, although the fruit are also avidly consumed by a wide variety of wild mammals which play a major role in seed dispersal. The hard seeds tend to survive the passage through the gut of an animal and, although there are conflicting reports on the effects of this passage on seed germination, it is generally accepted that the fruits and seeds are specialised for animal dispersion. Pods are eaten off the tree or off the ground and seeds are deposited in the faeces. Removal of the endocarp is, however, by no means ensured. Voided seed are given a positive advantage by being placed in faeces, with improved water holding capacity and high levels of nutrient. Livestock may tend to spend more time on better pasture or by water sources but voiding of seed in preferential locations is not guaranteed.

Different animals, however, have very different effects on seed survival. Seed with the endocarp shell removed were common in the faeces of goats and cattle but rarely seen in the faeces of horses or foxes (Solbrig and Cantino 1975). Pigs were found to destroy all seeds of *P. flexuosa* consumed, horses and foxes voided no clean seed but allowed germination of those in endocarps, while seed voided by cattle and rodents showed most improved germination (Campos and Ojeda 1997). Cattle ingestion improved germination of *P. caldenia* seed (Peinetti *et al* 1993). Harding (1991) found that sheep feeding on the pods reduced the recruitment of *Prosopis* seed in South Africa. With *P. juliflora* in West Africa, 25% of seed were destroyed by cattle and 86-90% by sheep and goat but most remaining seed went on to germinate (Danthu *et al* 1996). In Sudan, 75-96% of *Prosopis* seed was destroyed by goats but 50-58% of the excreted seed went on to germinate (El Houri 1986). Pasiecznik *et al* (1998) found only a slight increase in germination of *P. juliflora* following ingestion of clean seed by cattle. Passage through an animal is also thought to destroy seed eating insects, but some survival of bruchid beetles has been noted (Kingsolver *et al* 1977).

2.4 Ecology

2.4.1 Natural distribution

The natural distribution of the genus *Prosopis* includes arid and semi-arid zones of the Americas, Africa and Asia (Figure 14). The native range of *Prosopis* species can be approximately divided into five regions, simply defined as Asia, Africa, North America, Central America and South America. Although there is some overlap on to neighbouring continents, each of the five regions are geographically distinct. Asian species of section *Prosopis* are native to the Middle East, stretching east to India, north to Georgia and Turkmenistan and west to Algeria along the north African coast. *P. africana* is native to the Soudano-Guinean zone and neighbouring areas of Africa, from Senegal in the west to Sudan and Kenya in the east. There is no overlap between the ranges of *P. africana* and that of the other Old World species (Figure 14).

The majority of the species are native to the Americas, and can be approximately divided into three geographic areas. There is the northern Mexican/USA centre, the southern Argentinean centre including all neighbouring countries, and an intermediate central region. This intermediate region is populated by the *P. juliflora* - *P. pallida* complex and occupies northern South America, southern Central America and the Caribbean, but the northern and southern extremes of this region are not well defined, and some overlap may exist with the other centres (see 2.4.2). The latitudinal distribution of *Prosopis* species in the Americas is from approximately 37°N in the USA to 48°S in Argentina, shown in Figure 14, with the distribution of the *P. juliflora* - *P. pallida* complex highlighted. However, human influences including intentional introductions, weedy invasions and deforestation during the last 500 years have significantly altered the distribution of *Prosopis* species (see 1.4). The present, estimated global range of the genus *Prosopis* is presented in (Figure 15), noting the present global distribution of the *P. juliflora* - *P. pallida* complex.

The native range of the *P. juliflora* - *P. pallida* complex has also changed following human interventions. The present range as derived from existing literature and local knowledge is given in (Figure 16), including the location of known varieties and forms. The isolated populations may have been connected before deforestation during the last 500 years.

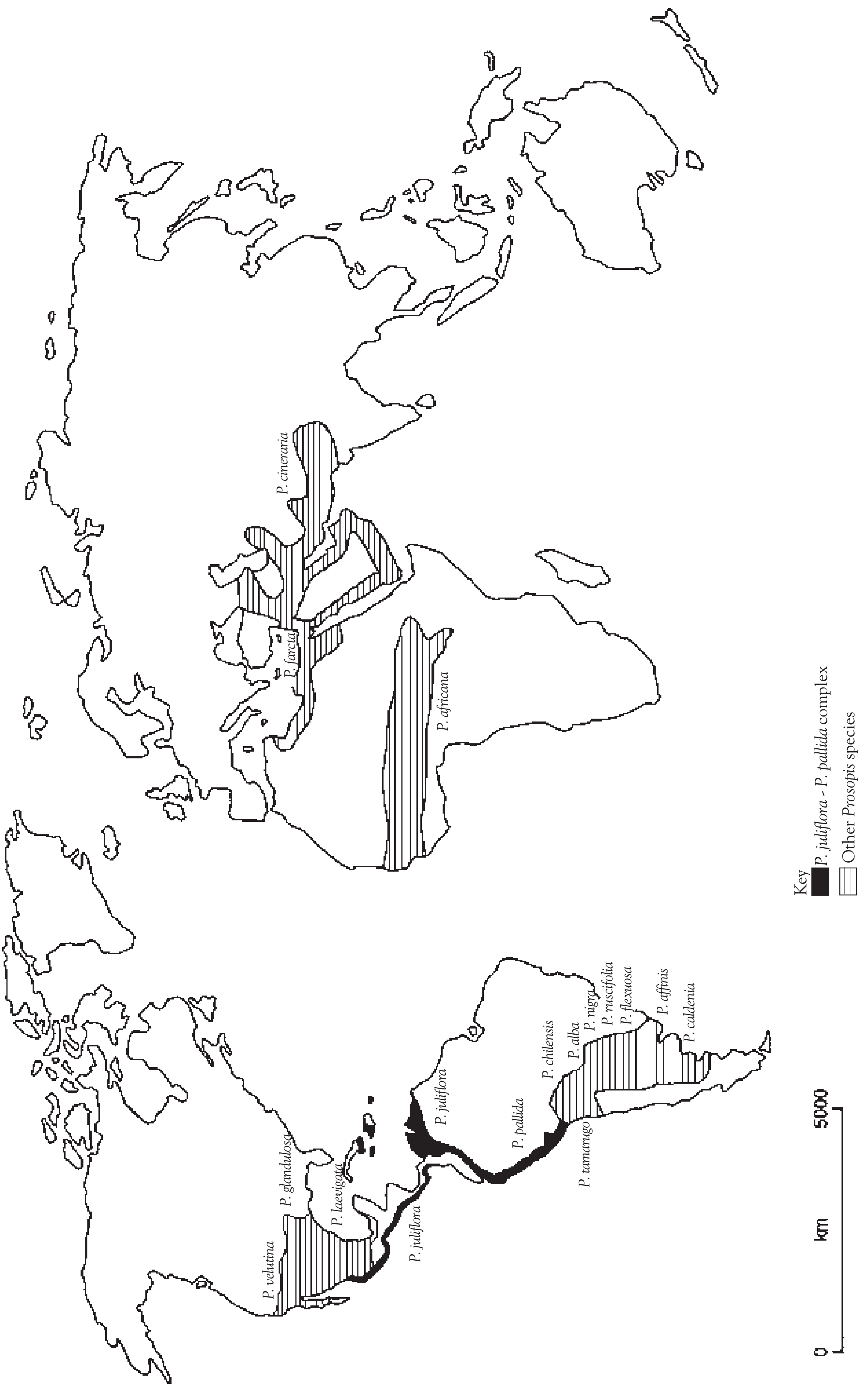


Figure 14. Natural distribution of the genus Prosopis (adopted from Burkart 1976, Simpson 1977), highlighting the distribution of the P. juliflora - P. pallida complex. All named species are economically important in their native range and/or with extensive distribution.

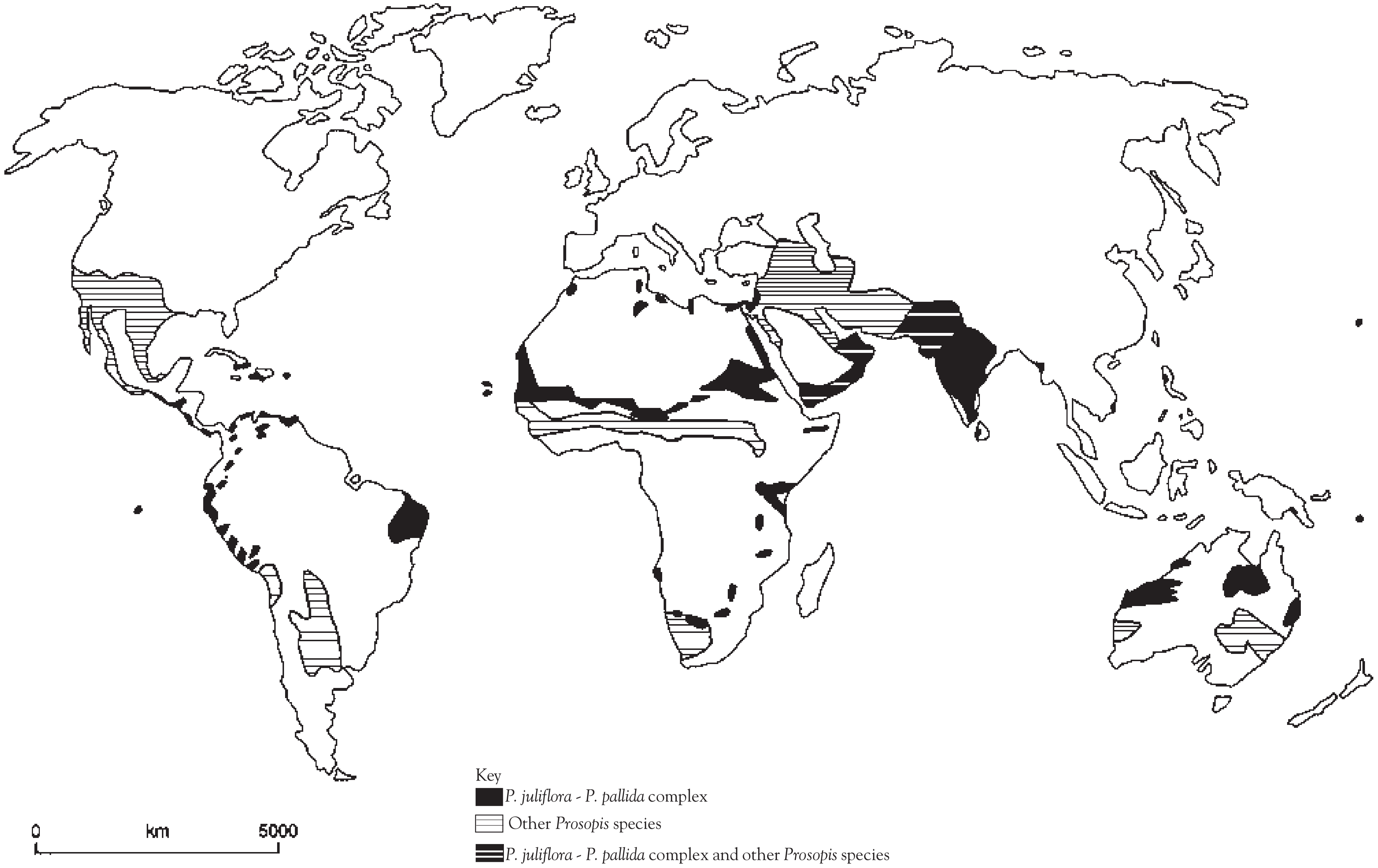


Figure 15. Approximate distribution of the genus Prosopis *(AD 2000), showing the distribution of the* P. juliflora - P. pallida *complex.*

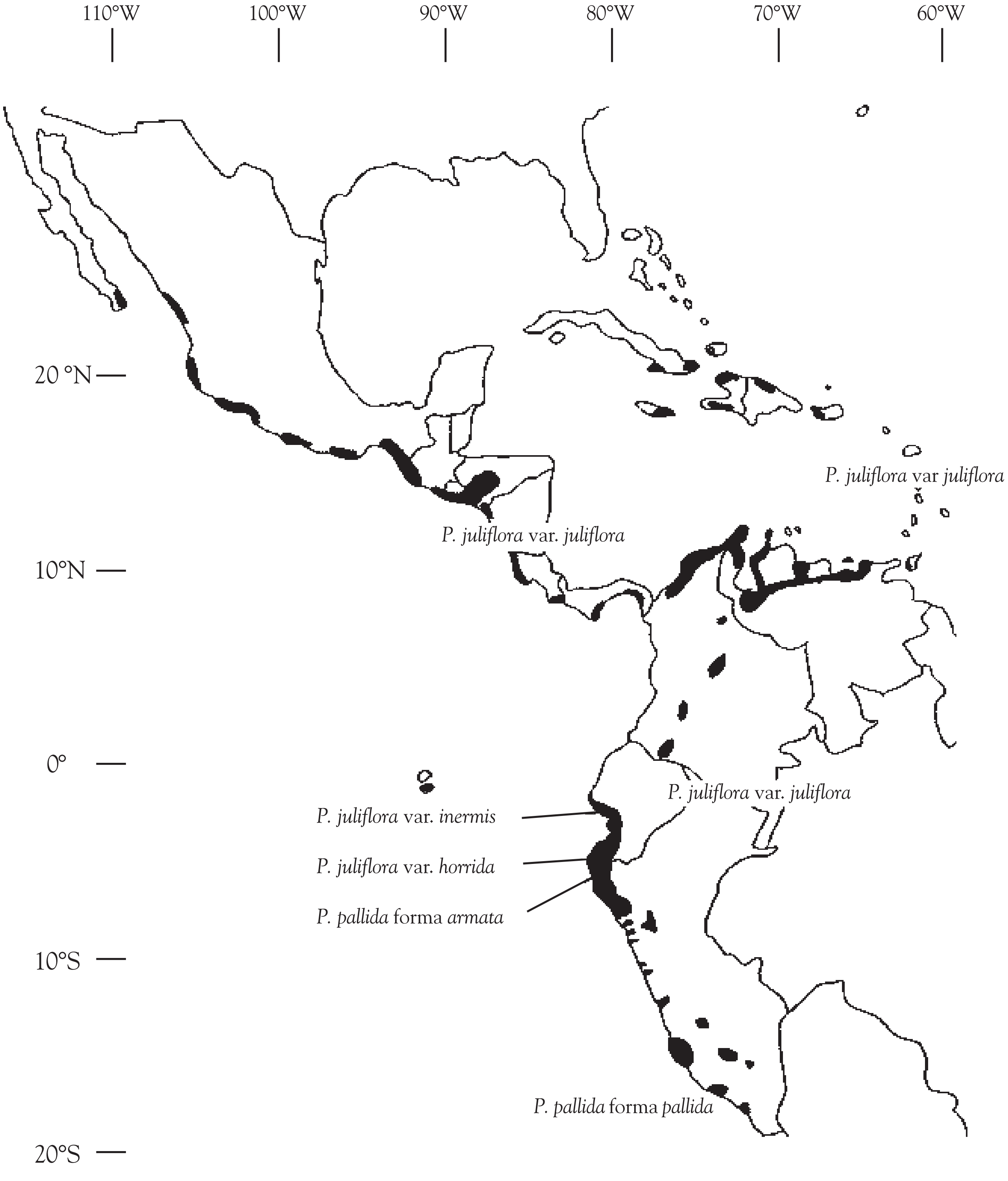


Figure 16. Present distribution of the* P.juliflora - P. pallida *complex, showing location of varieties and forms (from Burkart 1976, Ferreyra 1987, Daubeney Herbarium, Oxford, Diaz Celis 1995, Luis Alban pers.comm.).

The range of the *P. juliflora - P. pallida* complex covers a broad geographical area in such scattered populations, with the approximate latitudinal limits to the native range being the tropics of Cancer and Capricorn in the Americas. This includes a north-south range of 6000 km and east-west range of 6000 km. The range in latitude is from Mexico and Cuba in the North (22-25°N), to southern Peru in the south (18-20°S), and in longitude from eastern Venezuela and the Eastern Caribbean (62°W) to Mexico in the west (112°W). However, recent views that *P. juliflora* is not actually present in Mexico and possibly not in the Greater Antilles (e.g. Palacios pers. comm. 1999, Earl 1999) need to be confirmed (see 2.4.2).

The countries included in the native range of the *P. juliflora-P. pallida* complex includes Mexico, Guatemala, El Salvador, Honduras, Nicaragua, Costa Rica, Panama, Colombia, Venezuela, Ecuador and Peru. Several authorities have included the Caribbean in the native range, and if not native they became naturalised in prehistory (Timyan 1996). This includes Cuba, Haiti, Dominican Republic, Puerto Rico, Jamaica, Bahamas, Virgin Islands, Antigua, Trinidad and Tobago and Curaçao (Dutch West Indies). The same is probably true for populations on the Galapagos islands (Wiggins and Porter 1971). From the distribution map there appear to be several distinct populations which do not always coincide with species and varietal divisions (see 2.4.2).

Beginning in the south of the natural range, the Peruvian populations are generally low altitude, coastal, advancing inland on coastal flats and up valleys. At higher altitudes there is an intermediate population in northern Peru and Ecuador, which gives way to a long line of small populations, occasionally joined, from upland Colombia near to the Ecuadorian border to eastern Venezuela. There are also coastal populations in northern Colombia and Venezuela, similar to those present on Caribbean islands particularly Jamaica, Hispaniola and Puerto Rico, and another distinct group on the Pacific coast from Panama up to the states of Sonora and Baja California in Mexico, with some extensions inland up valleys and occasional montane populations, most notable in El Salvador and Honduras.

2.4.2 Origin and affinities

The genus Prosopis

The Cretaceous period at the end of the Mesozoic era (135-65 million years before present) saw the development and spread of angiosperms throughout the world. Primitive caesalpiniaceous species are accepted as the ancestors of the legume family, with mimosoid legumes thought to have evolved by the Maastrichtian stage at the end of the Cretaceous period. Legumes became a large and diverse group by the Eocene (54-38 million years before present), when Caesalpinoideae and Mimosoideae species were abundant (Raven and Polhill 1981). There continues to be debate concerning the exact origins of *Prosopis* and other legumes, and the history of evolutionary adaptations and distribution, with South America and Africa both postulated as the origin of the genus.

The part of West Gondwanaland that is present day South America is postulated as the origin of the Mimosoideae by Raven and Axelrod (1974), who suggest that it was here that genera such as *Prosopis* and *Acacia* originated, adapted to seasonally dry or more arid habitats. The great morphological diversity of the South American species which incorporate almost all of the characters found in species of North America, Africa and Asia (Burkart 1976), and the pattern of flavonoid chemistry (Solbrig *et al* 1977) suggested a South American origin for the genus (Burkart and Simpson 1977). There was undoubtedly an early interchange of legumes between Africa and South America, but the persistence of *P. africana*, the least specialised species, across the African continent suggests this as the original centre of origin (Raven and Polhill 1981). Africa has also been suggested as the origin of all tropical legumes (Raven and Polhill 1981). Although rich in legumes, South America has no endemic tribal groups of legume genera nor any notable concentration of the most archaic genera (Raven and Polhill 1981).

When *Prosopis* species are thought to have evolved, approximately 70 million years ago, the original super-continent of Gondwanaland was no longer intact. Land bridges which had facilitated the spread of plant and animal species to neighbouring continents were now separated by expanses of water. The oceanic expanses between continents were not nearly as large as they are today, and it is known that seed, particularly those of legume genera, were able to cross considerable distances (Raven and Polhill 1981). At the time of major legume expansion, South America was separated from both Africa and North America by an estimated 1200 km. An equivalent distance, Jamaica to the American mainland, did not prevent the dispersal of many plant species to that island. Also, that 13 legume genera reached Hawaii with none endemic, proves that oceanic dispersal was not uncommon (Raven and Polhill 1981).

Tribes of the sub-family Mimosoideae arose early on in the evolution of the legume family. The ancestral origins and affinities of tribes within the sub-family Mimosoideae is of some debate, although it is generally accepted that genera of the tribes Mimoseae and Acacieae arose later than those of other more primitive tribes as a result of subsequent specialisation. The true ancestral stock of *Prosopis* may have consisted of closely related genera such as *Adenanthera* and *Pseudoprosopis*, with dehiscent (self-splitting) legumes, from which evolved the more specialised genera with fleshy, indehiscent legumes (Burkart 1976). The genus *Prosopis* is a rather primitive member of the tribe Mimoseae and the sub-family Mimosoideae as a whole (Burkart 1976). *Prosopis* species maintain 14 as the base chromosome number and pollen is released in single grains and not two, four, eight or more (Burkart and Simpson 1977), supporting this theory. The presence of distinct groups (sections) of species within the genus and very similar species within these groups also indicate that *Prosopis* is an old genus which diverged early into several principal lineages, but that within some of these lineages, more recent episodes of expansion and isolation have produced further speciation (Burkart and Simpson 1977) (see 2.1.6).

Prosopis species evolved drought avoidance strategies making them well adapted to arid and semi-arid zones, including deep roots and special physiological adaptations maximising water uptake and minimising water loss. Continental drift, taking the original species from more humid equatorial zones to desertic latitudes may have promoted these evolutionary adaptations. Also, certain physical and physiological characteristics in the ancestral stock may have given *Prosopis* a comparative advantage in such dry zones, allowing for rapid colonisation. Although absent in *P. africana*, other *Prosopis* species evolved vegetatively differentiated megablasts and/or brachyblasts, pungent organs and armature of various types (Burkart 1976). *P. africana* remains native to a broad belt across Africa between the Sahelian and moist forest zones. The tree species of the eastern Asian population, *P. cineraria*, spread from native areas of the Arabian peninsula to colonise arid and semi-arid sites on the Asian mainland up to present day India. Several shrub species also evolved, occupying a similar range.

The western population is divided into many species in two main groups, with a single, intermediate species, *P. argentina*, now present only in Argentina. *P. argentina* has vegetative rhizomes and is the only other species besides *P. africana* without megablasts/ brachyblasts (Burkart 1976), suggesting that it may be a survivor of the ancestral stock of the American species. However, phenological similarities between species in section Prosopis in Asia and in section Strombocarpa in South America appear to contradict this (Burkart 1976, Martínez 1984) and evolution within the genus remains somewhat unclear. There are similarities between *P. farcta* (Asia) and *P. strombulifera* (South America) and their respective close relatives, in their comparatively smaller legumes and ability to spread vegetatively by means of rootsuckers. Vegetative propagation may have been a more primitive method of propagation than by seed, as is seen more in species of section Strombocarpa, which also exhibit more self-compatibility than species from section Algarobia (Hunziker *et al* 1975). Further molecular studies will confirm the genetic relationships between *Prosopis* populations and allow for an improved analysis of the origins and dispersion of *Prosopis* species, particularly in the Americas.

Prosopis has evolved considerable diversity in the 30 million years following the Cretaceous period (Raven and Polhill 1981). This time, including the Palaeocene, Eocene and Oligocene epochs, saw the evolution of early mammals. Although water is an important means of seed dispersal, particularly over long distances, it is very likely that the indehiscent, fleshy legumes and hard coated seed of *Prosopis* evolved alongside these mammalian herbivores which served as disseminators of seed (Mooney *et al* 1977). Fossil records show that *Prosopis* pods were eaten by several now extinct sloth species in both North and South America, and were probably eaten and dispersed by mammals such as camelids, edenates, notoungulates and stegomastodons (Mooney *et al* 1977). North American species tend to have less palatable foliage than South American species, possibly due to a greater number of large herbivores in the north, and thus a need to evolve characters to protect against herbivory. Throughout evolutionary history, mammalian populations, particularly ungulates and ruminants, have been increasing in numbers and mobility. Seed and legume have evolved accordingly, and longer, larger pods may be viewed as a more recent evolutionary adaptation.

The three groups which evolved separately very early on in the evolution of *Prosopis* were a central population in Africa, an eastern population on the island that is now the Arabian peninsula, and a separate western population that separated and spread widely in the Americas. There may be fewer *Prosopis* species in Asia because the large water barrier that separated it from Africa following the Paleocene (63 million years ago) prevented further exchange, or the relative abundance of ecologically competitive groups restricted further speciation (Raven and Polhill 1981). Similarly, the fewer species present in the North American centre than in South America does not necessarily mean that it originated there later than in the South American centre. It may be that more competition with boreal floras in the north or increased numbers of large herbivores prevented further speciation (Burkart 1976).

The accepted centre of polymorphism for *Prosopis* is Argentina, with a secondary centre in the Texan-Mexican region, both with closely related species. The boreotropics theory states that many species crossed directly from Africa to North America before spreading south (Lavin and Luckow 1993). However, it appears probable that ancestral *Prosopis* crossed into South America and spread into North America before the two centres became separated and disjunct, with convergent evolution then occurring (Simpson 1977). Long distance dispersal could have occurred at any time, but spread may have been favoured in the Quaternary period when arid and semi-arid lands reached their widest extent.

High occurrence of hybridisation and introgression have obscured the existence of more primitive species, but relics of initial invasions such as *P. palmeri* in Mexico have been postulated (Simpson *et al* 1975). Repeated glaciations forced species and their respective ecosystems towards the equator with destructive effects, and expansions into more temperate regions followed, continuing to this day (Holland 1987). Falls in sea level associated with these periods of glaciation may have also facilitated dispersion through the creation of land bridges. Orographic uplift and other major changes in land form have had significant effects on regional climate which would have affected the evolution and dispersion of *Prosopis* (Johnston 1962).

The P. juliflora - P. pallida *complex*

The evolutionary origin of the *P. juliflora - P . pallida* complex and its relationships within the genus are confused, due to the very close relationship of all the species in section Algarobia. Species in Central America may be relicts of the original, transitional species between the North and South American centres of polymorphism. The dispersion from South to North America is thought to have occurred, possibly following the creation of the land bridge between the continents around 5.7 million years ago (Raven and Axelrod 1974). The only intermediate Central American species today is *P. juliflora*, native to dry coastal belts, inland spurs and isolated valleys and possibly some Caribbean islands. The native range of *P. pallida*, the only other truly tropical species, overlaps with *P. juliflora* in northern Peru and Ecuador, reaching Cuzco in the south of Peru (Ferreyra 1983).

There may be, or have been, overlap in the ranges of *P. pallida* and other species in southern Peru and northern Chile, such as *P. chilensis* and*P. flexuosa*, allowing gene flow from the South American centre to go north. From a possible Peruvian, Ecuadorian or Colombian centre, *P. juliflora* appears to have spread north in two directions. The Cuban population may be the cul-de-sac of a northerly expansion along the Caribbean island chain. The Pacific coast of Central America may be second route, and the remnants of a *Prosopis* 'gene bridge', with seed being washed up and down the coast facilitating spread to and from North America. Such corridors are known to be significant conduits for gene-flow in a variety of other species. The origins and dispersion of species in the *P. juliflora - P . pallida* complex are, however, speculative and require verification.

P. juliflora has been described as a North American Algarobia species, being more closely related to *P. glandulosa*, *P. velutina*, *P. laevigata* and others than to any of the South American Algarobia species. The native range of *P. juliflora* may even overlap with those of other Algarobia species such as *P. laevigata* in southern Mexico. However, this may be because only material from Mexico, rather than from Colombia or Peru was analysed. Assuming a South American origin, the more temperate North American *Prosopis* species of section Algarobia may have evolved from a tropical species such as *P. juliflora* as they spread northwards, which would explain the affinity of these species. The affinity of *P. pallida* has not been fully ascertained. Burkart (1976) placed it in a different series to *P. juliflora*, suggesting that they were not very closely related, but all subsequent research points to the insignificance of those series in the section Algarobia. *P. pallida* most probably has its origin in South America.

The range of the complex and its ancestors would have altered significantly during the large southward movement of biomes associated with periods of glaciation in North America. The most recent was the Wisconsin glaciation (~ 100000-10000 years BP), with northward expansion of these biomes during the subsequent Holocene interglacial. The end of the Wisconsin glaciation coincided with the estimated time that Colombian and Venezuelan populations became isolated (Solbrig and Bawa 1975). Expansion was limited by a range of environmental barriers such as high rainfall zones and competition with other biota. Expansion into existing stands of more temperate *Prosopis* species is observed in Mexico (Earl 1999) and Argentina (Saidman 1990). Hybridisation and backcrossing lead to the creation of hybrid swarms, with clines in vegetative characters in intermediate zones, blurring the boundaries of species distribution (Saidman 1990, Earl 1999).

Concerning the origin of the recognised varieties and forms of the two species within the complex, it can be seen that they are found in the coastal and montane zones of northern Peru and Ecuador, where the ranges of the defined species *P. juliflora* and *P. pallida* overlap. Also, in upland Ecuador at 570 m altitude, Burkart (1976) described a putative hybrid between *P. juliflora* and *P. pallida* but noted that it could have been a form of *P. juliflora* var. *horrida*. Johnston (1962) noted that *P. inermis* (syn. *P. juliflora* var. *inermis*) may be a synonym for *P. pallida*. Such intermediate forms support the hypothesis that the varieties of *P. juliflora* that exist in Peru and Ecuador are inter-specific hybrids between *P. juliflora* and *P. pallida* that would have arisen as a result of hybridisation and subsequent backcrossing. This has probably resulted in the forms of *P. pallida* noted by Fosberg (1966) in Hawaii and accepted by Díaz Celis (1995) in Peru.

From the information regarding the nature and spread of the *P. pallida - P. juliflora* complex, a hypothesis may be stated concerning the origins and affinities of the complex (see Figure 17). It is generally assumed that *Prosopis* species spread from South to North America. Only the *P. pallida - P. juliflora* complex occupies the 'middle ground' between the two centres, and thus the native range may present, or have presented, a route for gene flow from south to north from an Argentinean origin. The Amazon basin would have prevented the dispersion of seed across this vast region, meaning that the only route would have been over the Andes from Argentina to Bolivia and the drier coastal regions of Chile and southern Peru, before spreading northwards to Ecuador, Colombia and probably up through Central America. Speciation during and after this period of dispersion led to the formation of *P. pallida* and later *P. juliflora* originating from Argentinean material. The geographically closest species of section Algarobia are *P. chilensis* and *P. flexuosa*, but it is not known whether these species are sympatric with *P. pallida* in southern Peru, whether hybrids form or whether there is presently any gene flow between them.

The centre for *P. pallida* is clearly in Peru, whereas the centre for *P. juliflora* is more confused but may appear to be Ecuador or Colombia. A hybrid zone has formed between the two that corresponds largely to present day Ecuador and northern Peru, and also southern Colombia. It appears that *P. juliflora* spread north from the Colombian centre, and two routes of northward expansion are clear. The north-eastern expansion spread to the Caribbean coast of Colombia, Venezuela, and later through the Caribbean island chain to Hispaniola, Jamaica and Cuba. The north-western expansion spread up the drier Pacific coast of Central America to Mexico. Inland expansions eventually colonised Mexico and the USA and these populations underwent further evolutionary adaptations to new environments leading to the creation of new species that are the present day North American species of section Algarobia.

However, it is uncertain whether there continues to be gene flow through Colombia. The geographic isolation of populations in Colombian valleys following the last glaciation (Solbrig and Bawa 1975) may have effectively broken the genetic link between northern and southern races of *P. juliflora*. While there are distinct habitat differences between areas inhabited by montane Colombian populations and the coastal Caribbean populations, Johnston (1962) noted that they were still morphologically very similar. This may be because this expansion is in fact very recent, and there has been insufficient time for significant speciation to occur. Also, no other *Prosopis*

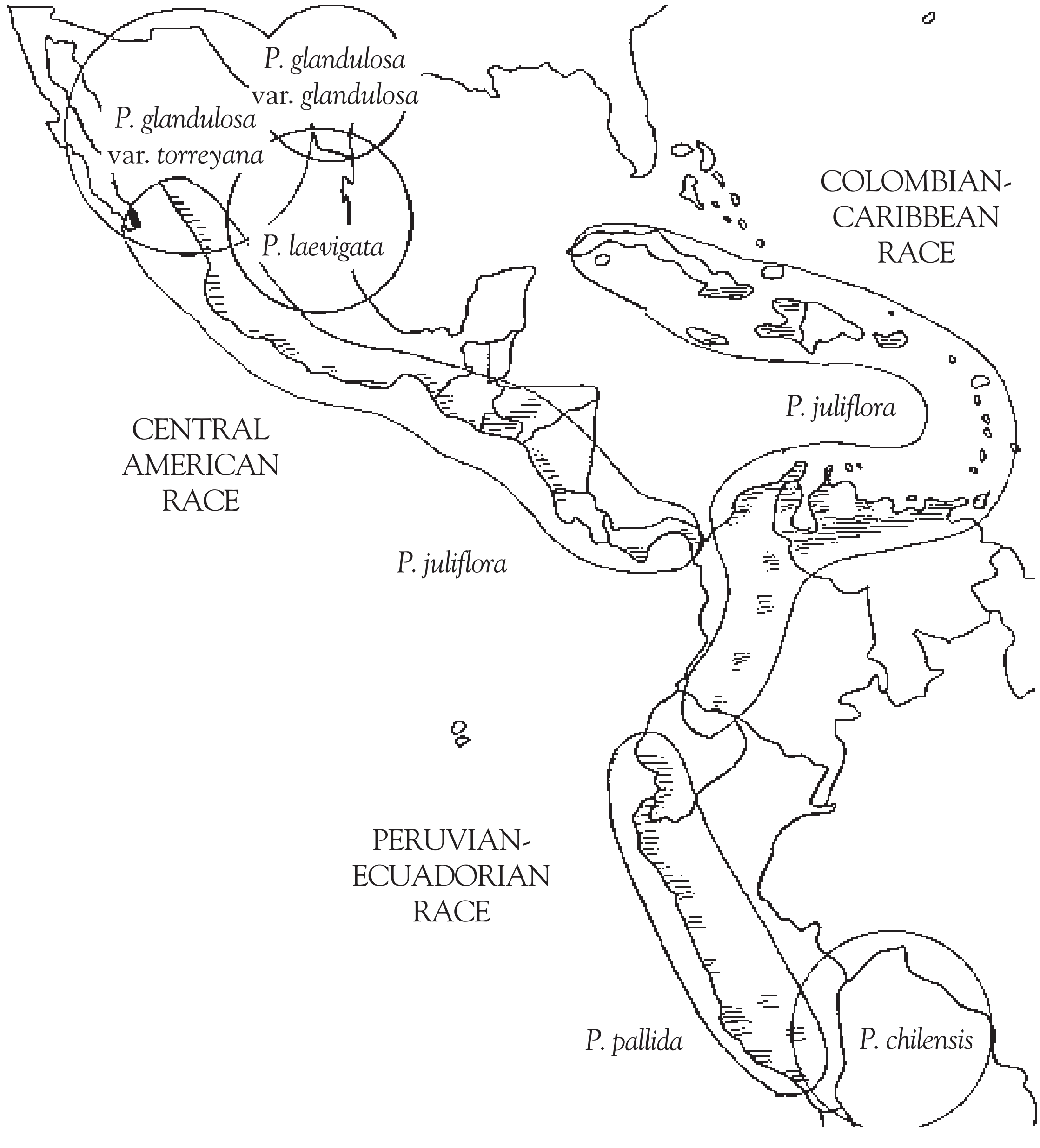


Figure 17. Native range of the* P. pallida - P. juliflora *complex, showing division into three geographically distinct areas and possibly morphological distinct races. Species with overlapping native ranges are also shown. The populations in coastal Mexico may undergo some taxonomic revision.

are present in this region and therefore there can not have been any introgression from different species. However, there exists the possibility that there may have been some gene flow between Caribbean populations of *P. juliflora* and populations of *P. laevigata* and *P. glandulosa* var. *glandulosa* from mainland Mexico and the USA via oceanic dispersal of seed over the Gulf of Mexico.

The Central American race is so morphologically distinct that Johnston (1962) suggested giving it species rank with the name *P. vidaliana*, now reduced to synonymity with *P. juliflora*. The range of *P. juliflora* given by Johnston (1962) overlaps with that of *P. glandulosa* var. *torreyana* in coastal Mexico and with *P. articulata* and *P. glandulosa* var. *torreyana* in Baja California. Inland expansions of *P. juliflora* in southern Mexico overlap with *P. laevigata*, creating another possible hybrid zone. The creation of the binomial *P. dulcis* (=*P. laevigata*) var. *dominguensis* (=*P. juliflora*) suggests that this may have been a hybrid form with intermediate characters (see Table 16, section 2.4.5). This race of *P. juliflora* may be assumed to be undergoing gene transfer with other North American species, in particular along the Pacific coast of Central America, where long distance seed dispersal can spread seed considerable distances. The longer leaflet lengths seen in the Central American race are more likely to be caused by relatively recent introgression from larger leafed temperate types such as *P. glandulosa*, than to the evolution of features specifically adapted to these coastal environments. Also, while it is generally accepted that populations in southern Central America are *P. juliflora*, several taxonomists state that *P. juliflora* is not actually present in Mexico, thus suggesting that the populations from Pacific coastal of Mexico be reclassified.

It appears that the *P. pallida - P. juliflora complex* can be divided into three distinct races based on leaf morphology, and geographic range, and the possible origins and affinities of each has been discussed. All of the races have similar site and climatic requirements, similar morphology can hybridise readily and share the same phylogenetic origins, and thus will continued to be treated as the *P. pallida - P. juliflora* complex. However, taxonomic revision of some of the populations may be expected following detailed range-wide molecular analysis. However, the differences between the races in relative growth rates, tree habit, thorniness and pod sugar noted in provenance field trials (see 3.1.3) suggests that it may be necessary to treat the three races separately in terms of silviculture.

2.4.3 Environmental requirements

Site and soil

Referring to North American *Prosopis* species, but equally applicable to *P. juliflora*, Harvard (1884, in Dahl 1982) noted that “there is hardly any soil, if it is not habitually damp, in which mesquite cannot grow; no hill too rocky or broken, no flat too sandy or saline, no dune too shifting... to entirely exclude it”. The *P. juliflora - P. pallida* complex has a broad ecological amplitude adapted to a very wide range of soils and site types from sand dunes to cracking clays. They are generally found in areas where water and poor soil fertility are the principle agents limiting plant growth, and are able to survive and even thrive on some of the poorest land, unsuitable for any other tree species. The *P. juliflora - P. pallida* complex dominates in dry, or seasonally dry water courses or depressions, and the presence and depth of the water table is a decisive factor in the distribution, size and growth of *Prosopis* species (e.g. Simpson 1977). Height of *Prosopis* trees has been used successfully to estimate the depth of the water table in the USA (Meinzer 1927).

The species occupy soils overlying a variety of geological formations with no specific affinities. Generally, the Afro-Asiatic species *P. cineraria*, *P. farcta* and *P. africana* prefer deep, free draining soils, while American *Prosopis* are less selective, preferring clay soils but tolerating a wide variety of soil types. The *P. juliflora - P. pallida* complex can be found on all soil types from pure sands to heavy clays and stony soils, but deep free draining soils are preferred (NAS 1980). Soil depth is important, with a noted limitation to tree growth occurring where soils are thin, or have a hard calcareous or iron pan. Above ground growth is stunted if root system development is impeded for any reason. Wind throw can be observed if root growth is impeded and the site is exposed. Poor drainage or water logging can have similar effects on tree growth and survival, with poor oxygen content in the soil thought to affect root growth.

Altitude does not appear to be a factor directly limiting distribution. In the native range, the *P. juliflora - P. pallida* complex is abundant at altitudes below 200 m, less common between 200m and 500 m, and frequency increases again above this (see 2.4.5), with some trees found up to 1500 m altitude in the Andes. Other *Prosopis* species can be found at even higher altitudes, with *P. chilensis* native to areas up to 2900 m (NAS 1980) and *P. ferox* up to 3700 m altitude (Braun Wilke 1988). The *P. juliflora - P. pallida* complex is also generally well adapted to different altitudes where introduced.

Soil nutrient status is not often a limiting factor to distribution. Nitrogen is very rarely limiting, with nitrogen fixation and soil improvement leading to an increase in soil fertility as *Prosopis* trees mature (Geesing *et al* 1999). Trees have been noted to fix nitrogen under conditions of high pH (Singh 1996), high salinity (Felker *et al* 1981b) and high water deficits (Felker and Clark 1982). Other macronutrients can occasionally be limiting to growth either directly or indirectly. Low phosphorus levels are thought to affect nitrogen fixing ability by limiting the activity of *Rhizobium* (Jarrell *et al* 1982). Micronutrients, although not normally limiting, will have reduced availability in sub-optimal conditions such as high pH. There was a strong positive correlation noted between soil nutrient status and leaf nutrient content in *P. juliflora* (Sharma 1984) and *P. glandulosa* (Cline *et al* 1986).

Saline and alkaline soils are often occupied by the *P. juliflora - P. pallida* complex. *Prosopis* species are seen to survive and grow with salinity levels equal to that of sea water (Felker *et al* 1981b) and in soils with a pH of 10.5 (Singh 1996). *P. pallida* was found to tolerate salinity levels up to 18000 mg NaCl/l with no reduction in growth or survival, and still grew at 36000 mg/l NaCl, equivalent to sea water (Felker *et al* 1981b). *P. juliflora* and *P. pallida* are known to tolerate saline sites in their native range such as lowland flats and coastal dunes and in such conditions they can often dominate. *P. juliflora* has been successfully raised using saline irrigation water, with an electrical conductivity of 20 dS/m in India (Singh 1996) and 6-21 dS/m in Pakistan (Khan *et al* 1986).

P. juliflora is also particularly well able to tolerate alkaline soils, with marginal reduction in growth up to pH 9.0, and will survive and grow in soils of pH 11 but performs much better following soil amendments (Singh 1996). *Prosopis* species, however, appear to be not well suited to acidic soils, and the possibility that low pH is a limiting factor to the distribution has been suggested for *P. glandulosa* (Peacock and MacMillan 1965, Jarrell *et al* 1982) but not specifically for *P. juliflora*.

Water requirements

The *P. juliflora - P. pallida* complex thrives in a wide range of rainfall zones, from 100 mm mean annual rainfall (m.a.r.) or less in dry coastal zones, to 1500 mm m.a.r. in the Andean region. *Prosopis* species are, however, generally much less common in regions with more than 1000 mm m.a.r., but their ability to tolerate very low annual rainfall is well known. *P. cineraria* and *P. tamarugo* are able to survive with under 50 mm m.a.r., and these *Prosopis* species dominate in parts of the Arabian and Atacama deserts, with some of the lowest recorded rainfall in the world. Species native to very arid zones of the Americas such as *P. chilensis*, *P. glandulosa*, *P. juliflora* and *P. pallida* can survive with annual rainfall in the range of 50-250 mm (NAS 1980, FAO 1997). Many other species are noted as having a rainfall requirements in the range of 300-600 mm/yr.

Leaves of *Prosopis* show many xerophytic adaptations to drought (Vilela and Palacios 1997), but the existence of two root systems, a deep tap root to reach ground water and a mat of surface lateral roots to make use of infrequent rainfall events, places *Prosopis* as phreatophytes (Mooney *et al* 1977). All *Prosopis* species are able to survive in areas with exceptionally low annual rainfall or very lengthy dry periods but only if roots are able to tap ground water within the first few years, or if sufficient atmospheric moisture is available, as in many coastal desert areas with persistent trade winds or seasonal fog. *P. tamarugo* and *P. cineraria* that occur in hyper-arid regions have been studied in regard to foliar water uptake and were reported to practise reverse transpiration (Sudzuki 1985, Gates and Brown 1988). The importance of foliar water uptake is unclear as water tables are present where these two species grow, and mucilaginous cells in the leaves could serve as water reserves (Vilela and Palacios 1997). Research that claimed to prove foliar water uptake is seriously questioned and, if it does occur, it probably plays an insignificant part in the water balance of these *Prosopis* species.

In dry coastal regions, *P. juliflora* and *P. pallida* grow well where rainfall is low, often less than 200 mm m.a.r. but where there is a water table fed from high rainfall areas in the mountain ranges inland. Trees are found in higher densities along water courses (Simpson 1977) and, when found in valleys, tend to congregate along the valley bottom where there is likely to be a permanent supply of sub-surface water. In montane areas, species tend to inhabit dry valleys in the rain shadow of large mountains (Solbrig and Bawa 1975) with rainfall up to 1500 mm m.a.r.

Chaturvedi *et al* (1988) estimated water use efficiency of *P. juliflora* at 710 kg H_20/ kg dry matter. The estimates of Singh *et al* (1990) were 8943 kg H_20/ kg dry matter in rainfed plantations and 13271 kg H_20/ kg dry matter in irrigated plantations. It was suggested that these high levels observed by Singh *et al* (1990) were due to excessive evaporation associated with incomplete canopy cover. With other species, 345 kg H_20/ kg dry matter was estimated for *P. chilensis* (Felker *et al* 1983a) and 4800 kg H_20/ kg dry matter for *Prosopis* spp. in Mexico (Dwyer and De Garmo 1970). In Kenya, water use efficiency of Peruvian *P. pallida* and local *P. juliflora* was twice as high as Chilean *P. chilensis* (Kaarakka and Johansson 1992). Estimates of water use efficiency of *Prosopis* species vary widely, probably due as much to methods of analysis as to species or site.

Temperature

Mean annual air temperature in the shade where the *P. juliflora - P. pallida* complex is found is generally above 20°C, with optimum temperatures for growth being in the range 20-30°C. There appears to be no natural upper limit to temperature, with introduced *P. juliflora* known to tolerate day time shade temperatures of over 50°C, and soil temperatures in full sunlight as high as 70°C in Africa and Asia. In its native range in coastal or montane environments, such high temperatures are rarely recorded. A major limitation to the distribution of *Prosopis* species, and particularly the truly tropical *P. juliflora - P. pallida* complex, is mean minimum temperatures and the frequency and duration of winter frosts. Light frosts cause dieback of branches, with complete stem mortality with harder frosts, and complete death of the plant when frosts are more severe or longer lasting (Felker *et al* 1982b). Frost damage is more severe on seedlings and younger trees of *P. juliflora* and on trees in interdunal or other low lying areas (Muthana 1974).

P. juliflora and *P. pallida* are the most frost sensitive of *Prosopis* species, along with *P. africana*, the latter two of which tolerated several -1.5°C frosts but died with a frost of -5°C (Felker *et al* 1982b). Hyde *et al* (1990) found that *P. juliflora* seedlings were killed by a -2°C frost in Spain, while *P. juliflora* was noted to suffer frost damage but survive when temperatures fell below 0°C in India (Muthana 1974). *P. pallida* in Peru is noted to be damaged by temperatures below +5°C (FAO 1997). More sub-tropical *Prosopis* species native to Mexico, Argentina and Chile survived a -5°C frost but were killed by 12 hours below 0°C (Felker *et al* 1982b). *P. glandulosa* and *P. velutina* are known to survive severe frosts to -20°C in the USA (Fisher *et al* 1959), and in South America, *P. caldenia* is often snow covered in winter (Burkart 1976) and *P. denudans* is native to areas with the 12°C isotherm (mean annual temperature) being an approximate southern limit (Hunziker *et al* 1986). *P. cineraria* can withstand frosts of -6°C in the Indian Thar desert without damage but is killed by colder or more extensive frosts (Muthana 1974). The relative frost tolerance of 21 *Prosopis* tree species is presented in Table 1 (see 1.2.1).

There is also considerable variations in frost tolerance exhibited by different provenances of the same species. In India, of the forms of *P. juliflora* described by Raizada and Chatterji (1954), the Argentinean and Mexican forms were more frost tolerant, the Australian form frost tender and the Peruvian form most frost sensitive (Muthana and Arora 1983, Luna 1996). Owing to the more sub-tropical native range of *P. juliflora* in Mexico, it can be assumed that they would be more frost tolerant than *P. pallida* and other land races from the *P. juliflora* complex native to the equatorial regions of Peru, Ecuador and Colombia. *P. chilensis* is recorded as tolerating temperatures as low as -20°C in Argentina, only -5°C in Chile and is frost sensitive in Bolivia, particularly when juvenile (FAO 1997).

2.4.4 Environmental effects

Effects on soil fertility

Over time, *P. juliflora* exhibits the ability to improve soils via biological nitrogen fixation, leaf litter addition and incorporation, nutrient pumping, changes in soil structure and in soil fauna and microbial populations. It is generally accepted that *Prosopis* species ameliorate the soils in which they grow (e.g. Aggarwal 1998) although some authors (e.g. Zainal *et al* 1988) note that soils receiving *P. juliflora* litter are always of low fertility. However, the ability of *Prosopis* to fix nitrogen may be severely reduced in highly saline or alkaline soils (Pasiecznik *et al* 1993, Singh 1996), or where phosphorus is limiting (Jarrell *et al* 1982). Many studies on *Prosopis* species have shown that the quantities of soil nutrients are greater under the tree crown, with additions to soil fertility from root symbionts and also decomposition of senesced foliage (see 3.5.3).

There is an increase in organic matter content and increases in soil macronutrients and many micronutrients. That 'islands of fertility' exist around trees in nutrient poor areas is accepted, although whether the improved fertility precedes the tree has often been debated. An increase in silt and clay particles was also noted under the canopies of *P. juliflora* trees in Sudan by El Fadl (1997), with a corresponding decrease in sand particles. This was thought to be due to a reduction in wind and water erosion and/or entrapment of wind-blown dust resulting in surface sealing and an increase in surface runoff and soil cracks.

Martin (1948) considered that *Prosopis* selectively occurs on islands of fertility and increased fertility is not created by active nitrogen fixation, a view that was maintained by several authors such as Barth and Klemmedson (1982). However, Geesing *et al* (2000) found high levels of nitrogen fixation during establishment, decreasing as the tree aged. As levels of soil nitrogen increase, this leads to a suppression of nitrogen fixation. There was little nitrogen fixation observed in mature trees, with most nutrients now readily available from the improved soil under the canopy (Geesing *et al* 2000).

There are many records confirming higher levels of nutrients, particularly nitrogen, under *Prosopis* canopies than in open spaces between trees, but much less data on estimates of annual nitrogen accrual. East and Felker (1993) noted that nitrogen levels were 1.3 t/ha higher under *P. glandulosa* tree crowns than in open spaces. However, there appears to be an effect of species, with much higher nitrogen levels found under *P. glandulosa* than under *P. alba* or *P. chilensis* (Abrams *et al* 1990). Total nitrogen accumulation during the lifetime of a plantation was estimated at 13-30 t N/ha by Dommergues *et al* (1999). This accumulation occurs throughout the soil profile, with significant increases noted at all depths to 1.5 m under canopies of *P. juliflora* (El Fadl 1997).

Individual *P. juliflora* trees were estimated to fix 31 g N/yr by Diagne and Baker (1994), which was considered satisfactory, but only 5.5 g N/yr by Diagne (1992). At a density of 400 trees/ha, these estimates correspond to an accumulation of 2.2-12.4 kg N/ha/yr. Annual accumulation of nitrogen under *P. glandulosa* was estimated by Geesing *et al* (2000) to be 9-22 kg N/ha/yr in the top 20 cm of the soil profile, and 25-30 kg N/ha/yr by Rundel *et al* (1982). Dommergues *et al* (1999) estimated that 40 kg N/ha/yr was fixed by *Prosopis* species. Other estimates are, however, considerably higher. Abrams *et al* (1990) calculated an increment of 100 kg N/ha/yr in California under *P. glandulosa* var. *torreyana*, and Jarrell and Virginia (1990) estimated an accumulation of 26-175 kg N/ha/yr over the lifetime of a *P. glandulosa* stand. Such large variations in nitrogen accumulation could be due to tree species, microbial symbiont strain, site conditions or tree age, all considered to have significant effects on nitrogen fixation, or to differences in sampling, chemical analysis and interpretation of results (Dommergues *et al* 1999). However, Pasiecznik *et al* (1993) noted no significant increase in soil nutrient status under four-year-old *P. juliflora* trees in Cape Verde, assumed to be due to soil water deficit or salinity limiting nitrogen fixation.

Levels of soil carbon were found by East and Felker (1993) to be 8.3 t/ha higher under the crowns of *P. glandulosa* than in open spaces. Geesing *et al* (2000) also noted a large increase in soil carbon under *P. glandulosa*, estimated to be 35-88 kg C/ha/yr. Aggarwal (1998) found no effect of *P. juliflora* on organic matter but reported increases in soil microbial populations under the crowns of *P. juliflora* trees in India. Singh (1996) noted significant increases in soil carbon under a *P. juliflora* plantation after 8 years, with mean soil carbon content increasing from 0.12% to 0.58% over 20 years.

Levels of phosphorus and other nutrients are higher under the crown of *P. juliflora* than in open spaces (e.g. Aggarwal *et al* 1976), thought to be because of increased leaf litter deposition, mycorrhizal associations and/or nutrient pumping. The incorporation of leaf litter plays an important role in improving soil nutrient status and soil physical qualities. Large quantities of leaves are shed each year, leading to a considerable potential source of nutrients (see 3.3.3). Leaves have a larger percentage of minerals and nutrients than either the stem, branches or roots of *P. juliflora* (e.g. Singh *et al* 1990). Leaves contain approximately 3% nitrogen and are rich in macro- and micro-nutrients (see 3.3.1).

Trees also appear to reduce salinity and alkalinity in soils on which they are grown and highly alkaline soils (pH 10) can be neutralised by *P. juliflora* plantations (Bhojvaid *et al* 1996, Singh 1996). Trees in the *P. juliflora - P. pallida* complex have the ability to acidify alkaline soils, with reductions in pH of approximately one unit every ten years. While this effect is not uncommon with fast growing legumes in tropical soils, rates of change appear considerably higher under *P. juliflora* than with other species. *P. juliflora* is tolerant to very high pH (over 10.5) but will not grow well in soils with a pH 9 or above unless supplemented with manure and calcium sulphate (Singh and Singh 1993, Singh 1996). Considerable research has been undertaken in India on the reclamation effect over time (e.g. Maliwal *et al* 1991, Jain and Garg 1996, Singh 1996). *P. juliflora* was found to improve physical and chemical properties of soil by decreasing pH, electrical conductivity and exchangeable sodium levels, and by increasing infiltration capacity, organic carbon, total nitrogen, available phosphorus and exchangeable calcium, magnesium and potassium levels (Bhojvaid *et al* 1996).

Allelopathy

The leaves of *P. juliflora - P. pallida* contain various chemicals including tannins, flavonoids, steroids, hydrocarbons, waxes and alkaloids (see 3.3.1). These are known to affect palatability to livestock but also have effects on the germination and growth of *Prosopis*, crops, weeds and other trees. Leaf extracts were also noted to kill some insects, bacteria and fungi (see 3.3.2). However, there is some debate as to the importance of allelopathy in tree-crop interactions and the applicability of results from pot trials to field conditions. Alkaloids and flavonoids are known to degrade rapidly following leaf senescence but other chemicals may accumulate under tree crowns (Sola *et al* 1992). Most studies have utilised leaf extracts or dry leaves incorporated into soil for analysis in pot trials. This often exaggerates the concentrations of chemicals leading to misleading results. Reduction in crop seed germination due to chemical inhibition was noted with *P. juliflora* leaf concentrations of more than 3%, but it was thought that this would not be noticeable under field conditions (El Fadl 1997).

Effects of these allelo-chemicals may be direct, acting upon the seeds and seedlings, or may be indirect, via effects on other soil organisms. Extracts from plant parts of *P. juliflora* decreased germination and growth of almost all plants tested in several studies, indicating that allelopathic effects are important in the ecology of the *P. juliflora - P. pallida* complex. However, Sen and Chawan (1970) assessed the effects of *P. juliflora* extracts on germination of a *Euphorbia* species and concluded that the phytotoxicity was without ecological significance. Sola *et al* (1992) thought that the accumulation of steroids, hydrocarbons and waxes in *P. ruscifolia* leaf litter affected hydrophobic constituents and soil moisture capacity, whereas all other authors discuss only allelo-chemical effects.

Autotoxicity of *P. juliflora* has been observed on seed germination and subsequent seedling development (Lahari and Gaur 1969, Warrag 1994). Most studies have concentrated on effects on germination and growth of crop plants. Lahari and Gaur (1969) found decreased shoot and, particularly, root growth of a range of plants following treatment with *P. juliflora* leaf extract. Fresh leaf extracts of *P. juliflora* were found to have greater negative effects on germination than extracts from stems, dry litter or fruit by Sen and Chawan (1970) and Sundaramoorthy *et al* (1996). However, Noor *et al* (1995) observed a greater effect from fruit and seed extracts than from root, leaf or flower extracts. Bark extracts have also proved effective at inhibiting germination (Velu *et al* 1996). The role of leaves for the bio-control of weed species is discussed in 3.3.2.

Physical effects

The physical effects of *Prosopis*, relating to ecological interactions, include the ameliorating environmental effects offered by shelter from the wind and shade from the sun (see 3.5). Studies show decreased wind speeds and alterations to the microclimate under the tree canopy that can be assumed to affect the ecology of trees of the *P. juliflora - P. pallida* complex. Shade and shelter positively affect water balance by increasing relative humidity and reducing evapotranspiration, through effects on wind speed and maximum temperature. Reduced wind speed decreases direct physical stresses on neighbouring plants but, more importantly in arid zones, also reduces the desiccating effect of the wind, thus decreasing evapotranspiration.

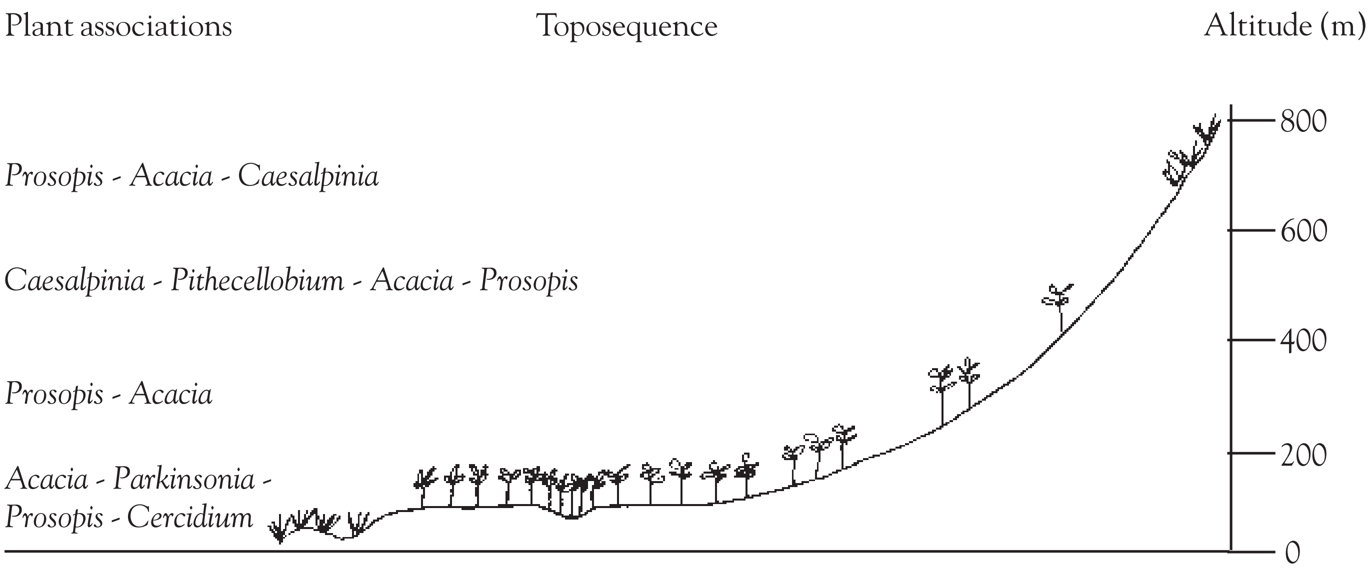


Figure 18. Generalised toposequence for the* P. juliflora - P. pallida *complex in Peru and Central America (adapted from Tables 14 and 15).

Table 15. Plant associations of P. pallida in its native range in Peru, ranked per location in order of frequency (adapted from Díaz Celis 1995).

Country	Location	Species	Site	Altitude (m)	Comments
Peru	Piura, Zarumilla-Tumbes, Ica, Mares-Arequipa	*Capparis angulata* *Capparis ovalifolia* *Capparis cordata* *Cordia lutea* *Cercidium praecox* *Parkinsonia aculeata* *Acacia macracantha* *Acacia huarango* *Vallesia glabra* *Scypharia spicata* *Maytenus octogona* *Graboskia boerhavifolia* *Encelia canescens* *Cryptocarpus pyriformis* *Neoraimondia macrostibas* *Caesalpinia corymbosa* *Psittacanthus* spp.	coastal and low altitude	0-200	in tropical and sub-tropical desert, in three formations: i) algarrobo woodland ii) dispersed woody plants iii) montane valleys
		Bursera graveolens *Laxopterigium huasango*	mid-altitude savanna-type	200-600	in tropical and sub-tropical thorn forest, in xerophytic formations
	Maranon, Mantaro, Aputimac	*Salix chilensis* *Pithecellobium multiflorum* *Tessaria integratifolia* *Gynerium sagitatum* *Celtis iguanae*	mid-altitude in montane valleys	200-600	in tropical and sub-tropical thorn forest, in xerophytic formations
	Cuzco	*Schinus molle* *Caesalpinia tinctoria* *Muntingia calabura*	montane, in Andean valleys	500-1500	dominant in xerophytic formations

Shade decreases the level of solar radiation under the canopy, reducing temperature, which is particularly important during periods of active plant growth. The increased shade and shelter offered also provides improved habitats for a variety of fauna. Inside a *P. juliflora* plantation in Sudan, daily maximum temperatures were on average 2°C cooler than in the open at 0800 and 1400 h, periods that coincided with times of active growth (El Fadl 1997). However, while recording reduced daily evaporation rates inside the plantation, El Fadl (1997) also noted the highest maximum temperatures occurred inside rather than outside the plantation (see also 3.5).

Table 16. Plant associations of* P. juliflora *in its native range in Central America (adapted from Daubeney Herbarium, Oxford).

Country	**Location**	**Species**	**Site**	**Altitude** (m)	**Comments**
Mexico	Baja California	*Acacia* spp. *Cercidium* spp.	coastal		-
	Michoacán	*Gliricidia sepium*	sand dunes		abundant in dense thickets
	Oaxaca	*Acacia farnesiana* *Parkinsonia aculeata* *Prosopis laevigata*	salt flats	5	abundant
	Oaxaca	*Acacia farnesiana*	coastal	15	-
Guatemala	Motagua	*Guiacum sanctum* *Apoplanesia paniculata* *Caesalpinia velutina* *Acacia picachensis* *Leucaena collinsii* *Cactaceae*	montane valleys	210	rare in valley scrub
	Motagua	*Caesalpinia* spp. *Haematoxylon* spp. *Acacia* spp. *Pithecellobium* spp. *Guiacum* spp. *Cordia* spp. *Cactaceae*	montane	200	rare in dry thorn scrub
Honduras	Comayagua	*Acacia farnesiana* *Acacia picachensis* *Goldmania foetida* *Chloroleucon mangense* *Pithecellobium dulce*	montane	700	a weed, in secondary dry thorn scrub
	Comayagua	*Acacia* spp. *Leucaena* spp. *Senna* spp. *Cresentia* spp.	montane	690	almost weedy in degraded dry forest and pasture
	Choluteca	*Sesbania emerus* *Acacia farnesiana*	coastal	30	locally common, otherwise rare
Nicaragua	San Francisco	*Acacia farnesiana* *Acacia cornigera* *Caesalpinia coriaria* *Parkinsonia aculeata* *Cresentia elata* *Capparis* spp. *Opuntia* spp.	inland, on cracking clays	90	abundant
	Managua	*Acacia farnesiana* *Parkinsonia aculeata*	inland on deep, black vertisols	60	abundant
	Fonseca	*Pithecellobium dulce*	raised beach	20	abundant

2.4.5 Associations

Plant associations

Mares *et al* (1977) summarised the ecological associations, describing American *Prosopis* tree species as "representative large desert trees which provide protection from grazing animals, shade, a moist microhabitat, a substrate for climbing or perching, and a reliable supply of nutrients for parasitic and semiparasitic plants. In providing these habitat components, such desert scrub trees allow an increase in plant density and richness in the community as a whole. These species, which would be rare or absent without the presence of trees and shrubs such as *Prosopis*, in turn contribute to the support of other trophic levels by providing food sources (leaves, flowers and fruits) for desert scrub animals". There have, however, been few detailed studies on ecological interactions with the *P. juliflora - P. pallida* complex.

Covering such a wide area, *Prosopis* species form a part of many ecosystems and subsequently have a large variety of plant associations. In a majority of American arid and semi-arid ecosystems, *Prosopis* are the dominant or co-dominant species. The many tree and shrub species occupy a variety of ecological niches with other species or hybrids, and are particularly dense along water courses or where there is a permanent underground water supply. The complex is common in coastal, savanna, montane or intermontane valleys, as part of xerophytic tropical or sub-tropical thorn scrub or forest formations. A generalised catena sequence for the *P. juliflora - P. pallida* complex in Pacific coastal and

Table 17. Plant associations of the* P. juliflora - P. pallida *complex where naturalised in India (adapted from Pandya and Sidha 1985, Pandit 1996, Chinnimani 1998).

Country	Location	Species	Comments
India	Yamuna, Chambal, Beas, Mahi, Banas, Sabarmati, Narmada and Tapi ravines, north India	*Prosopis cineraria* *Azadirachta indica* *Acacia nilotica* *Acacia leucocephala* *Holoptelia intregrifolia* *Zizyphus nummularia* *Balanites aegyptiaca* *Tamarindus indica* *Acacia senegal* *Cordia mixa* *Albizia lebbek* *Dalbergia sissoo* *Dichrostachys cinerea* *Feronia elephantum*	dominant in northern tropical thorn forest
	Loriya, Gujarat	*Salvadora persica* *Prosopis cineraria* *Acacia nilotica*	dominant in *P. juliflora- Salvadora persica* association
	Bhachuan, Gujarat	*Salvadora persica* *Acacia nilotica*	dominant in *P. juliflora- Salvadora persica* association
	Sumarasar, Gujarat	*Acacia nilotica* *Prosopis cineraria* *Tamarix troupi* *Salvadora persica* *Zizyphus mauritiana*	existing in *Acacia nilotica-Prosopis cineraria* association protected from grazing and wood cutting
	Kutibandh, Gujarat	*Euphorbia nivulia* *Acacia senegal* *Acacia nilotica* *Prosopis cineraria*	existing in *Euphorbia-Commiphora-Acacia senegal* association in drier locality
	Sherdi, Gujarat	*Acacia senegal* *Prosopis cineraria* *Acacia nilotica*	existing in *Acacia senegal-Prosopis cineraria* association
	Bhavnagar, Gujarat	*Balanites aegyptiaca* *Dichrostachys cinerea*	dominant in *P. juliflora-Balanites aegyptiaca* association
	Bhavnagar, Gujarat	*Capparis sepiaria* *Securinega leucopyrus* *Balanites aegyptiaca*	dominant in *P. juliflora-Capparis sepiaria* association

inland populations is presented in (Figure 18). This has been derived from data on plant associations of *P. pallida* from Peru and *P. juliflora* from selected Central American countries presented in (Tables 15 and 16). A further list of plant associations is presented from India (Table 17) as an example of associated species where the *P. juliflora - P. pallida* complex is introduced.

Relative abundance and tree form of *P. juliflora* and *P. pallida* at different altitudes appears similar in the Central American and Peruvian populations. No data is presented on the Colombian-Caribbean race, which also exists at altitudes of 0-1500 m, but which may be expected to follow the same pattern. *P. juliflora* is abundant in Central America in coastal areas, sand dunes, raised beaches and salt flats below 20 m altitude. *P. juliflora* is also common in some coastal districts of Caribbean islands such as Jamaica and Puerto Rico (e.g. Little and Wadsworth 1964) as is *P. pallida* where introduced in Hawaii (e.g. Little and Skolmen 1989). On low lying plains (50-200 m altitude), *P. juliflora* is abundant on cracking clays and vertisols in Nicaragua and *P. pallida* forms nearly pure 'woodlands' in Peru. In valleys at higher altitude (200-500 m altitude), *P. juliflora* becomes increasingly rare in Central American thorn scrub formations and *P. pallida* also becomes more dispersed in Peru. Plant density increases above 500 m altitude, with *P. juliflora* becoming weedy in secondary forest and degraded pasture in Honduras and dominant in xerophytic formations around Cuzco.

Plant associations vary through the native range of the *P. juliflora - P. pallida* complex but some common genera are observed. The native range covers a large geographical area along the Pacific coast from southern Peru to Mexico (Figure 16, see 2.4.1). Besides *Capparis* spp. and *Cordia* spp., five woody legume genera are common associates of the *P. juliflora - P. pallida* complex; *Acacia*, *Caesalpinia*, *Cercidium*, *Parkinsonia* and *Pithecellobium*. Several species of these genera are widespread throughout the range of other American *Prosopis* species. While *Acacia* spp. are found at all altitudes, other associated species appear to dominate at certain altitudes, such as *Cercidium* spp. and *Parkinsonia aculeata* at low altitudes and *Caesalpinia* spp. and *Pithecellobium* spp. at higher elevations.

Prosopis trees have important effects on other vascular plants throughout the Americas via the shelter offered and amelioration of the microclimate (Mares *et al* 1977). Distinct microhabitats are formed beneath the canopies, with decreased solar radiation and air temperature, increased moisture levels in the air and soil, and increased levels of soil nutrients. In general, annual grasses prefer open areas, while in the ameliorated conditions found below tree canopies, herbaceous plants with large mesophytic leaves are abundant. Although *Prosopis* species are not unique in providing these habitats, they may be the most important trees serving this function where they are abundant, especially along water courses (Mares *et al* 1977). Some grass species are known to prefer conditions below the crown of *Prosopis* species to the open spaces in between (East and Felker 1993). *Prosopis* species are also considered to have some negative allelopathic effects on neighbouring plants, particularly herbaceous and grass species (see 2.4.4, 3.3.2).

In coastal formations, *Prosopis* are abundant as multi-stemmed shrubs and small trees, often close to sea level. Tree forms are more common on inland flats, with tree size affected by soil depth, availability of moisture and competition from other species. There is a relationship between total biomass, basal area and plant density. Regression equations lead to self-thinning lines, but the -3/2 self-thinning line reported in the literature for many woody species was not applicable to *P. glandulosa* (Felker *et al* 1990). This was assumed to be because full site occupancy occurs without canopy closure, due to the extensive root systems that spread well beyond the crown in these species, particularly under arid conditions. Maximum biomass of *P. glandulosa* was estimated at a stand density of approximately 100 trees/ha (Felker *et al* 1990) (see 3.1.3).

Spread and succession

There are three main schools of thought pertaining to the spread of *Prosopis* in arid ecosystems and which may related also to many woody legumes. The first are natural invasions proposed by ecologists (e.g. Archer 1995) who suggest that the first trees that establish on such arid land are *Prosopis* which create 'islands of succession'. These 'islands' provide ameliorated conditions which aid the establishment of an increasing number of plants, and the ecosystem will stabilise over time. The second set of theories are by weed scientists, who state that *Prosopis* are just one of many weedy species that have a competitive advantage over native plants and require eradication or control (e.g. Jacoby and Ansley 1991, Zimmerman 1991). The third theory states that woody legumes have a competitive advantage only in ecosystems where soil nitrogen levels are very low (e.g. Geesing *et al* 2000) and management interventions should be aimed at minimising the nitrogen harvested as forage, and increasing soil fertility, which will reduce the competitive advantage of *Prosopis* over other species.

Natural invasions are those based on very gradual and almost imperceptible changes in the climate, and random and unpredictable factors affecting local vegetation. One such invasion is hypothesised to be occurring in Mexico as a result of the gentle warming following the Wisconsin glaciation which continues to this day. The retreat of temperate vegetation types is followed by an invasion of more tropical types from the south. In the case of *Prosopis* this is greatly complicated by the fact that both the advancing and the retreating species can hybridise and backcross, therefore losing the distinction between species and creating a myriad of hybrid forms (Earl 1998).

New physiological adaptations, as a result of either mutation or hybridisation, could have created a better adapted land race for a particular region (see 2.3.2). A change in climax community following a catastrophic event could have the same effect. Natural events have been involved in the spread of *Prosopis* species elsewhere in the world, but the reasons for this are complex as man may have influenced these invasions through inappropriate land uses. Where changes in land-use are seen to produce rapid changes in plant cover leading to weedy invasions, these are classified as man-induced invasions, in contrast to the purely natural invasions described above.

The spread of *Prosopis* species in its native range has been adequately discussed in relation to the spread of *P. glandulosa* and *P. velutina* in the USA (e.g. Fisher 1977, Dahl 1982), *Prosopis* spp. in Mexico (Johnston 1962) and of *P. ruscifolia* and other species in Argentina (e.g. Feldman 1972) (see 1.4.2). Invasion in the native range generally involves an increase in plant density in areas where the respective species is native, rather than invading new areas and increasing its range. Invasions have accompanied the arrival and expansion of cattle ranching and associated effects on the environment. These include preventing grassland fires, which otherwise killed young seedlings, over-stocking, reducing herbaceous cover and plant competition which had prevented seedling establishment, and increasing cattle numbers which act as effective disseminators of seed via their faeces. Soil erosion and soil degradation that follows overgrazing gives *Prosopis* seedlings a competitive advantage in the poorer, nitrogen deficient soils, and browsing and cutting result in the formation of multi-stemmed shrub forms. There have also been studies in North America showing a gradual northward expansion of *Prosopis* spp. during the Holocene interglacial (Connin *et al* 1997, Earl 1999), but at rates much lower than the recent explosion in *Prosopis* invasion following human interventions since 1800.

There has been much made of the invasion of exotic plants, including woody species, originally introduced for perceived benefits but which have since become agricultural weeds. *Prosopis* species have been widely introduced and have in many instances shown their ability to out-compete native vegetation and spread rapidly. These introductions can be divided into the subtropical invasions of *P. velutina* and *P. glandulosa* and respective hybrids, primarily in South Africa and Australia, and tropical invasions of *P. juliflora* and possible hybrids in Africa, Asia and Australasia. Following introduction there will have been fewer predatory insects attacking trees, and these have shown their ability to adapt to many different sites and climates.

Invasion by *Prosopis* is, however, mainly associated with large numbers of open-grazing cattle. Seed can be spread rapidly, either from established plantations or from single trees around houses or water-holes, and will persist for long periods in the seed bank. Invasive, exotic *Prosopis* species have been declared noxious weeds in Australia, South Africa, Sudan and Pakistan. Reasons for this spread have been put forward, including changes to, or interactions between, land use and management, competitive ecological advantages and changes in climate. There have, however, been few long term studies on vegetation succession, particularly where the *P. juliflora - P. pallida* complex has been introduced.

The interaction between climate and changes in land use appear to be the dominant factors involved in the spread of *Prosopis* species, whether native or exotic. Changes in the relationships with parasitic insects, mammals and birds, either in native ranges or where introduced, may also have assisted in the spread. It appears that many *Prosopis* species are potential weeds (Table 3, see 1.4.2) including several from section Algarobia. However, these will, under natural conditions, eventually produce wide-spaced trees within productive grasslands, if seedling recruitment is prevented by competition or fire. Under artificial conditions induced by the introduction of livestock rearing, herbaceous competition is reduced or destroyed, soil nitrogen levels decline, fire is excluded as a management option and seeds are widely dispersed. Under these conditions, seed in the expanding *Prosopis* seed bank has only to wait for favourable years to germinate and become established.

Ecological studies on the spread of *Prosopis* into savanna grassland in their native range have analysed the ecological interactions and vegetation succession (e.g. Archer 1995) and modelled future scenarios (e.g. Scanlan and Archer 1991). Invasion in the Texas savanna in the last 100-200 years involved *P. glandulosa* as the pioneer coloniser. There was no correlation between years of high rainfall and the spread of *P. glandulosa*, resulting in uneven aged stands (Brown and Archer 1989). The seed germination and seedling establishment of *P. glandulosa* in relation to soil moisture, soil type, seed depth and plant cover have been studied in detail (e.g. Scifres and Brock 1970, Brown and Archer 1990). This primary invasion is followed by the invasion of other woody perennials (e.g. *Acacia farnesiana*, *Parkinsonia aculeata*). The resulting vegetation community then facilitates the decline in *Prosopis* numbers, preventing further establishment, and is thought to lead to a stable woodland community in 400-500 years (Archer 1995).

The spread of *Prosopis* species where introduced has followed similar patterns. In Australia and South Africa, the spread of *Prosopis* species followed periods of high rainfall (Zimmerman 1991, Csurhes 1996), possibly due to improved conditions for germination and establishment or increased water dispersion of the seed. This has lead to the establishment of even aged *Prosopis* stands. As *Prosopis* species have been naturalised in most countries for less than 100 years, this limits the possibility of detailed studies on plant succession. However, a long term study in northern India found *P. juliflora* as the pioneer species in denuded or abandoned ravines (Chinnimani 1998). It proceeded to colonise rapidly, with cover increasing in year two, three, four, five and ten after initial establishment, from 1-5%, 5-15%, 10-20%, 20-50% to 35-90% respectively. It dominated sites under severe biotic and edaphic conditions. After the fifth year, *P. juliflora* gave way to other indigenous species such as *Azadiracta indica*, *Dalbergia sissoo* and *Acacia nilotica*, and in 50-60 years, *P. juliflora* was observed to form only 15-20% of the total tree composition (Sharma *et al* 1981, in Chinnimani 1998).

Invasions in riverine areas and degraded rangelands of Africa, Asia and Australia have resulted in high density populations of *Prosopis* plants. These could be in the early stages of succession as has been detailed in Texas (Archer 1995) and India (Chinnimani 1998). Soil amelioration following nitrogen fixation, leaf litter accumulation and changes in microclimates leads to evolving conditions favouring the establishment and growth of different plant species. The changes in soil fertility and ecology appears to result in a decrease in *Prosopis* numbers and an increase in mean tree age and tree spacing, which could occur over time in high density invasion. Decreases in plant density are accompanied by increases in basal area and total biomass per hectare as predicted by the self-thinning equations of Felker *et al* (1990). However, succession is also intimately related to land management (see 4.3.3). More detailed studies are required on the ecological interactions involved in the succession in plant communities involving the invasion of *Prosopis* species.

Root symbionts

Like many legume genera, *Prosopis* has evolved a symbiotic relationship with *Rhizobium* and other nitrogen fixing bacteria and also mycorrhizal associations to varying degrees. All species tested have shown an ability to fix atmospheric nitrogen and as such play an important role in desert ecosystems where nitrogen is very often limiting. Two types of nodules were found on *P. glandulosa* by Virginia *et al* (1984). The 'crotalarioïde' type is elongated and found also in association with many other woody species, while the spherical 'desmodioïde' type is less frequently observed. Most work has been conducted where *Prosopis* has been introduced, and these species are often noted forming a relationship with native *Rhizobium* belonging to fast-growing strains (e.g. Diagne 1992).

Some host specificity with rhizobia has been noted (Diagne 1992, Felker and Clark 1982), but many strains of *Rhizobium* are able to form a symbiotic relationship with several species of *Prosopis* or other legume genera (Dommergues *et al* 1999) A total of 29 strains of *Rhizobium* were isolated from *P. chilensis* in Sudan and Kenya (assumed to be *P. juliflora*) by Zhang *et al* (1991), while only eight strains were isolated from *P. juliflora* in Kenya by Miettinen (1989). These strains were very tolerant to salinity and high temperatures and drought and salt resistant strains have also been identified by Diagne (1996). Fast growing strains of *Rhizobium* and also *Bradyrhizobium* were isolated from both *P. juliflora* and *P. chilensis* by Olivares *et al* (1988), who stated there was more host specificity in regards to nodule activity than to nodulation alone.

More *Rhizobium* strains are noted in native stands in the Americas (e.g. Jenkins *et al* 1989) than in Africa, possibly due to evolutionary adaptations favouring symbiotic relationships, with 98 strains identified in association with *P. glandulosa*, of both the fast-growing and slow-growing (*Bradyrhizobium*) types (Jenkins *et al* 1987). In contrast, it may be expected that where *Prosopis* species have been introduced, fewer strains of native rhizobia may be compatible with the new exotic tree. Where introduced for over a century such as in Senegal, more strains were noted in association with *P. juliflora* (e.g. Diagne 1992) than where introductions are thought to be much more recent such as in Kenya (e.g. Miettinen 1989). In Cape Verde, of 50 provenances of *Prosopis* belonging to 10 species, only the naturalised *P. juliflora* was observed to have formed a symbiotic relationship with native rhizobia (Harris *et al* 1996a). Newly introduced species may have little or no symbiosis with native rhizobia, but this relationship appears to develop as tree species become naturalised. This may occur in as little as 10 years but is probably a continuous process, developing symbiotic relationships with more strains of rhizobia over time.

In the arid and semi-arid regions, nodules are rarely found on *Prosopis* in the upper soil horizons which are susceptible to water deficit and high temperatures. The number of root nodules associated with *P. juliflora* decreases with depth, and numbers and activity decrease with increasing aridity and salinity (Diagne 1996). Growth of rhizobia associated with *P. juliflora* was observed at all soil pH levels but was affected at pH below 3.3 or over 6.8, and growth declined at soil temperatures above 37°C and stopped at 50°C (Diagne 1992). Rhizobia associated with *P. glandulosa* were found to depths of 13 m in the soil profile, and to vary seasonally (Jenkins *et al* 1988). Irregular distribution of nodules both vertically and horizontally was also observed by Johnson and Mayeux (1990) with *P. glandulosa* but assumed to be related to soil properties. Waldon *et al* (1989) suggested that surface rhizobia and deep soil rhizobia have different physiological characteristics due to the lower nutrient level, increased acidity and salinity and constant humidity and temperature of deep soil profiles. More information on the nitrogen fixing potential of rhizobia in association with *P. juliflora* and *P. pallida* are detailed. While information on the rhizobial associations of *P. pallida* is very limited, it is thought that the rhizobia will be of the same group as those which are found with *P. juliflora* (Dommergues *et al* 1999).

Mycorrhizal fungi have been isolated from *Prosopis* roots, and their presence has positive benefits on plant survival and growth (Kaushik *et al* 1992, Dixon *et al* 1997, Dommergues *et al* 1999). Effects on plant growth are dependent on the compatibility of the strain of fungus present (Dommergues *et al* 1999). Mycorrhizal fungi are also known to tolerate conditions of high pH (Sidhu and Behl 1997). In Senegal, 64% of *P. juliflora* plants were colonised by mycorrhizal fungi (Ingleby *et al* 1997). Of the many species isolated from *Prosopis* roots in north west India, most belonged to the genera *Glomus* and *Gigaspora* (Bhatia *et al* 1998). *Glomus fasciculatum* was the most common and appeared most beneficial to growth of *P. juliflora* (Dixon *et al* 1993, Tarafdar and Rao 1998).

Faunal associations

Mammals utilise *Prosopis* along with other desert trees for shade, protection and food (for an extensive list see Mares *et al* 1977). Physical protection is offered from the sun by a wide crown, and the thorns and shrubby form can offer excellent protection from large predators. Small mammals feed on the foliage as well as the pods. Birds use the trees as perches and nesting sites, and *Prosopis* species have been identified as important for native and migratory birds (e.g. Hardy *et al* 1999). Some birds and mammals may prefer *Prosopis* species but most appear not to be restricted to them. The seeds and pods form an important part of the diet of many small desert mammals and, where *Prosopis* plants are common, it is thought that their removal would cause a significant decrease in the populations of small wild mammals (Mares *et al* 1977).

Species richness is important, measured by the number of different species inhabiting a *Prosopis* dominated area, which was found to be between 4 and 20 species of small mammal in the Americas (Mares *et al* 1977). Including a measure of their relative abundance provides a measure of species diversity. Small rodents are common, browsing the saplings particularly in young stands. Introduced *Prosopis* species have also become important habitats for many wild mammals and birds (e.g. Chavan 1986) (see 3.5.4). A main association today, however, is often with domestic mammals, which have quickly developed a strong relationship with native *Prosopis*. Reptiles and amphibians are also associated with *Prosopis* species, and will seek the shade and shelter offered by trees.

Invertebrates are important in the overall ecology of *Prosopis* trees and stands, feeding on living or dead tissue or using the tree for shelter and as a hunting and mating ground. Invertebrate associations with *Prosopis* can be discriminated by the type of association (Table 18). Seed feeding beetles, many of the family Bruchidae, have evolved alongside *Prosopis* and are very important in the ecology of American *Prosopis* species. They are the primary agents which destroy seeds and their presence can lead to a substantial reduction in the number of viable seed. Adult bruchids feed on pollen

Table 18. Invertebrates associated with* P. pallida *and* P. juliflora *(adapted from Johnson 1983, Silva 1990b, de Arruda* et al *1990, Lima and Haji 1993, Núñez-Sacarías 1994, Díaz Celis 1995, Singh 1998, Yousuf and Gaur 1998).

Effect	Order	Family	Species	Location
Seed or fruit feeding beetles	Coleoptera	Anobidae	*Lasioderma spp.*	Brazil
			L. seeicorne	Peru
		Bruchidae	*Acanthoscelides* spp.	S. America
			A. obtectus	Peru
			A. mimesae	S. America
			Algarobius spp.	S. America
			A. bottimeri	S. America
			A. prosopis	S. America
			Amblycerus spp.	S. America.
			A. epsilon	S. America
			A. piurae	Peru
			Bruchus rufimanus	Peru
			B. pisorum	Peru
			Caryedon gonagra	S. Asia
			C. serratus	Asia/Africa
			Mimosestes spp.	Peru
			M. amicus	N/S.America
			M. insularis	Americas
			M. mimosae	Brazil
			M. nubigens	Americas
			Rhipibruchus prosopis	Americas
			R. psephenopygus	Americas
			Scutobruchus spp.	Peru
			S. ceratioborus	S. America
			S. gastoi	Peru
			Stitollilus granarius	Peru
		Cucujidae	*Cathartus quadricollis*	Peru
		Tenebrionidae	*Trilobium castaneum*	Peru
	Diptera	Lonchaeidae	*Silba pseudopendula*	Peru
	Heteroptera	Pentatomidae	*Mormidea ypsilon*	Peru

continued overleaf

and nectar and many mate on flowers (Kingsolver *et al* 1977). Of the species of beetles found to feed on the pods of native American *Prosopis*, 93% were obligately restricted to *Prosopis*, showing a high degree of specialisation. Eggs are laid singly or in clusters by the female insect in cracks, or glued on the outside of the pod. Larvae hatch, burrow into the fruit and feed on the seed. After several moults the bruchids pupate within the feeding cavity and the adults emerge through the characteristic holes. Larger seeds provide more food and more space to grow, and larger seeded species and individuals tend to have a higher number of associated bruchid beetles (Kingsolver *et al* 1977).

Pollinating insects are of great importance and several detailed reviews exist (see 2.3.4). Some insects feed on the flowers, while others use them as a mating ground. Many spider species have been found on American *Prosopis*, particularly during flowering, but the spider to insect ratio was lower than that of other desert plant species (Mares *et al* 1977). Defoliating insects vary in their severity of attack but have been found to be a major factor affecting the timing of bud break in North America (Nilsen *et al* 1991). Locusts are not uncommon and twig girdlers (*Oncideres* spp.) are another damaging insect in some areas (e.g. Felker *et al* 1983b, Silva 1990b), with adult beetles girdling small branches before ovipositing. Wood boring beetles are rarely specific to *Prosopis*, attacking several taxa of woody perennials (Fiorentino and Bellomo 1995). Most are found in the sapwood, which is frequently attacked, in single tunnels or interconnected galleries. The heartwood is more resistant but many species can still be found burrowing in living stems or deadwood (Fiorentino and Bellomo 1995). Secretory glands are present on the leaves of *P. juliflora* and *P. pallida* (Burkart 1976, Ferreyra 1987) but their exact

Table 18 - continued

Effect	**Order**	**Family**	**Species**	**Location**
Seed or fruit feeding beetles (continued)	Lepidoptera	Olethreutidae	*Cryptophlebia* sp.	Peru
			Laspeyresia sp.	Peru
			L. leguminis	Peru
		Pyralidae	*Plodia* sp.	Peru
			P. interpunctella	Peru
Wood feeders	Isoptera	Termitidae	*Odontotermes obesus*	South Asia
			Microtermes mycophagus	South Asia
	Coleoptera	Cerambycidae	*Achyryson galapogoensis*	S. America
			Eburia pilosa	S. America
			Tetrapriocera longicornis	Peru
		Buprestidae	*Agrilus* spp.	South Asia
			Chrysobothris lateralis	South Asia
			C. octecola	South Asia
			Psiloptera cupreopuncata	South Asia
			P. drummondii	South Asia
			P. webbii	South Asia
			Tyndaris robuster	South Asia
			Xenorhipis sp.	S. America
		Cerambycidae	*Aorcadocerus barbatus*	Brazil
			Coccoderus novempunctatus	Brazil.
			Neoclytus jekeli	Peru
			N. rufus	Brazil.
			Neosozineus griseolus	Brazil
		Scarbaeidae	*Gymnetosoma* sp.	Peru
Nematodes			*Diphterophora* sp.	Peru
			Heliocotilenchus sp.	Peru
			Meloidogyne incognita	Asia/Africa
			M. javanica	Asia/Africa
			M. halpa	Brazil
			Rotylenchus sp.	Peru
Twig girdlers	Coleoptera	Cerambycidae	*Oncideres limpida*	Brazil
			O. rhodosticta	N. America
			O. saga	Brazil
			Oreodera quinquetuberculata	Brazil
			Trachyderes thoraxicus	S.Amer/Asia

continued opposite

purpose is unclear as associations with ants that are common in *Acacia* species are almost unknown in *Prosopis*. Termites are common in young stands of *P. juliflora* (Muthana 1985). Nematodes are known to attack the roots of *P. juliflora* (Mehrortra and Sharma 1992), *P. pallida* (Díaz Celis 1995) and other species such as *P. glandulosa* (Freckman and Virginia 1989), while occasionally infesting neighbouring crops.

Table 18 - continued

Effect	Order	Family	Species	Location
Flower feeders	Lepidoptera	Lycainidae	*Hemiargus ramon*	Brazil
Defoliators and sap-suckers	Hemiptera	Coreidae	*Homoeocerus signatus*	South Asia
		Fulgoridae	*Eurybachys tomentosa*	South Asia
		Margarodidae	*Drosicha* spp.	South Asia
	Heteroptera	Lygaeidae	*Oxycarens hyalinipennis*	South Asia
		Pentatomidae	*Halys dentatus*	South Asia
	Homoptera	Asterolecaniidae	*Asterolecanium pustulans*	Brazil
		Aleyrodidae	*Aleyrodids* spp.	S.Amer/Asia
		Diaspiaidae	*Asoidiotus* sp.	Peru
			Hemiberlesia sp.	Peru
			Ischnapis sp.	Peru
			Pseudoischnapis sp.	Peru
		Membracidae	*Oxyrachis tarandus*	South Asia
	Lepidoptera	Lasiocampidae	*Taragama siva*	South Asia
		Noctuidae	*Aspidiotus* sp.	Peru
			Heliothis sp.	Peru
			Hemiberiesia sp.	Peru
			Ischnapis longirotris	Peru
			Lecanodiaspis sp.	Peru
			Mellipotis spp.	Peru
			Spodoptera ochrea	Peru
		Pieridae	*Ascia monuste*	Brazil
	Orthoptera	Acrididae	*Anacridium rubrispinum*	South Asia
		Aeridae	*Poekilocerus pictus*	South Asia
		Proscopiidae	*Anchotatus* sp.	Peru
			Stiphra algaroba	Brazil
			S. robusta	Brazil

Chapter 3

The complex as a resource

3.1 Fuel and wood products

3.1.1 Wood composition and properties

Chemical composition

The constituents of woody biomass can be divided into cellulose, hemi-cellulose, lignin, extractives, ash and water. Levels of hemi-cellulose in *P. juliflora* have been estimated at 25-30%, cellulose 40-45%, lignin 11-28% and extractives 3-15% (Patel and Safaya 1986). Rajput and Tewari (1986) found 54% cellulose and 31% lignin, while Madan and Tandon (1991) found 70% holocellulose and cellulose combined and 20% lignin. Similar levels were found in the wood of *P. glandulosa*. Cox and Tock (1982) found 20-30% hemi-cellulose and 25% lignin, and Goldstein and Villarreal (1972) found lignin contents of 25% and 29% in the sapwood and heartwood respectively. Extractive chemicals from woody biomass include sugar resins, volatile oils, fatty acids, tannins, alcohols and phenols, with tannin content up to 9% of woody material.

Ash levels of *P. juliflora* wood were found to be low, at 0.5-0.6% by Patel and Safaya (1986), Rajput and Tewari (1986) and Madan and Tandon (1991). Goel and Behl (1992) reported a higher ash content of 1.6%, with even higher contents of 1.8-4.8% reported by Khan *et al* (1986) and 7.1% in wood and 11.8% in *P. juliflora* bark by Sharma (1968). Several studies have assessed the quantities of mineral elements in wood of *P. juliflora* (Table 19). Compared with woods of other Indian tree species, Sharma (1968) found that wood of *P. juliflora* has the lowest levels of N and low Na and P. The bark had high levels of Na, low P, and both wood and bark had low ash and silica contents. Sharma (1984) found silica content of wood and bark to be 0.8% and 2.8%, respectively. Singh *et al* (1986) found the mineral contents of *P. juliflora* trees with grass understorey (data shown in Table 19) was consistently lower than that of trees without grass. Calcium oxalate crystals are found in the parenchyma and procumbent ray cells of *P. juliflora* wood (Gomes and de Muñiz 1990).

Much work has been conducted on the chemical extractives of *P. glandulosa* wood (e.g. Parker 1982a), looking primarily at sugars as a livestock feed. Goldstein and Villarreal (1972) found that the holocellulose comprised approximately 75% glucan, 23% xylan, 1% rhamnan and galactan and under 1% arabinan and mannan. Several chemicals including 'furfural' and 'mesquitol' have been extracted and isolated from *P. glandulosa* and the potential economic benefits from production of such organic chemicals has been discussed (Bartsch *et al* 1982). Gaul and Bartsch (1979, in Bartsch *et al* 1982) surveyed the literature on organic extracts from *P. glandulosa* wood and found only a few references to tannins, waxes and flavonoids. Levels of pentosans in *P. juliflora* were found to be 19-21% by Abohassan *et al* (1988), and 11-12% by Rajput and Tewari (1986) and Madan and Tandon (1991).

Extractives are quantified by the solubility of woody biomass in water, benzene-ethanol and 1% sodium hydroxide. Cold and hot water solubility of *P. juliflora* pulp was 5% and 12% respectively (Vimal and Tyagi 1986). Sodium hydroxide solubility was 23% in *P. juliflora* (Vimal and Tyagi 1986) and 21 and 29% in sapwood and heartwood of *P. glandulosa* (Goldstein and Villarreal 1972). The benzene-ethanol solubility of *P. juliflora* wood was approximately 9% (Vimal and Tyagi 1986, Madan and Tandon 1991). When sapwood and heartwood were assessed separately, benzene-ethanol solubility of *P. juliflora* was 6% and 9% respectively (Abohassan *et al* 1988) and of *P. glandulosa* was 4% and 12% respectively (Goldstein and Villarreal 1972). Further analyses of extractives of *P. glandulosa* can be found in Parker (1982a).

Table 19. Mineral element composition (%) of wood from different parts of* P. juliflora *trees.

Plant part	N	P	K	Ca	Mg	S	Na	Source
Branch	1.00	0.10	1.00	0.48	0.12	0.15	0.14	Singh *et al* (1988)
Stem	0.90	0.07	0.70	0.40	0.09	0.12	0.08	Singh *et al* (1988)
Root	1.40	0.08	1.10	0.69	0.18	0.24	0.21	Singh *et al* (1988)
Bark	0.08	0.13	0.07	3.00	1.85	-	5.13	Sharma (1968)
Wood	0.39	0.02	0.70	1.85	0.38	-	4.17	Sharma (1968)
Small branches	1.60	0.10	1.11	0.60	0.06	-	-	Maghembe *et al* (1983)
Large branches	0.67	0.05	0.66	0.81	0.03	-	-	Maghembe *et al* (1983)
Stem	0.40	0.03	0.22	0.55	0.02	-	-	Maghembe *et al* (1983)

Physical and mechanical properties

The following is a summary of *P. juliflora* wood structure given by Gomes and de Muñiz (1990) (for a full description, see 2.2.2). Fibrous tissues are abundant in regular, tangential bands, forming 48% of the wood volume. Fibres are extremely short (approximately 1 mm long) and narrow with very thick walls. Rays are homogenous and constitute 18% of the wood volume. Axial parenchyma are not abundant, represent 16% of the wood volume, are invisible to the naked eye and contain frequent calcium oxalate crystals. Vessels are diffuse-porous and make up 18% of the wood volume. Vessels are visible with a X10 lens and vessel elements are very short, approximately 0.2 mm long. Heartwood vessels are often filled by resin-like organic inclusions. Vessel-parenchyma pits and ray-parenchyma pits are alternate and similar to the intervascular pits.

P. juliflora sapwood is sharply demarcated from the heartwood. Heartwood constitutes 42-47% of the trunks of young *P. juliflora* trees with a mean diameter of 11 cm, with significantly more heartwood under lower levels of available soil moisture (Abohassan *et al* 1988). As stem diameter increases, the percentage sapwood decreases. The sapwood is yellow or light yellow and appears as a narrow band below the bark. In sharp contrast, the heartwood is red-brown, sometimes purplish and darkend considerably on ageing or exposure to sunlight. The heartwood has a deep colour said to be pleasant to the eye and comparable to many commercial tropical hardwoods such as the mahoganies (*Swietenia* spp. and *Khaya* spp.). While the inner bark has a slightly bitter taste (Little and Wadsworth 1964), the wood has no taste or smell. The grain is straight or slightly interlocked and moderately coarse textured (Kazmi and Singh 1992). Poor growth form and persistent damage to trees from man and animals lead to many defects in the timber, which may also be due to natural infestations from fungi or insects. Such defects often take the form of holes or cracks in the wood.

The moisture content of *P. juliflora* wood in India is 42-46% when green (Sekhar and Rawat 1960, Sanyal and Saxena 1980, Rajput and Tewari 1986, Pandey *et al* 1990, Shukla *et al* 1990) and 11-12% when dry (Pandey *et al* 1990, Shukla *et al* 1990). However, moisture contents from Brazil and Sudan are lower in the range of 20-30%. Khan *et al* (1986) found a wide range in specific gravity between 0.6 and 1.1, while other studies confirmed the specific gravity of *P. juliflora* wood to be in the range 0.74-0.86 (Table 20). Abohassan *et al* (1988) found a significant reduction in specific gravity of the sapwood with reduced irrigation but the lower specific gravity found is probably due to the young age of the stems tested and the higher percentage of sapwood. Wood densities also vary between studies, with densities of green wood in the range 1050-1250 kg/m^3 and dry wood densities in the range 710-910 kg/m^3. The variations noted by Lima (1994) were from sections taken from the trunk at different heights, with wood density decreasing with height, possibly due to increasing percentages of sapwood in smaller diameter cross sections.

The wood of *P. juliflora* and *P. pallida* has generally been described as heavy or very heavy, strong or very strong, extremely tough and extremely hard (e.g. Shukla *et al* 1990,

Table 20. Specific gravity and density of the* Prosopis juliflora *complex

Spp.	Location	Moisture content (%)	Specific gravity	Density green (kg/m^3)	dry (kg/m^3)	Source
PJ	Brazil	29.8	-	-	910	Lima 1994
PP	Brazil	31.5	-	-	890	Lima 1994
PJ	Brazil	31.1-40.8	-	745-934	-	Riegelhaupt *et al* 1990
PJ	Brazil	33.2	-	1126	-	IPA 1989
PJ	Sudan	38.7	0.77	1151	708	El Fadl 1997
PJ	S. Arabia	-	0.55-0.66	-	-	Abohassan *et al* 1988
PJ	Pakistan	-	0.57-1.07	-	-	Khan *et al* 1986
PJ	India	42.0	0.74-0.76	1052	848	Shukla *et al* 1990
PJ	India	43.2-46.3	0.78-0.85	1123-1251	-	Sekhar and Rawat 1960
PC	India	44.8	0.82	-	-	Rajput and Tewari 1986
PJ	India	-	0.83-0.86	-	-	Kazmi and Singh 1992
PJ	India	46.3	0.85	1249	-	Sanyal and Saxena 1980
PJ	India	45.0	-	-	730	Pandey *et al* 1990
PJ	India	-	-	-	800-890	Goel and Behl 1992

PJ - P. juliflora *PP -* P. pallida *PC -* P. chilensis, *thought to be* P. juliflora

Díaz Celis 1995). There is limited data on the shrinkage of *P. juliflora* and *P. pallida* wood. Other *Prosopis* species are known to have very low values, lower than most commercial hardwoods. For example, *P. glandulosa* from the USA has radial, tangential and volumetric shrinkage values of 2.7, 4.8 and 8.0, respectively, considerably lower than oak (*Quercus* spp.), walnut (*Juglans* spp.) and other quality timbers. Barrios *et al* (undated) gave shrinkage values of 2.0, 4.0 and 7.0 for *P. chilensis* from Peru. Sekhar and Rawat (1960) gave similar values for radial and tangential shrinkage for *P. juliflora* from Pune, India of 2.3 and 4.0, while from Jodhpur, India, these values were only 1.7 and 2.6. This marked reduction in shrinkage corresponds with the lower moisture availability at the more arid site at Jodhpur.

Information on other physical and mechanical properties of the timber is sparse, but two detailed sources covering a broad range of characters of the timber from *P. juliflora* in India are shown in (Table 21). Data given in Sanyal and Saxena (1980) appears to be that of the specimens from Pune of Sekhar and Rawat (1960), while the data of Rajput and Tewari (1986) is the mean of both samples presented by Sekhar and Rawat (1960). For comparison, data for teak (*Tectona grandis*) are summarised in (Tables 22 and 23). All data for physical and mechanical properties of *P. juliflora* wood fall well within acceptable limits. There are, however, clear differences in timber qualities and properties between trees grown in higher and lower rainfall areas (Sekhar and Rawat 1960), and between green and dry timber (Shukla *et al* 1990) (Table 21). In India, Sekhar and Rawat (1960) found that the wood from the drier site at Jodhpur had a lower performance in bending tests, with a brittleness value (work absorbed) of almost half that of wood from the higher rainfall site. Values for compression were equivalent, while the denser wood from the dry zone was expectedly harder. Shear was equivalent and tension could not be compared due to lack of data. Shukla *et al* (1990) found contrasting properties with green or dry wood, as might be expected, with marked differences in moisture content (45% to 11%). Differences in bending properties were not consistent, while resistance to compression was generally higher in the dry wood. Hardness was equivalent and only very slightly lower in the dry wood. The dry wood had a higher tension parallel to the grain but lower tension perpendicular to the grain and shear parallel to the grain when compared with the green timber.

3.1.2 Wood as a resource

Fuel

Wood of *P. juliflora* and *P. pallida* is a very important source of domestic fuel for millions of people in many arid and semi-arid zones of the world. It is the preferred firewood for many households, but the presence of thorns is a disadvantage. The wood does nor spit, spark or smoke excessively, and the smoke is never unpleasant. It must be noted, however, that its popularity is also linked to its ubiquity, i.e. that where trees are present they are generally present in large numbers and are often found on common land and are, thus, freely available to all sections of society. Accurate measurement of firewood production is difficult, as much is auto-consumed, but information on numbers of people who depend on different sources of energy is more readily available. In Haiti, Lea (1996) estimated that *P. juliflora* firewood provides 70% of rural energy requirements. In arid and semi-arid regions of India, *P. juliflora* accounts for up to 70% (Patel 1986) or 80-90% (Saxena and Ventashwarlu 1991) of all the domestic fuel requirements for rural populations. Similarly high levels of use are recorded in Peru (Díaz Celis 1995).

P. juliflora wood burns evenly and hot. Goel and Behl (1992) stated that the good heat of combustion of *P. juliflora* wood is due to its high carbon content and high levels of lignin. The wood has a high calorific value, estimated at 4216 kcal/kg by Khan *et al* (1986), although 4800 kcal/kg is often quoted (e.g. NAS 1980). The positive qualities as firewood are present even in juvenile wood, and *P. juliflora* wood burns well even when green. This is a benefit as firewood does not require storage and drying, avoiding losses from theft and decay. Moisture and ash content of one year old *P. juliflora* were estimated at 39% and 2.2% respectively (Goel 1987). Khan *et al* (1986) found calorific values to be high even after one year's growth and to gradually increase until 13 years of age. The following formula for assessing value as a fuelwood was published by Goel and Behl (1992):

$$\begin{array}{c}\text{Fuelwood}\\ \text{Value Index}\\ \text{(FVI)}\end{array} = \frac{\text{calorific value (J/kg) x density (g/cm}^3\text{)}}{\text{ash content (g/g) x moisture content (g/g)}}$$

Charcoal is consumed mostly in urban areas and is often produced considerable distances from the point of consumption. Firewood is bulky and expensive to transport, whereas conversion to charcoal reduces the weight and increases the value of the product in energy and economic terms. In many remote regions, charcoal manufacturing forms an integral part of daily activities and the revenue earned often plays a vital role in rural livelihoods. In many areas, the sale of firewood and particularly charcoal is the main, or only, source of income for much of the year. Lea (1996) estimated that in Haiti, charcoal contributed only 6% towards the nation's energy requirements but the resulting business employed 150000 people in 1991 and generated over US$50 million. In India, forestry departments produce and market charcoal, predominantly of *P. juliflora*, through special development corporations. From 1986-93, Gujarat state estimated that they had produced up to 3 million tonnes of charcoal per year, creating an average annual 55500 man-days of employment (Kanzaria and Varshney 1998). In a single district in northern Peru, charcoal production was estimated at 3000-16000 t/yr (Díaz Celis 1995).

Approximately 3-6 kg of wood of *P. juliflora* or *P. pallida* is required to produce 1 kg of charcoal depending on the method used. Charcoal is manufactured in traditional or improved earth kilns, or less commonly in metal kilns. Before

Table 21. Physical and mechanical properties of* P. juliflora *wood in India.

	Sekhar and Rawat 1960 *		Shukla *et al* 1990	
	Green Pune	Green Jodhpur	Green -	Dry -
Static bending				
Fibre stress at elastic limit (kg/cm^2)	825	397	485	626
Modulus of rupture (kg/cm^2)	1303	1044	883	1061
Modulus of elasticity (1000 kg/cm^2)	116.3	99.9	77.7	90.5
Work to elastic limit (kg-cm/cm^2)	0.35	0.09	0.22	0.32
Work to maximum load (kg-cm/cm^3)	-	-	1.83	1.22
Total work (kg-cm/cm^3)		-	2.64	2.73
Impact bending				
Fibre stress at elastic limit (kg/cm^2)	-	-	1126	1080
Maximum height of drop (cm)	-	170	158	94
Modulus of elasticity (1000 kg/cm^2)	-	-	116.9	156.2
Work to elastic limit (kg-cm/cm^2)	-	-	0.63	0.43
Brittleness (work absorbed) (kg-cm)	214	110	180	138
Compression parallel to grain				
Compressive strength at elastic limit (kg/cm^2)	-	204	237	301
Maximum crushing stress (kg/cm^2)	578	480	441	649
Modulus of elasticity (1000 kg/cm^2)	97.6	89.1	99.2	
Compression perpendicular to grain				
Compressive strength at elastic limit (kg/cm^2)	161	129	136	182
Hardness**				
Radial (kg)	897	997	882	869
Tangential (kg)	953	1042	906	857
End (kg)	844	990	842	815
Shear parallel to grain				
Radial (kg/cm^2)	186.5	180.1	114.6	105.0
Tangential (kg/cm^2)	216.0	215.3	151.7	113.2
Tension parallel to grain				
Tensile stress at elastic limit (kg/cm^2)	-	-	589	751
Maximum tensile stress (kg/cm^2)	-	-	951	1126
Modulus of elasticity (1000 kg/cm^2)	-	-	97.1	106.4
Tension perpendicular to grain				
Radial (kg/cm^2)	-	-	67.8	41.0
Tangential (kg/cm^2)	-	126.1	86.1	75.8

* *converted to metric from imperial measurements*
***(load required to embed a 1.128 cm diameter steel ball to half its diameter)*

processing, wood is first sorted into similar diameters and lengths. Earth kilns can be made up on flat ground, but charcoal manufacturers use large pits, on sloping ground. Wood is stacked and moistened before firing. The stack is covered with soil and burns very slowly for several days depending on the size and condition of the stack and site. The moisture content of the wood is reduced from approximately 45% to close to zero. After 2-8 days, the stack is opened and the coals are removed, allowed to cool, graded and bagged up for use or for sale.

Large metal cylinders specially made or adapted as charcoal making kilns, are becoming increasingly popular. These can be vertical, approximately 1 m high and up to 2 m in diameter, or arranged horizontally when they are often 2 m long and 1 m in diameter. They can be externally heated and have adjustable ventilation. Wood is stacked and fired, and after only 8-48 hours, the kiln is allowed to cool, and the charcoal removed before cleaning and reloading. The advantage of a such kilns is the increased rates of production which can be economically viable if wood supply and charcoal demand are both high. The kilns may also be mobile, offering additional advantages. Disadvantages are the initial capital cost and that relatively straight logs are required to minimise air spaces and maintain conversion efficiency. Such kilns have produced charcoal of *P. juliflora* with a conversion efficiency of 32% in 2 days (Maua and Otsamo 1993).

The wood of some *Prosopis* species, particularly *P. glandulosa* in the USA, is known to impart a pleasant taste to food cooked over it, and it is exploited as a barbecue wood and for smoking fish and meat. The pleasant taste is a result of polycyclic aromatic hydrocarbons found in the smoke (Maga 1986). However, the wood of *P. juliflora* and *P. pallida* is not known to impart an especially pleasant taste or smell and has not been marketed as such. It is sold widely as firewood and as charcoal but purely for practical uses.

As domestic firewood, small branches with diameters of 1-10 cm are preferred. Although the presence of thorns can hinder firewood collection, the wood is hard but not difficult to cut with a machete or small axe (Pasiecznik *et al* 1999). Firewood is usually cut in lengths approximately 1 m long, but in India, short wood (0.5 m) and long wood (over 1 m) are sold separated (Hugar *et al* 1989). Harvesting by hand is a labour-intensive activity. It is preferred in India as an employment generating activity but in the USA, where labour is expensive, mechanical systems have been developed. Tractor drawn harvesters have proved successful (e.g. Ulich 1982). These are generally rotary flail mowers that can harvest stems up to 5-10 cm in diameter, producing chips that can be loaded straight into a waiting container (e.g. Felker *et al* 1999). The economics of mechanical harvesting have, however, proved only marginally viable.

Larger trunks (over 10 cm diameter and over 2 m long) take much more time to cut to length, are more difficult to handle and may be too large for some hearths and stoves. Larger trunks and stumps of *P. juliflora* and *P. pallida* are more often used as industrial fuels for feeding ovens and kilns for smelting ores, treating and purifying minerals, firing pottery, baking bread and distilling oils and alcohol. These uses required vast quantities of fuel and were a primary reason for over exploitation and depletion of *Prosopis* woodlands in the native range. During the colonial period, a Peruvian governor passed legislation banning the use of *P. pallida* wood for industrial purposes, with a fine for the use of firewood for bread ovens, gypsum kilns and for firing clay tiles (Díaz Celis 1995). Wood is still used for firing ovens where availability is not a constraint, notably in Peru (Díaz Celis 1995), Brazil (Silva 1990b) and India (Goel and Behl 1992, Kanzaria and Varshney 1998).

Boilers can be fired directly, for example for the drying of agricultural products or grain processing. Gasification of *P. juliflora* for powering water pumps for irrigation in India has been shown to be profitable (Patel 1986). Much interest in bio-energy has traditionally been placed in the production of transportation fuels, ethanol and methanol, which could be used to power pumps and turbines as well as tractors and vehicles. Liquification, extraction and subsequent fermentation produces ethanol but is not economically viable (Parker 1982b). Destructive distillation of *P. juliflora* wood has produced 1.2% methanol (Vimal and Tyagi 1986), while the production of alcohols as a by-product from other processing techniques has also been investigated. Parker (1982b) suggested severely refining the very crude oil produced by pyrolysis or conversion by synthesis of the gas produced by gasification.

Many studies have suggested the use of *P. juliflora* and *P. pallida* as a fuel for the generation of electricity by direct burning or via gasification (Parker 1982b, Patel 1986, Sutaria *et al* 1986). The biomass is low in sulphur and therefore not as polluting as other sources such as coal (Parker 1982b). While these studies indicate efficiency and potential profitability, only a few small-scale plants are in operation. Felker (1984) calculated that with *P. glandulosa* in the USA, a 500 MW generating facility could be fed with biomass from a farm with a 22 km radius, with a production level of 16 t/ha/yr (dry matter). Steam boilers have also been employed to convert wood energy directly into mechanical energy for the pumping of water (Rao and Vasanthi 1986).

In India, many studies have shown the profitability of electricity generation from short rotation biomass plantations (e.g. Bose and Bandoyopadhyay 1986). These involve utilisation of harvested wood in several ways, either by direct burning (Patel 1986, Sutaria *et al* 1986), carbonisation (Hingorani 1986, Raju 1986), gasification (Rao and Vasanthi 1986, Vyarawalla and Jain 1986) or pulverisation (Felker 1984). Gasification has been promoted as the most efficient method of converting *P.*

juliflora wood energy to electrical energy (e.g. Patel 1986). Wood is first chipped to increase the surface area to weight ratio, then preheated in a specially designed gasifier (Vyarawalla and Jain 1986). The wood chips are dried and pyrolised into charcoal before reaching the oxidation zone where nearly total consumption of oxygen takes place. The water vapour and carbon dioxide produced are then reduced to carbon monoxide, hydrogen and methane. Approximately 1 kg of *P. juliflora* biomass generates 2.5 m^3 of gas, which can supply 3000 Kcal of thermal energy (Rao and Vasanthi 1986). Several small plants are in operation in northern India, producing 1-5 MW of electricity solely from *P. juliflora* biomass (Sutaria *et al* 1986).

Posts and sawn timber

The wood of *P. pallida* and *P. juliflora* has been used for almost every purpose for which wood as a raw material can be used. The widespread use of wood from these species is attributable to its excellent durability, strength and hardness, and also because the trees are often the main source of locally available wood. Wood quality and ubiquity allow the production of higher value items. Posts and poles are more valuable than fuelwood, but the maximum value that can be obtained for *P. juliflora* and *P. pallida* wood is by conversion into boards and cants. Constraints to the use of *P. juliflora* and *P. pallida* as a roundwood include its general crookedness, short lengths and thorniness. Historically it was often used when no other trunks of better form were available, and its use declined as soon as more suitable material became available, either from imports or local plantations.

The durability of heartwood of *P. juliflora* and *P. pallida* and an ability to coppice and produce large numbers of long, straight shoots has meant that they are a preferred source of fence posts, even though the sapwood is easily attacked by boring insects and fungi. Fence posts have been reported to last for up to 30 years if treated by drying or soaking (Esbenshade 1980), although 5-15 years is more common. Larger stems are used as corner or gate posts, thinner ones in the making of corrals. Longer and larger stems were traditionally used for posts, beams and frames in house construction but this has declined to use only in rustic, rural dwellings (Díaz Celis 1995). Roundwood can be converted to wood products without the need for a sawmill. Small items such as tool handles or craft items can be manufactured by turning, carving or the use of other hand tools. Shukla *et al* (1990) found that *P. juliflora* was a class I timber for tool handles, with a better retention of shape and tool handle figure than teak. It is also useful for agricultural implements, blocks and crushers and other uses where strength, hardness, toughness and steadiness are required (Rajput and Tewari 1986).

Based on its physical and mechanical properties, *P. juliflora* is suitable for construction purposes as a group C timber (Shukla *et al* 1990) and a group B timber (Lima *et al* 1996). Values of strength and stiffness as a beam were consistently higher than those of teak (Table 22), showing its suitability for this purpose (Shukla *et al* 1990, Rajput and Tewari 1986). The safe working stresses for *P. juliflora* timber under different working conditions are shown in Table 23. Being very hard, flooring is a common use for *Prosopis* timber, however its use in cabinetry and for furniture manufacture is increasing because of its excellent structural stability and pleasant appearance.

Larger diameter stems and trunks can be processed into sawn wood using chainsaws or small sawmills, producing cants and/or boards. Primitive sawmills and hand sawing are used for cutting *P. juliflora* logs in Haiti (Roig 1990), but sawing in this manner is time consuming and results in boards that are of variable quality. Relatively straight logs are preferred as they give good recovery of sawn wood from the sawing process, but the sawing of short and crooked logs into marketable timber is becoming increasingly important. *P. juliflora* and *P. pallida* logs are almost always slightly crooked. Surveys of kitchen cabinet manufacturers in the USA found that 90% of the wood pieces used are less than 10 cm wide and less than 1.6 m long. Thus, even *Prosopis* logs 1 m long by 20 cm diameter can yield marketable timber in the form of hardwood blanks. These should be squared on all sides and could be planed. When sawing with a single blade, the log should be positioned so that the first cut approaches the concave face. One or two cuts will produce the first straight edge. The log is then turned so the straight face faces down. The log can be cut into boards with one straight edge, or squared into a cant by successive turnings. Boards and cants with no straight edges can also be produced by some sawing processes, for squaring up on conventional table saws.

Most conventional sawmills used to saw long and large diameter logs are unable to process the short and crooked logs of *P. juliflora* and *P. pallida*, and other processes are required. The simplest mechanical processing of logs is with a chainsaw, either hand held or, increasingly, with some form of chainsaw jig, specially designed chainsaw table or ‘micro sawmill’. A skilled chainsaw operator can cut a *Prosopis* log into boards or cants that are relatively straight and suitable for further processing. Using only a hand held chainsaw, the thinnest boards that can practically be cut are approximately 5 cm thick with a length of 1-2 m. Such boards, however, require considerable planing before they can be processed further.

A simple jig attached onto the chainsaw blade creates what is called an ‘Alaskan’ saw and allows for the accurate cutting of boards as thin as 1 cm once a preliminary straight edge has been effected. Several models of chainsaw sawmills are now commercially available, specifically for converting small logs into boards. These are small tables or frames on which a chainsaw is attached to a sliding jig. These can be dismantled and transported by a small work team or pick-up truck. Logs have to be lifted or levered onto a rack or platform. Depth of cut can be varied as desired, and the boards squared on conventional table saws. In comparison with the more standard circular saw and bandsaw type sawmills, the advantages to the use of chainsaws either alone, with attachments or as a chainsaw 'micro sawmill' are the relatively low initial capital cost and high mobility. Initial processing can be carried out in the field facilitating manual extraction or loading. Non-recoverable wood is left on site and can be used as firewood. Disadvantages are the large kerf taken by the chainsaw blade, significantly reducing timber recovery and the longer time taken to process logs. It is recommended that chainsaw processing is used for initial processing into cants or boards where capital for investment is limited, or on inaccessible sites or where only a small number of logs are available. Where there is limited experience of the potential and processing of *P. juliflora - P. pallida* wood for timber, a simple low cost chainsaw based system may be introduced to develop an understanding of this under-utilised resource.

Sawmills with large, single circular saw blades are the traditional mill used for processing timber, where logs are fixed onto an adjustable platform or fixings ('dogs'), which are moved past the blade effecting the cut. In many mills of this type, the tables and feeding system have been designed for much larger logs and cannot feasibly be converted, but several old sawmills of this type were built to cut smaller logs, are still in operation and are used to cut *Prosopis* logs (East *et al* 1992). For smaller and more crooked logs, sawmills with two circular saw blades at a set distance apart allow for the cutting of square cants in two passes. Some have technical differences such as a V-notch that automatically centres the log, a feeder system with chain pulled dogs or adjustable blades to vary cant thickness, and are called 'scragg mills', 'bolter saws' or 'double slabbers'. The advantages of these sawmills is the much increased throughput and their low cost relative to larger, conventional mills. Some are powered by, and carried behind, conventional farm tractors, making them highly mobile.

There are many designs of bandsaw on the market that are suitable for processing small and crooked logs. The standard bandsaw has a single blade through an open table. Many work with manual feeding without guides. This results in boards and cants of variable quality, depending on the skill of the operator. Fitting of guides improves cutting consistency, and larger bandsaws made specifically for cutting

Table 22. Suitability indices of* P. juliflora *in India compared with teak (*Tectona grandis*) (teak=100).

Weight	Strength as a beam	Stiffness as a beam	Suitability as a post	Shock resisting ability	Shear	Hardness	Source
125	103	75	88	184	128	166	Shukla *et al* 1990
136	137	97	100	229	130	175	Rajput and Tewari 1986

Table 23. Safe working stresses for standard grade of* P. juliflora *(adapted from Shukla* et al *1990).

Properties	Safe working stress (kg/cm^2)	Suitability index (teak=100)
Modulus of elasticity (for all grades)	77700	71
Bending and tension along grain. Extreme fibre stress		
Inside location	177	105
Outside location	147	105
Wet location	118	105
Shear		
Horizontal (all locations)	14.6	140
Along grain (all locations)	20.9	140
Compression parallel to grain. Maximum compressive stress		
Inside location	110	106
Outside location	98	107
Wet location	80	107
Compression perpendicular to grain. Compressive stress		
Inside location	78	159
Outside location	60	158
Wet location	49	158

logs have automated feeding systems. Many portable bandsaws are available that are either complete units towed as trailers, or frames with bandsaw units that can be dismantled and transported in a pick-up truck. Both of these types of portable bandsaws are capable of processing logs that are much larger than those normally found with *P. juliflora* and *P. pallida*. However, micro-bandsaws are also now available that are fitted onto portable saw frames and tables also suitable for use with a chainsaw. Towed trailer bandsaws are generally more expensive but have improved efficiency and require less labour to operate. Several have multiple blades that reduce the number of passes required and markedly increase throughput of timber. Larger models require the raising of logs onto a saw table while with some smaller models, the saw blade moves over the stationary log. Assembled frame bandsaws, all with a mobile band saw on a fixed frame, are versatile and generally much cheaper.

Modified conventional sawmills and specially designed sawmills, of both the circular saw and band saw types, are used successfully to process large quantities of *Prosopis* logs around the world. Bandsaw blades require frequent replacement every 1-2 hours which increases maintenance costs, but having several blades and re-sharpening facilities available much reduces ‘down time’. Circular saw blades require less sharpening and can be sharpened without removing the blade from the shaft. The most suitable timber processing system for a given situation depends on stand accessibility, total timber volume and mean trunk size and shape of *P. juliflora* and *P. pallida* trees, availability of capital, labour and equipment, and market factors. All the types of sawmill have shown their viability in certain situations, but variations from site to site require a specific analysis of each. While transporting logs to a central sawmill may be more economically viable than portable sawmills where timber is plentiful, the costs of haulage from disparate stands in arid and semi-arid zones may increase profitability of portable sawmills. The added social benefits of producing sawn timber in rural areas and thus stimulating the manufacture of other timber products should also to be taken into consideration.

P. juliflora and *P. pallida* wood has been used for similar purposes as other *Prosopis* species, although, where they have been introduced, the timber is seldom used because of small log size and limited knowledge of its value and processing. The timber of *P. juliflora* and *P. pallida* has been used for special railway sleepers, in bridges and crossings, boat building, dunnage pallets, furniture, household items, parquet flooring, tool handles and for other purposes where the strength and hardness of the timber is required. Furniture and parquet flooring have become the largest volume products in the Americas. For other purposes, the additional weight of the timber can be undesirable even considering its strength. In north-west Argentina, *Prosopis* wood is the most common timber for medium quality chairs and tables.

The timber requires careful seasoning, however, as it is liable to develop some surface cracking and end splitting (Rajput and Tewari 1986). Boards and cants can be stacked and air-dried in 3-12 months depending on board thickness and spacing, stack covering and location, and climatic conditions. Alternatively, kiln drying is possible. In the USA, a 15 day schedule was found to yield *P. glandulosa* timber with negligible degrade (Larson and Sodjoudee 1982). Kiln drying schedules have also been developed for *P. juliflora* in India. Pandey *et al* (1990) found all deformations of *P. juliflora*, when kiln dried from 45% to 11% moisture content, to be well within accepted limits. *P. juliflora* wood is said by Schiffino (1945) to split but not to warp. The seasoning behaviour of *P. juliflora* is described as highly refractory (Pandey *et al* 1990). Although kiln drying requires capital investment and labour, it greatly increases turnover while also eliminating losses from wood boring beetles that might otherwise necessitate chemical treatment. Portable kilns are commercially available, as are air conditioning units that fit into old shipping containers, and a solar drier that has proved effective and cost efficient in several tropical countries.

Dried boards and cants can be processed into finished products using standard resaws and carpentry tools. Planing and edging is required, but these can also be carried out prior to seasoning as it is often said that the wood of *P. juliflora* and *P. pallida* works better when green. The wood of *P. juliflora* was found to have strong screw and nail holding resistance, considerably stronger than that of teak (*Tectona grandis*), particularly when dry (Table 24). The timber produced is not difficult to work. It finishes smoothly and takes polish, wax and oil treatments well. *P. juliflora* and *P. pallida* wood tends to have more physical defects than many other

Table 24. Nail and screw withdrawal resistance of* P. juliflora *in India. Figures in parentheses compare withdrawal resistance with teak (*Tectona grandis*) (teak=100) (adapted from Shukla* et al *1990).

	Nail withdrawal resistance		Screw withdrawal resistance	
	Side (kg)	End (kg)	Side (kg)	End (kg)
Nail/screw driven in green condition and pulled out immediately	242 (148)	192 (156)	345 (98)	260 (116)
Nail/screw driven in dry condition and pulled out immediately	256 (233)	163 (173)	350 (124)	269 (137)

commercially available hardwoods, but these can be attractively filled with common resins.

Blunting of cutting saws has been expressed as a constraint, thought to be due more to hardened, crystalline resin pockets within the wood than to the nature of the wood itself. Also, in desert areas, much sand becomes embedded in the bark (Sharma 1968) although the wood itself has a low silica content (0.75%). Deformation on drying has been reported, particularly radial cracking, surface cracking and warping, though not consistently. There are, however, clear and often large differences between the wood quality from different regions and between individual trees, which affect all aspects of development of the timber as a resource.

Chipped wood products

Processed wood includes all products from mechanical and/or chemical processing of wood other than sawing or carving. Primary processing involves chipping or pulverising, before chemical or direct heat treatment. Chipped wood has a variety of uses. Particle board, which compared well with and was denser than that from teak wood (Kanzaria and Varshney 1998), has been prepared from wood chips of *P. juliflora* in India. However, larger chips tended to be produced from *P. juliflora* wood, leading to a coarser finish to the board and *P. juliflora* was not considered ideal as the raw material for such products (Rajput and Tewari 1986). *Prosopis* wood chips are used in the USA and Australia as a mulch in parks and gardens. Wood chips can be processed to prepare fibreboard (Vimal and Tyagi 1986), which has been produced to an acceptable quality from *P. juliflora*. Although there are references to the use of fibres from other *Prosopis* species to manufacture ropes, fishing nets and baskets, there are few references to the use of fibres from *P. juliflora* and *P. pallida*. However, Vimal and Tyagi (1986) reported the use of fibres in India for ropes, string and baskets.

The wood of *P. juliflora* is soluble to varying degrees in water, sodium hydroxide, alcohol and benzene (see 3.1.1), which means that it can be successfully pulped for the production of writing and printing papers, textile fibres, tyre cord or cellophane (Madan and Tandon 1991). Paper has been produced to an adequate quality for commercial use (e.g. Guha *et al* 1970), with pulp of satisfactory yield and required strength produced by the sulphate process (Rajput and Tewari 1986). Full details of the stock preparation and strength properties in a pilot plant process are explained in Rajput and Tewari (1986) and full analysis of bleaching and resulting pulp composition for *P. juliflora* is detailed in Madan and Tandon (1991). Vimal and Tyagi (1986) estimated that oven-dry wood yields 33% bleached sulphate pulp, similar to the yield of 34% calculated by Madan and Tandon (1991). Activated charcoal has a variety of uses as a filter and purifier, and can be made from the wood of *P. pallida* (Azañedo 1988, in Díaz Celis 1995). It is used mainly in the food and pharmaceutical industries.

The potential for processing the wood of weedy species such as *P. glandulosa* into animal feeds has been investigated (see Parker 1982a). All methods involved chipping the wood and sometimes grinding it to powder. Bryant *et al* (1982) found ozone conversion the most efficient, while Richardson (1982) found chemical conversion effective in transforming indigestible cellulose into lower sugars. These methods gave satisfactory yields of digestible feed chemicals, mainly sugars, but the high cost of processing made the system uneconomic. Converting the wood into methanol and ethanol also proved to be uneconomic. Potentially economic extractive chemicals have been produced from *P. glandulosa* wood (Bartsch *et al* 1982). Of most interest in agriculture is the possible production of ammonia from synthesised gas of *Prosopis* (Beck and Wang 1980, in Parker 1982b). While wood has been successfully processed into a variety of useful and economically important chemicals, the processes have always proved too expensive and have not yet been accepted by the commercial sector.

3.1.3 Wood production

Establishment and juvenile growth

The production of woody biomass begins while *P. juliflora* and *P. pallida* are only seedlings, although at least one year's growth is required before the woody biomass becomes suitable as a resource. While nursery growth may not directly relate to wood production, it indicates rate of establishment, particularly when comparing different species and provenances. Seedling survival is generally very high during nursery establishment, with negligible losses in a 3-4 month nursery period (e.g. Harris *et al* 1996a, Harsh *et al* 1998). However, seedling survival as low as 50% has been reported (Rehman *et al* 1988). Poor nursery survival has been attributed to irrigation with saline water (Hussain *et al* 1994, Somashekhar 1998, Ahmad *et al* 1994), saline or alkaline potting soils (e.g. Singh *et al* 1988a, Singh 1996) or inhibitory levels of other soil nutrients (e.g. Bradbury and Ahmad 1990, Imo and Timmer 1997).

Plant growth in the nursery has been measured frequently to assess the effects of soil type, nutrient status, watering regimes, salinity or alkalinity in a semi-controlled environment (e.g. Aronson *et al* 1992, Imo and Timmer 1992, Pasiecznik 1998). Such data has also been used to compare the performance or physiological response of different species and provenances. Biomass production and partitioning experiments have also been conducted in the nursery. All these experiments have yielded an enormous quantity of data on seedling survival, height, stem base diameter, leaf areas, root lengths and dry matter of plant parts but with little relevance to actual wood yield. In general, *P. juliflora* and *P. pallida* seedlings reach 0.4-1.0 m high in 3-4 months in the nursery, with a good nursery soil mixture and regular irrigation (see 4.1.3). Nursery growth is often measured from the date of seed sowing. Germination and seedling emergence can occur from 2-3 days to several weeks after sowing, depending on seed quality, seed pre-treatment, sowing depth and other cultural factors. Time to emergence can therefore have an effect on early growth or biomass production.

With *P. juliflora*, Gupta and Balara (1972) noted respective shoot and root lengths of 6 cm and 21 cm after 1 week, increasing to 20 cm and 52 cm after 10 weeks, with equivalent increases in the number of leaves, dry weights and number of secondary roots (37 after 10 weeks). Goel (1987) recorded shoot and root lengths of 69 cm and 27 cm, with 30 secondary roots after 8 weeks, and Rodriguez and Silva (1990) found shoot and root lengths of 32 cm and 27 cm after 7 weeks. However, the validity and comparability of many nursery pot trials are severely hampered by the use of relatively small pots, which restrict root growth, and the use of different soil media and irrigation regimes. Several studies have shown poor correlation between nursery growth and subsequent field performance of *Prosopis* species and thus results from the nursery should not be used as the sole means of early selection of improved material.

Field performance

Survival, height and diameter are the traditional parameters of measuring field performance of trees. Seedling survival is an important aspect, having a direct impact on per hectare production or the need for replanting. *P. juliflora* and *P. pallida* are preferred species because of their ability to tolerate a wide variety of conditions and their high survival and rapid growth rates. No attempt will be made to list or compare the data which exist on nursery and field survival for *P. juliflora* and *P. pallida*, because of great environmental variations between sites. Survival rates of *P. juliflora* and *P. pallida* are often the highest of all species tested in any trial and 90-100% survival after 2 years is not uncommon (Lima 1990a, Harris *et al* 1996a, Harsh *et al* 1996). There are very few additional losses after initial establishment unless site conditions are particularly difficult.

Height and diameter are the most commonly used growth parameters for calculating biomass yields or timber volume. Multi-purpose and multi-stemmed trees such as *P. juliflora* and *P. pallida* are not well suited to the use of growth measurements such as diameter at breast height and top height, employed in traditional forestry. *P. juliflora* and *P. pallida* often have a very different tree form from commercial timber species and end products other than timber, such as fuel biomass, that require quantification . Height and stem base diameter have been judged as the two growth parameters that give the best indication of relative performance in a single trial and are most likely to give an adequate estimate of total plant biomass and tree volume.

Length of the longest shoot or maximum shoot length has been used instead of vertical height as a better measure of the growth of sub-erect trees (Stewart *et al* 1992, Stewart and Salazar 1992). This measure is useful for comparing young trees, which often have differing and sometimes prostrate habits, and heights and shoot lengths short enough to be measured practically. The ratio of maximum shoot length to vertical height gives a measure of habit, as the degree of prostrateness of the plants. In older trees, vertical height is the only practical measurement option. Crown diameter is another parameter often employed, giving limited information with younger plants but a better indication of foliage volume and possibly fruit yield in older trees. Diameters at other heights that are employed in biomass and tree volume estimations are dealt with later in this section.

The different parameters as well as the markedly different sites on which trees have been grown make comparisons between results somewhat meaningless. Some indications of tree growth can be given from sample experiments employing a more consistent approach and a variety of germplasm. However, these are most useful when looking at comparative performance on a single site. Annual increments give a good indication of rates of growth and also of the performance response of a tree or stand to different management inputs. More meaningful data are biomass or volume estimates that allow comparisons of actual production, or growth data for individual provenances on a variety of sites. A few global field trials incorporating *P. juliflora* and/or *P. pallida* have been established using standard techniques and the same germplasm, but these have yielded limited results to date.

A very large trial of many arid land tree species was established by the FAO in 1979, involving DANIDA, and detailed analysis at various sites found that diameter at 30 cm height yielded the most accurate biomass estimations. Data after 15 years growth have been collected but await publication. Field trials established by the Oxford Forestry Institute (OFI) tested many Central American species in 12 sites world-wide, but *P. juliflora* was included in only half of them (Stewart *et al* 1992). Performance was generally poor, but a particularly thorny and prostrate provenance from Honduras was used throughout which was the most prostrate of 40 *Prosopis* provenances tested in Cape Verde (Harris *et al* 1996a). In the OFI trial in Egypt, *P. juliflora* was excluded from the 42 month assessment “because of its exceptionally spreading, rampant habit which, combined with its extreme thorniness, made the plots of this species completely impenetrable” (Stewart *et al* 1993). With the large differences in growth and form noted between different species and races of the *P. juliflora - P. pallida* complex, this shows the difficulty of reaching conclusions as to the relative performance of ‘*P. juliflora*’ when using seed from only a single provenance in field trials.

In contrast to this prostrate Central American *P. juliflora*, a large number of accessions of superior, selected trees from the *P. juliflora - P. pallida* complex collected in Peru, thought to be *P. pallida*, have been tested in field trials in three continents. In the field trial in Haiti, Lee *et al* (1992) found that eight of the Peruvian accessions outperformed all others, achieving heights of over 2 m after 27 months, and several had other desirable characters of being thornless, having an erect form and being unpalatable to livestock. In the field trials in Cape Verde, Harris *et al* (1996a) also found that these Peruvian accessions were amongst the best performing of 40 *Prosopis* accessions tested, with shoot lengths of 1-2 m in 18 months. In field trials in Rajasthan, India, Harsh *et al* (1996) found identical accessions from Peru to be of superior form and growth rate to all others tested in a large selection programme, with heights averaging 2.8 m in 4 years.

Prosopis species general out-perform those from all other genera in field trials in very arid and poor conditions such as found in Haiti, Cape Verde and India. On more saline and alkaline sites, however, *Acacia* spp. and halophytes such as *Atriplex* sometimes show better survival and growth rates than *Prosopis*. While growth rates may appear low in many of these trials, rainfall in all the sites referred to above is also very low. In the Cape Verde trials for example, a maximum shoot length of 2 m was possible in 18 months, with no rain falling for 15 months post planting and only 200 mm in the entire period (Harris *et al* 1996a). The mean annual rainfall during the trial period in Haiti was 400 mm in India only 300 mm. Rapid early growth, particularly root growth, is thought to be an adaptation to drought, with an essential need for roots to access ground water at an early age. Plants are not expected to have tapped any ground water at such an early age when assessed in these trials, growth rates would be expected to increase markedly as soon as roots locate a supply of permanent water, growth would then be limited by other environmental factors, before declining as the tree ages. No long term data is available on the mean annual increments of *P. juliflora* and *P. pallida* over the course of a rotation.

Biomass production

Generally, only above-ground woody biomass is assessed, including branches and twigs above a fixed diameter, i.e. all that material which will be used as firewood. Values for leaf, root and absolute total biomass production are also occasionally calculated. Obtaining accurate data involves destructive direct measurement, which is time consuming and expensive when assessing a large numbers of trees. The common approach is the destructive analysis of a random sample of trees, and the use of this data to construct formulae and tables whereby biomass or volume can be calculated from standard tree growth parameters.

Many relationships have been tested for estimating biomass production of *P. juliflora - P. pallida*, relating to total green weight, total dry weight, browse (leaf) weight, twig, branch and stem weight. The growth parameters tested include vertical height, length of longest branch, diameter at various heights above ground level and basal area. Biomass data is correlated directly against a one or more of these parameters or calculated from simple or complicated multiple regression equations. Formulae used with traditional forestry species and parameters such as diameter at breast height are unsuitable or must be adapted for use on the multi-stemmed forms of *P. juliflora* and *P. pallida* (Chaturvedi 1984). Biomass is calculated from stem volume estimates and mean wood density data. Linear regressions were adequate, but log-log expressions were found to yield closer correlations with several *Prosopis* species (Felker *et al* 1983b). Riegelhaupt *et al* (1990) also found log-log expressions to be most effective with planted *P. juliflora* but the same equation gave a very poor fit when applied to trees arising from natural regeneration.

As biomass and volume are linked by wood density, either can be used to calculate total productivity. Many formulae are only suitable for a certain site, a certain provenance or trees within a pre-defined range in diameter, height or age. For extrapolation over many sites, data has to be collected from each and used to calculated a further cross-site equation. Some loss of accuracy is to be expected following the creation of such a wide ranging equation. Many other variables exist, and the need to allow for as many as possible is clearly required. Wood density and specific gravity are known to vary, not only between species and locations but also between trees of different ages (Khan *et al* 1986), at different positions on the stem (Lima 1994) or due to different cultural treatments (Abohassan *et al* 1988). Biomass and volume yield tables have been developed from calculations on single trees and estimates of mass and volume per tree and per hectare based on one or two growth parameters and tree density (e.g. Chaturvedi 1983, Riegelhaupt *et al* 1990, Stewart *et al* 1992, Negi *et al* 1998).

Stem base diameter and height were found to give good estimates of biomass for a variety of *Prosopis* species in the USA (Felker *et al* 1982a). However, Felker *et al* (1983a) found that stem base diameter alone gave equivalent results and height measurements were discontinued. Similar correlation coefficients were also observed by Chaturvedi (1984) between weight and diameter at 50 cm height, and between weight and diameter squared multiplied by height. Riegelhaupt *et al* (1990) also noted no increase in accuracy of biomass estimates by including height data. Diameters at various heights, or more accurately the sum of the diameters of all the branches present at various heights, have been used to calculate biomass. Maximum shoot length and diameter at 30 cm above ground level were the best indicators for a variety of species including *P. juliflora* at a variety of sites (Stewart *et al* 1992, Stewart and Salazar 1992).

Measuring stem diameter is also not an easy operation, with thorns and a multi-stemmed nature. In field trials, stem base diameter is often assumed to be the diameter at a height of 0.1 m, thus avoiding false readings associated with the broader stem base found at ground level. Diameter at 0.3 m height has been employed by several authors and seen to be accurate and relatively simple to measure. However, the higher number of stems present further from the ground complicates the measurement and analysis procedure. When using the sum of diameters at 0.5 m from the ground or above, the large number of stems to be measured is often impractical. The use of stem base diameter thus has the advantage of limiting the number of stems to be measured. Diameter at breast height can only be used practically with erect trees but has been successfully applied to *P. juliflora* in Brazil (Riegelhaupt *et al* 1990).

Lack of consistent methodology in biomass estimation, also including differences in diameter classes used for assessing biomass production of different tree component parts, makes comparison of data difficult. Also differences in plant spacing, site preparation, soil type, rainfall, and management interventions make accurate comparison of data between field trials almost impossible. Important aspects of data on biomass production are comparisons with the production of other species in trials aimed at selecting the most productive species for a particular site. *P. juliflora* and *P. pallida* are generally seen to be amongst the most productive species in trials in arid and semi-arid zones with regard to biomass and/ or volume. No attempt is made here to present the wealth of data on biomass yields from around the world, but the following summary gives an indication of the range of annual yields possible from plantations of *P. juliflora* and *P. pallida*.

There is a very wide range in biomass estimates from different sites, from as little as 0.5 t/ha/yr to very high yield estimates of over 39 t/ha/yr. Examples of *P. juliflora* biomass yield estimates include 7-20 t/ha/yr in the USA (Felker *et al* 1983a), 6-12 t/ha/yr in Kenya (Kaarakka and Johansson 1992), 11-20 t/ha/yr in India (Chaturvedi and Behl 1996) and 10-16 m^3/ha/yr in Ethiopia (Abebe 1994). While these estimates are relatively consistent, they are significantly higher than estimated yields from many other trials, for example 1.6 t/ha/yr in Sudan (Wunder 1966) and 0.6-1.8 t/ha/yr in India (Singh *et al* 1990). El Fadl (1997) notes biomass yields from literature in the range 2-39 t/ha/yr. Very low yields are obtained from trials in arid locations in India and Africa with mean annual rainfall often below 300 mm and with no irrigation or post-planting care. Some of the highest values were obtained from a trial in Kenya, with mean annual rainfall above 1500 mm and with supplemental irrigation and some post-planting care (Maghembe *et al* 1983). When calculated over a 5-10 year rotation, as would be expected for fuelwood harvesting, *P. juliflora* biomass production is generally in the range of 2-8 t/ha/yr, with plant densities of 400-2500 trees/ha and in mean annual rainfall zones of approximately 400-800 mm without supplemental irrigation.

Variation in production has also been noted due to age and habitat differences (Bhimaya *et al* 1967), stand density (Tewari and Wais 1996) and between planted and naturalised stands (Riegelhaupt *et al* 1990). In Brazil, production was noted to vary widely between site types, with yields of greater than 11 m^3/ha/yr in valleys, approximately 2 m^3/ha/yr on lowlands and less than 1 m^3/ha/yr on table land and sloping ground (IPA 1989). Such ranges in yield are influenced primarily by soil type and depth and the availability of sub-surface water, rainfall or irrigation. Annual biomass production per tree is also stated. While tree growth is also affected by plant spacing, such data can be used to indicate approximate yields at different planting densities, or production from trees in roadside or shelterbelt rows. Examples of individual biomass increments for *P. juliflora* include 0.2-1.7 kg/tree/yr in Somalia (Helin *et al* 1989), 4.9-8.4 kg/tree/yr in India (Kalla 1977, Chaturvedi *et al* 1988) and up to 10 kg/tree/yr in Pakistan (Khan *et al* 1986).

Total biomass is often calculated as woody biomass, with a stated minimum branch diameter, such as 2 cm, i.e. that which is useful as a source of fuel. However, more accurate data are available on total biomass partitioning. This allows for estimates of fuelwood of various dimensions, leaves and percentage of stemwood, for possible use as timber, to be calculated from a single data set. An example of a volume table for use with erect *P. juliflora* trees in India is shown in Table 25. However, this may not be accurate for different sites or different tree forms observed in the *P. juliflora - P. pallida* complex. Root biomass is rarely measured in large or mature trees because of difficulties in excavation, even though root stumps are often used for making charcoal. Leaf biomass is rarely assessed, or leaves, twigs and small branches are measured together.

Table 25. Volume table for* P. juliflora *(with bark) in cubic metres (adapted from Chaturvedi 1985).

Diameter at breast height (dbh) (cm)	Tree height (m) 6	9	12	15
5-10	0.034	0.040	0.045	0.051
10-15	0.054	0.069	0.084	0.099
15-20	0.083	0.113	0.143	0.172
20-25	0.122	0.117	0.220	0.270
25-30	0.171	0.244	0.318	0.392
30-35	0.229	0.332	0.435	0.538
35-40	0.297	0.434	0.571	0.708

Woody biomass is usefully divided by mean or minimum stem diameter into possible outputs, approximately relating to fuel (2-5 cm), post and poles (5-20 cm), and timber (over 20 cm). Biomass yield tables and volume tables, when they incorporate biomass partitioning, can be used to calculate the output of different products. Fuel has been the main product considered, while yield of poles suitable for fence posts, although an important product in some areas, has been received limited attention. Once the percentage of the total production of stems over a predetermined size is calculated, timber production can be quantified. Timber is generally taken as stems with a minimum mid-point diameter of 20 cm, suitable as sawlogs. However, estimates of sawlog production do not provide any information on actual sawn timber yield, with often low timber recovery with short and crooked *Prosopis* logs.

3.2 Fruit (pod) products

3.2.1 Pod composition

The fruits of the *P. juliflora - P. pallida* complex are indehiscent pods, generally pale yellow in colour. Pods of *P. pallida* in Peru are 10-25 cm long, 1.5 cm wide and 0.8 cm thick with an average weight of 12 g. A pod consists of three separable components: exo- and mesocarp (pulp), endocarp (fibrous hulls) and seeds. The seeds are enclosed in the endocarp, which can be opened by hand only with difficulty. There is an average of 25 seeds per pod (Solano 1989, Bravo *et al* 1994). The seeds are small and very hard, approximately 5 mm in diameter, ovoid in shape and weigh about 40 mg. Seeds are made up of three parts, an episperm being the thin, brown seed coat, the endosperm which is adhered to the seed coat, and the cotyledon. Figure 19 shows the structure of a *P. pallida* pod and seed, with percentages of each component.

Several authors have studied the nutritional properties of pods of different *Prosopis* species. An interpretation of the results is difficult, however, because the terms used to identify the different parts of the fruit are not consistent. For example, the term 'pod' is predominantly applied as a descriptor for the whole fruit but in some cases it refers to the pericarp (pod without seeds). It is therefore important to clearly define the meaning of the terms. The term 'pulp' describes the sum of exo and mesocarp only, which represent the sweet portion of the fruit, while the term pod refers to the whole fruit with seeds. Table 26 presents the proximate analysis of *P. juliflora - P. pallida* pods from around the world but predominantly from Peru, Brazil and India where they are most valued.

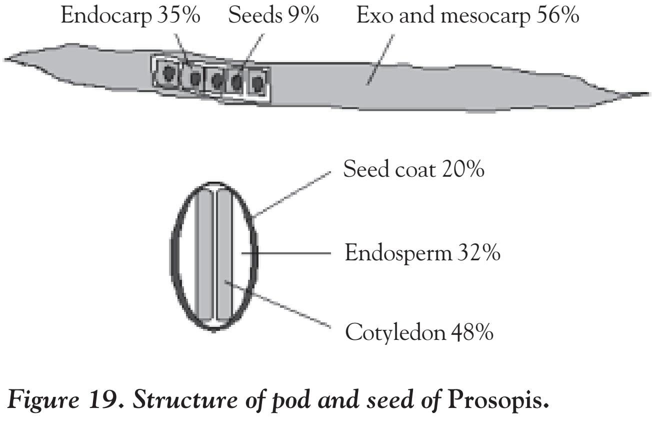


Figure 19. Structure of pod and seed of **Prosopis.**

The data show that there has been considerable research undertaken in assessing pod composition, and that some trends are visible. Dry matter content is quite consistent at approximately 90%. Crude protein levels vary within the range 7-17%. This variation may be because of genetic differences in pod composition or differences in methods used. Crude fibre and nitrogen free extract also vary widely, from 12 to 32%, and 40 to 75%, respectively, which may again be caused by differences in methods. However, results from India and Africa appear to indicate that the *P. juliflora - P. pallida* complex introduced there have pods with lower levels of desirable carbohydrates and higher levels of unwanted fibre than pods from Peru and Brazil. This may not be significant but it may suggest that Peruvian *Prosopis* pods are of an inherently better quality than pods from *P. juliflora* of the northern races.

Several authors reviewed in Cruz (1990) and Díaz Celis (1995) have studied the Peruvian species *P. pallida* and *P. juliflora* as whole fruits for animal feeding. Ranges reported are; protein 9-12%, fibre 14-23%, ash 3-5% and less than 1.7% fat. Pods from Ecuador, identified as *P. juliflora*, were reported to have almost identical composition with exception of slightly more fibre (Marangoni and Alli 1988). However, Figueiredo (1975) reported higher levels of protein (15%) and fat (4.9%) for *P. juliflora* pods from north east Brazil. The protein content for most species and provenances is approximately 10%. Although the values for fibre are strongly dependent on the analytical method used, it may be assumed that Peruvian *Prosopis* pods are less fibrous than other species. Proximate analyses of whole pods show similar results to those of several other *Prosopis* species. For example, Del Valle *et al* (1987) reported 11% protein, 29% fibre, 4.6% ash and 1.7% fat for whole pods of *P. glandulosa* and *P. velutina*. Zolfaghari and Harden (1982) and Zolfaghari *et al* (1986) analysed green and ripe *P. glandulosa* pods with comparable results. Pak *et al* (1977) reported similar values for *P. tamarugo* pods from Chile.

The separate composition of pulp and seeds from Peruvian *P. pallida*, as well as the properties of syrup obtained by different procedures, have also been reported. Sucrose was identified as the main sugar in the pulp. Further studies on each part of the fruit of *P. pallida* has yielded detailed nutritional information and the results are described below and compared where possible with data available for other species. The pulp represents 56% of the total weight of the fruit. The composition of *P. pallida* pulp is presented in Table 27. The main soluble component of the pulp is sucrose

Table 26. Proximate analysis of* P. juliflora *and* P. pallida *pods.

	Location	Dry matter(%)	Crude protein(%)	Crude fibre(%)	Ether extract(%)	Ash (%)	Nitrogen free extract(%)	Source
PP	Peru	85.9	9.1	18.4	1.0	3.9	65.3	López and Manrique 1988*
PP	Peru	88.4	10.2	13.9	1.1	3.8	71.0	Sáenz *et al* 1988*
PP	Peru	-	8.1	32.2	0.8	3.6	48.5	Cruz 1999
PJ	Peru	82.0	9.1	13.6	0.4	5.8	71.1	Estrada 1974*
PJ	Peru	77.8	11.9	13.3	0.5	3.8	70.6	Burga 1988*
Psp	Peru	92.6	9.7	21.4	1.4	3.8	63.7	Vidal 1978*
Psp	Peru	84.9	9.2	20.2	1.2	3.5	65.8	Vilchez 1987*
Psp	Peru	87.4	11.4	16.0	1.7	4.2	67.2	Sáenz *et al* 1988*
PP	Brazil	-	8.1	22.1	1.3	5.0	64.0	Lima 1994
PJ	Brazil	83.0	12.9	19.1	4.1	3.8	-	Azevedo 1955**
PJ	Brazil	87.4	7.1	12.3	1.1	3.3	63.6	Gomes 1961**
PJ	Brazil	82.4	9.9	-	0.8	3.8	54.2	Barbosa 1977**
PJ	Brazil	83.0	15.6	21.9	4.9	4.3	75.2	Figueiredo 1980**
PJ	Brazil	89.6	9.7	15.9	1.1	-	-	Campos 1981**
PJ	Brazil	92.1	10.2	10.9	0.8	-	-	Nobre 1981**
PJ	Brazil	81.6	13.6	28.6	4.3	5.8	29.7	de Barros 1982
PJ	Brazil	90.3	21.8	20.2	3.2	3.3	39.9	Negreiros 1986**
PJ	Brazil	83.2	9.2	14.2	0.6	-	65.3	Barros *et al* 1988**
PJ	Brazil	87.8	12.4	22.0	1.3	3.2	48.9	Silva *et al* 1990
PJ	Brazil	-	7.8	12.4	1.2	4.5	72.5	Lima 1994
Psp	Brazil	88.4	10.9	17.8	1.3	3.7	66.3	Burga 1988*
PJ	India	88.5	12.3	28.0	1.3	1.4	46.3	Anon 1943
PJ	India	-	12.5	25.6	3.6	5.1	53.3	Shukla *et al* 1986
PJ	India	-	16.5	16.8	4.2	5.4	57.0	Vimal and Tyagi 1986
PJ	India	-	7.6	19.9	2.5	8.4	61.6	Talpada *et al* 1987
PJ	India	-	12.3	19.0	3.8	5.1	59.8	Talpada and Shukla 1988
PJ	India	-	13.0	28.1	2.8	5.1	51.0	Kanzaria and Varshney 1998
PJ	Mexico	90.1	16.2	23.4	3.5	6.0	50.9	Burga 1988*
PJ	Niger	92.6	12.9	18.0	4.0	4.5	58.9	Touzeau 1973
PC	Sudan	-	12.5	27.2	-	4.9	53.3	Gabar 1990
PJ	Kenya	-	16.0	22.0	3.4	4.5	54.1	Anttila *et al* 1993
PJ	S. Africa	-	13.9	27.7	3.0	4.8	50.6	Gohl 1981

All figures are rounded to one decimal place for consistency
** - in Díaz Celis (1995)* *** - in Galera* et al *(1992)*
PP - P. pallida *Psp -* Prosopis *(species unknown)* *PJ -* P. juliflora *PC -* P. chilensis *(thought to be* P. juliflora*)*

(46%), representing over 90% of total soluble sugars, while the reducing sugars, glucose, fructose and xylose, are present in very small amounts (Cruz *et al* 1987, Sáenz *et al* 1987). The sucrose/glucose/fructose ratio agrees well with that for the pulp of *P. glandulosa* (Meyer 1984). Talpada (1985) found that sugar content of *P. juliflora* pods varied from 13% to 20% in different seasons and years showing a strong environmental effect on pod compositions, as did Lee and Felker (1992) with *P. glandulosa* var. *glandulosa*. Soluble sugars from the pericarp of *P. juliflora* from Ecuador comprise 75% sucrose, 12% being fructose, 5% glucose, 5% inositol and 1% raffinose (Marangoni and Alli 1988). A sucrose content of 30% and very low amounts of raffinose, inositol, fructose and glucose have been found in the pericarp of *P. glandulosa* and *P. velutina* from Texas and Arizona, respectively, and after autolysis of the pericarp, a small increase in glucose and fructose indicated low invertase activity (Becker and Grosjean 1980).

Dietary fibre represents 30% of the pulp and is largely insoluble. More than half of the fibre fraction consists of neutral polysaccharides (Bravo *et al* 1994). Analysed by different methods, higher dietary fibre contents of pulp from other species have been published. Meyer (1984) found 35% dietary fibre in mesquite pulp and Zolfaghari *et al* (1986) reported 25% cellulose, 11% hemicellulose and 7% lignin for the pericarp from *P. glandulosa*. Insoluble dietary fibre represents by far the main component of the endocarp (Table 27), which is the very hard and fibrous hull in which the seeds are enclosed. In a detailed analysis this fraction was shown to contain cellulosic polysaccharides (40%) and lignin (17%) as major constituents (Saura *et al* 1991). *P. pallida* pulp contains considerably higher amounts of iron and lower levels of calcium than *P. glandulosa* (Becker and Grosjean 1980, Zolfaghari and Harden 1982). High iron levels have been reported in *P. juliflora* from Ecuador and Brazil (Figueiredo 1975, Marangoni and Alli 1988) and in *P. tamarugo* from Chile (Pak *et al* 1977), but no figures for its bio-availability are given. The vitamins C, B6 and calcium pantothenate are present in significant amounts in pulp from *P. pallida* pods (Grados and Cruz 1996) (Table 28).

The crude protein content of the pulp from *P. pallida* is surprisingly high (8%) considering that seeds are not included. From the amino acid composition (Table 29) it can be seen that nearly all the essential amino acids are present in amounts which fulfil the requirements of the FAO/WHO ‘standard protein’, thus indicating an acceptable nutritional quality of the protein. Methionine and cysteine are the limiting amino acids. These results are in agreement with studies on *P. juliflora* from Ecuador (Marangoni and Alli 1988) and *P. glandulosa* from North America (Felker and Bandurski 1977, Zolfaghari and Harden 1982, Meyer 1984). Compared with other species, remarkably high amounts of proline and hydroxyproline have been determined in *Prosopis* pulp from Peru (Cruz 1990) but the reasons for these differences are unclear.

The seeds of *P. pallida* comprise 32% endosperm, 48% cotyledon and 20% episperm (seed coat) (Figure 19). *P. pallida* cotyledons contain 65% protein, which represents 31% of the seed weight. The amino acid composition of the cotyledon proteins has been determined (Cruz *et al* 1987) (Table 29) and essential amino acid content is remarkably high, with cysteine and methionine being the first limiting amino acids. These results are comparable to those for *P. juliflora* and *P. glandulosa* (Figueiredo 1975, Zolfaghari and Harden 1982, Meyer 1984, Baião et el 1987). Data on protein digestibility and protein fractionation are not available for the *P. pallida* cotyledon fraction. However, apparent digestibility of proteins from raw seeds of *P. glandulosa* was reported to be 71% (Zolfaghari and Harden 1982). The fat content of *P. pallida* cotyledons has been reported to be 7% (Jiménez and Vergara 1977) with the major fatty acids found in extracted oil being linoleic acid (39%), oleic acid (29%), palmitic acid (13%) and stearic acid (10%). Similar values have been reported for *P. juliflora* (Marangoni and Alli 1988) and other *Prosopis* species (Becker and Grosjean 1980, Ochoa 1996). Fatty acid and sterol compositions of seed oils from several *Prosopis* species in Argentina have also been reported (Lamarque *et al* 1994).

No significant quantities of antinutritional factors have been isolated from *Prosopis* pod fractions (e.g. Rajaram and Janardhanan 1991, Vijayakumari *et al* 1997). Each fraction of *P. pallida* fruit has been investigated for polyphenols and tannins (Salazar 1993, Bravo *et al* 1994) and significantly smaller amounts were found than in carob (*Ceratonia siliqua*) pods. The presence of further antinutrients has not yet been studied in the Peruvian *Prosopis* pods. *Prosopis* pods and seeds have been reported to be almost totally devoid of trypsin inhibitor activity (under 6 TIU/mg) (Zolfaghari and Harden 1982, Ortega-Nieblas *et al* 1996), although a trypsin inhibitor from *P. juliflora* seeds has been characterised (Monte-Negreiros *et al* 1991). Cyanogenic glycosides, which occur in some legumes, have not been found in *P. glandulosa* (Becker and Grosjean 1980) or in *P. tamarugo* (Pak *et al* 1977). It may be assumed that *P. pallida* contains no more antinutritive substances than other *Prosopis* species.

3.2.2 Pods as a resource

Animal feed

Fruit of the *P. juliflora - P. pallida* complex is sweet, nutritious, has low concentrations of tannins and other unpalatable chemicals, and has moderate to high digestibility. Natural selection favoured these characters as they are attractive to foraging animals and thus help in dispersal of seed. *Prosopis* pods and seeds are consumed by a wide variety of animals, both in their native range and where introduced, and are often an important part of mammalian diets when trees are present in large numbers. Insects, reptiles and birds are minor disseminators of seed, but pods may play an important role as a source of nutrition of such animals (e.g. Mooney *et al* 1977).

P. juliflora - P. pallida pods are used as a feed mainly for cattle but also for sheep, goats, camels, pigs and poultry. Pods are mainly used as a forage, browsed directly from the tree or the ground below, rather than as a fodder, where the pods are collected and fed to stalled stock. As a part of extensive grazing systems, livestock was introduced into native *Prosopis* woodlands in the Americas and still browse in natural woodland today. Many introductions of *P. juliflora* and *P. pallida* were made in arid and semi-arid zones around the world primarily because of a perceived need for additional sources of forage. Livestock is often allowed access to naturalised stands and plantations of *P. juliflora* and *P. pallida* where introduced. These species are especially suitable for extensive grazing systems as the leaves are unpalatable and pods are produced either towards the end of the dry season

Table 27. Composition of* P. pallida *pulp and endocarps (Cruz* et al *1987, Cruz 1990, Saura* et al *1991, Salazar 1993, Bravo* et al *1994, Grados and Cruz 1994).

Main components	**Pulp** (g/100 g dry matter)	**Endocarp**
Soluble sugars	48.5	1.6
Total sucrose	46.1	-
Total fructose	1.26	-
Total glucose	1.02	-
Total xylose	0.27	-
Dietary fibre	32.2	92.3
Total insoluble dietary fibre	30.6	88.9
Total soluble dietary fibre	1.6	3.4
Protein (NX6.25)	8.1	2.3
Sum of amino acids	7.1	-
Resistant	2.2	-
Fat	0.8	1.3
Ash	3.6	1.3
Condensed tannins	0.4	-
Total soluble polyphenols	0.81	0.7

Table 28. Mineral and vitamin composition of pulp from* P. pallida *pods (Cruz* et al *1987).

Minerals	**(g/kg dry matter)**	**Vitamins**	**(mg/kg sample)**
Potassium	26.5	Vitamin A	not detected
Sodium	1.1	Vitamin E	5
Calcium	0.8	Vitamin B1	1.9
Magnesium	0.9	Vitamin B2	0.6
Copper	trace	Vitamin B6	2.35
Zinc	trace	Nicotinic acid	31
Manganese	trace	Vitamin C	60
Iron	0.3	Folic acid	0.18
		Calcium pantothenate	10.5

Table 29. Amino acid composition of* P. pallida *pulp and seed cotyledon (Cruz* et al *1987).

Amino acids (g/100 g DM)	**Pulp**	**Seed cotyledon**	**Amino acids** (g/100 g DM)	**Pulp**	**Seed cotyledon**
Aspartic acid	8.51	8.30	Isoleucine	3.26	3.09
Throenine	4.68	2.42	Leucine	7.94	7.51
Serine	4.96	4.87	Tyrosine	2.84	1.84
Glutamic acid	10.07	21.31	Phenylalanine	2.98	4.29
Proline	23.40	7.49	Lysine	4.26	4.09
Glycine	4.68	4.59	Histidine	1.99	3.10
Alanine	4.26	4.34	Arginine	4.82	14.63
Cysteine	0.43	1.31	Tryptophan	0.89	1.37
Methionine	0.57	0.88	Hydroxyproline	2.13	-
Valine	7.80	7.80			

or are easily stored until then, coinciding with the period when alternative sources of forage are lacking.

Collected pods are fed to stalled livestock, whole or processed, alone or as part of a ration and fresh or after storage. Processing involves the pounding, grinding or milling of pods, either as a single process producing a whole pod extract, or with some separation of pod parts and further processing of each fraction. Processing usually involves milling of whole pods into a homogeneous, coarse flour, although in some cases exocarp and mesocarp (pulp) are separated from the endocarp and seed. Considerable research has been undertaken on the use of milled pods in livestock rations, particularly in Brazil and India. Pods must be ground or milled to secure the full nutritive value as most of the protein rich seeds would otherwise pass undigested through the digestive tract of livestock.

Whole pods *P. juliflora* were found to provide 7% digestible crude protein and 75% total digestible nutrients on a dry matter basis (Shukla *et al* 1984). The digestibility of crude protein from *P. juliflora* pods was 50-60%, with the average digestibility of ether extract being 70%, crude fibre 80%, nitrogen free extract 79% and organic matter 74% (Shukla *et al* 1984). The *in vitro* digestibility of *P. pallida* pulp protein has been determined to be 73% (Bravo *et al* 1994), similar to the value for *P. juliflora* pulp from Ecuador (Marangoni and Alli 1988). These figures are comparable with other results for *P. juliflora, P. pallida* and other *Prosopis* species. Nitrogen and calcium balances were positive, but the phosphorus balance was negative suggesting that pods should be fed with a phosphorus rich feed supplement. Levels of anti-nutritional chemicals are not significant in pods of *Prosopis* species, and the tannin content of pods is low (0.7-1.5%) (Shukla *et al* 1984). Makkar *et al* (1990) found low levels of total phenols and condensed tannins in pods of *P. juliflora* with no protein-precipitation capacity, as a measure of biological activity.

Consumption of rations containing up to 45% *P. juliflora* pods was 1.5% of cattle body weight in India, with acceptable liveweight gains (Shukla *et al* 1984). Other studies have indicated that cattle rations containing less than 50% *P. juliflora* pods lead to no adverse effects on consumption, digestibility, nutrient balance and animal health. However, there are several records of pods causing ill effects in livestock when used alone as a feed. Alder (1949) observed 1% of cattle becoming ill when *P. pallida* pods were used as a sole ration. This was assumed to be due to the regression of rumen bacterial cellulase activity due to the high sugar content of the pods. Rations containing *Prosopis* pods have been recommended for lactating animals, with milk production often said to improve following inclusion of pods in the ration. No effects on milk flavour were noted at less than 50% pods in the ration, though as a sole feed some taste change has been suggested (e.g. Silva 1990b). It may be seen that pods have a valuable role either as a forage for grazing animals, or as part of milled rations for stalled livestock. Considerable work has also been undertaken in Brazil (e.g. Habit and Saavedra 1990).

Pod collection in the Americas is done manually, by children and women and sometimes by the whole rural family, as an activity marginal to their home and agricultural tasks. Considering that bearing trees are often widely dispersed and there may be no means of transport, one person can collect no more than 150 kg of pods per day (see 4.1.1). Collectors in Peru earn an equivalent of less than US$5/day, as during the production season pods fetch a very low price because of their abundance (e.g. US$27/t in February 1995). People use the pods for feeding their small livestock or sell them to merchants. In Peru, most of the merchants have storage facilities, allowing them to supply ranchers in other regions of the country throughout the year. They profit from the fact that the price for *Prosopis* pods can quadruple by the end of the dry season in September, when other forages are lacking.

Commercial production of *Prosopis* pods is not well documented in government statistics and the merchants do not usually declare the real amounts. A compilation of records shows that 12635 t of pods were collected in northern Peru in 1996, of which 60% were transported to Lima. This figure is, however, thought to be only a very small part of the total (Asencio Díaz 1997). An estimation based on sampling studies and forestry maps suggests 400000 t of pods are available annually in the northern region of Peru, more than 50% of which may not be collected (Jara and Otivo 1989, INRENA 1998).

Storage must protect pods from the rain and livestock, and avoid infestations such as those by insects of the family Bruchidae and Pyralidae (Domínguez 1982, Núñez-Sacarías 1994) Traditional pod stores in North America tended to consist of large baskets made from natural fibres, with a rain-proof roof, and raised off the ground to prevent predation and to keep the pods dry (Felger 1977). In Brazil, standard agricultural barns used for storing other dried animal feeds or special rooms with wooden floors and walls are used (e.g. da Silva 1996). In Peru, rustic closed rooms were used, made from mud bricks. These have largely been replaced with block buildings (Grados and Cruz 1996). Special storage units for *P. pallida* pods are built, 5 m x 5 m x 4 m high, which are capable of storing 40 t of pods (Díaz Celis 1995). In India, layers of dry pods are laid down alternately with layers of sand. This is said to increase storage time up to three years. Periodic checking of the pods in the store is recommended to assess any damage due to fungal infections, high moisture or pests. Removal of infected pods should be carried out immediately. In Peru, however, once a pod store is filled, it is sealed with clay and opened only when the whole batch is to be sold. Chemicals are not often used for insect control during storage. Fumigants and dusting with insecticide powders have been reported to be effective, but the use of natural repellent plants such as neem is preferred and recommended (Tewari *et al* 2000). Another suggested use is as a binding agent in preparing compact roughage blocks from agricultural waste (Shukla *et al* 1984).

Human food

Being nutritious and readily available, pods from the *P. juliflora - P. pallida* complex can be used to supplement human diets. Pods can be sucked, chewed or eaten raw but for processing into human food, separation of pod parts is generally undertaken, with the mesocarp (pulp) fraction undergoing further processing. Traditionally, dried pods are pounded in a pestle and mortar to produce a coarse flour, or ground using a variety of stone mills. Mills made of two stones, suitable for grinding cereals have been used, while a special rotary mill was used to grind *Prosopis* pods in North America and Asia (Felger 1977, Fisher 1977). This consisted of a larger basal stone with a conical shaped hole in the centre and a smaller conical stone that was rotated in the hole. Other methods of manual grinding and milling require hand turned rollers or corkscrew mills with perforated end plates. For hand processing in particular, adequate drying is essential to reduce the problems caused by sticking of moist mesocarps. Small hand-fed mechanical threshers and mills such as a disc mill (Flynt and Morton 1969) or a meat grinder (Pasiecznik and Felker 1992) have proved successful for processing small quantities of *Prosopis* pods.

Several large, semi-industrial sized processing units have been adapted or designed specifically for processing *Prosopis* pods (Grados and Cruz 1996). In Peru, a mill prototype was constructed specifically for processing *P. pallida* pods by improving the design of a cereal thresher (Cruz 1986), having several hammers fixed to a rotating shaft and short hammers mounted on the screening housing (Coronado 1988). Mills for processing pods are in use through the native range of *Prosopis* species in the Americas. In Brazil, facilities are being built in various locations specifically for drying and milling *P. juliflora* pods. These provide a good example of small scale pod processing for communal use by local farmers and land owners. Processing involves the drying of pods with a wood burning drier in large open bins at approximately 80°C for four hours immediately before milling. 'Micro-mills' are adapted rotating mills with meshed screens of various sizes. Several types of mill that are used for grinding cereals and animal feeds are also used for *P. juliflora* pods (Kanzaria and Varshney 1998).

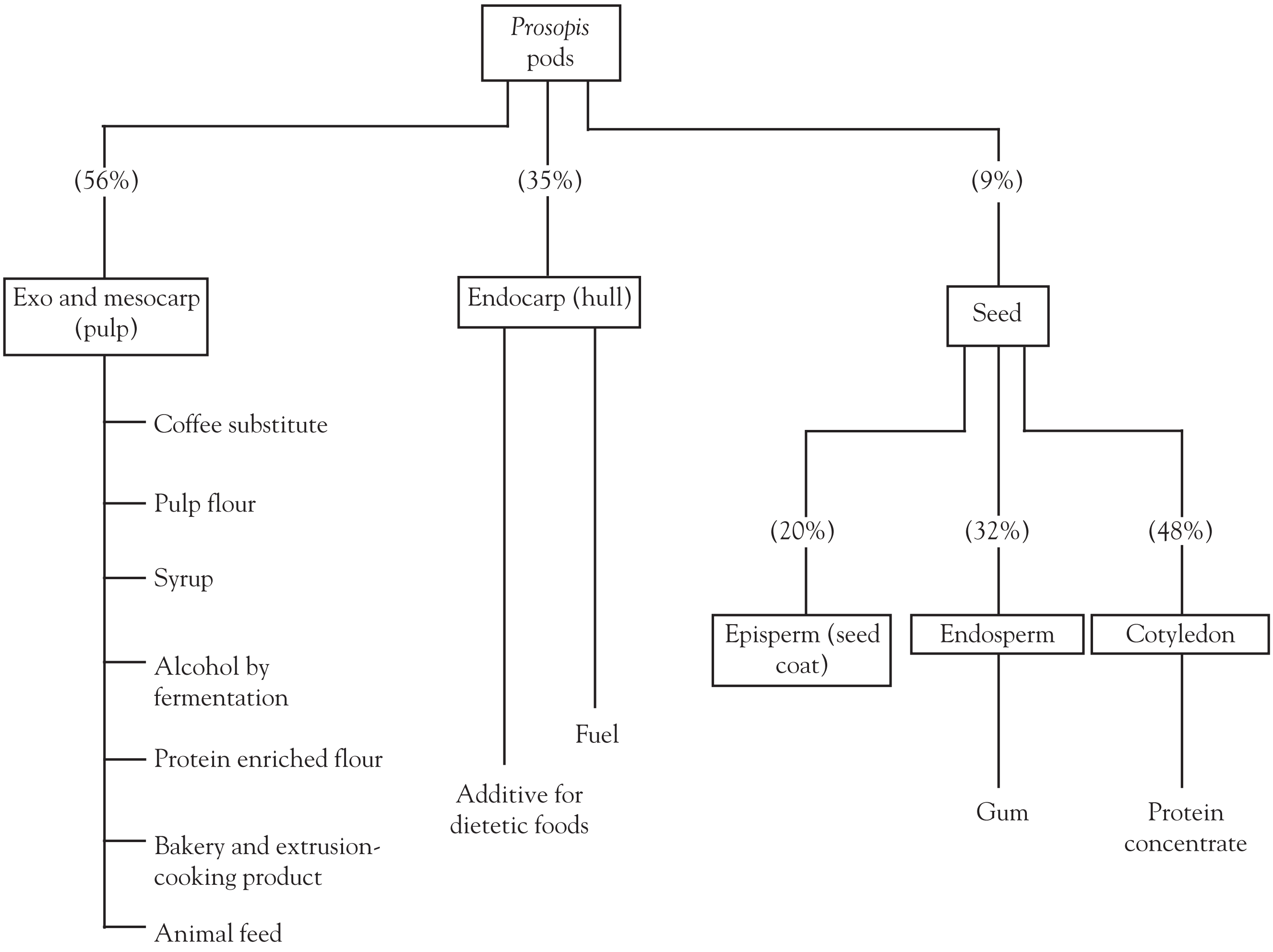


Figure 20. Fractions and potential uses from processing and separation of* P. juliflora - P. pallida *pods.

There have been several detailed studies on the milling and separation of pod parts of the North American *P. glandulosa* (Meyer *et al* 1982, Meyer 1984, Saunders *et al* 1986). Pulp flour, seeds and endocarp hulls were obtained, and techniques were proposed for further separation of the seed into endosperm, cotyledon and seed coat. The integral grinding of pods including seeds was investigated by Del Valle *et al* (1986, 1987) for the production of high-protein, low-fibre flours, recoverable by sieving. A pilot plant in Peru allows the separation of pods into four fractions and the recovery of entire seeds (Grados and Cruz 1996). The fractions from the separation and processing of *P. juliflora* and *P. pallida* pods and their end uses are presented in Figure 20, with flour and syrup the most commonly used.

A syrup, or concentrated sugary extract from *Prosopis* pods, called 'algarrobina', is commonly made from *P. pallida* in rural areas of northern Peru. This syrup is made from whole or crushed pods which are soaked in water for two hours before pressing and filtering the resulting liquid, and finally concentrating the liquid by evaporation. The dark brown syrup obtained is more viscous than honey and exhibits a peculiar brightness. The process is carried out on a household level in rural Peru using very simple kitchen equipment, and the 'algarrobina' produced is sold in reusable glass bottles. No quality standards exist for this product (Estrada 1974, Alza *et al* 1998). Modern processes are much quicker and require no heating as they use a finely ground flour from the pulp (Bravo *et al* 1998). The solid residue that remains following extraction is called the filter cake which can be washed and dried and could be used to enrich food products with dietary fibre. Such syrups and dietary fibres, made using different conditions and processes, have slight differences, which have been characterised (Bravo *et al* 1998).

'Algarrobina' is consumed in different ways. In Peru, some people recommend taking a spoon daily as a health food. It is consumed directly or added to fruit juices or milk, where it acts as both sweetener and flavouring agent. It is often given in this way to children and elderly people in Peru because it is believed that the syrup has fortifying and revitalising properties. In urban zones, the syrup is used as an ingredient in home confectionery and to prepare a tasty drink, the 'cocktail de algarrobina', which is a mixture of a small quantity of 'algarrobina' with brandy and milk (Cruz 1999).

Another food product from *Prosopis* is 'yupisín', a beverage which is obtained by water extraction of the sugars from the pod. In contrast to 'algarrobina' it is consumed directly without concentration or used to prepare desserts with sweet potato flour. 'yupisín' is presently consumed only in rural zones , and it is not bottled. A very similar beverage is known in Argentina as 'añapa'. A fermented beverage, 'aloja' can be obtained from 'añapa' and is a substitute for beer or wine (Cruz 1986, Ochoa 1996). In Peru, no fermented beverages are prepared commercially from the sugary pulp of *P. pallida*. *Prosopis* pods played an important role in the Sonoran Desert in North America, where Indian tribes made flour and dough with the dried or toasted pulp from ripe pods. A kind of durable cake was prepared by drying dough balls (Simpson 1977, Meyer 1984). In Northern Argentina, flour made from the sugary pulp of several *Prosopis* species is known as 'patay' and is still consumed today (Ochoa 1996). The flour can be incorporated into a variety of food products including bread, biscuits and cakes. These are sometimes consumed in the native range of *P. juliflora* and *P. pallida* in Peru but rarely elsewhere and not at all where the species have been introduced. The absence of starch is, however, a limitation to *Prosopis* flour levels in bread formulations. Mixing 5-25% *Prosopis* flour with wheat flour produces products which have acceptable taste. The rheological behaviour of *P. pallida*-wheat composite flours has been studied (Cruz 1986), and *P. pallida* flour causes dough resistance to decrease and dough elasticity to increase resulting in softer leavened bread. Sweet bread containing 5% *P. pallida* flour is acceptable in texture and taste. Up to 25% *P. pallida* flour has been used in making biscuits, which reduced the amount of additional sugar required. There is a slightly bitter aftertaste reported by some after consuming these products, but which some people, however, find pleasant (Cruz 1999). In Brazil, the production of a protein isolate (Baião *et al* 1987) and a protein-enriched flour (Ruiz 1997) from *P. juliflora* seeds and its application in bread making have been reported. *P. pallida* pulp flour can also be used as an ingredient in many other food preparations, such as cakes, ice creams and other desserts.

P. pallida pulp flour has been converted into an instantly soluble powder, and could be used as a cocoa powder substitute. A similar 'instant' soluble powder derived from carob (*Ceratonia siliqua*) pulp is currently commercialised. A preliminary study has shown that a soluble powder can be obtained from the fine *Prosopis* pulp flour by re-milling and sieving through a 100-mesh screen (La Torre 1990). In order to improve the dispersability in milk, yoghurt and juices, the agglomeration of the fine powder should be studied. Improvements to the nutritional or sensorial properties of *Prosopis* pulp flour have been achieved by mixing with other cereal flours and with cocoa (Grados and Cruz 1996). New food products from *Prosopis* pods are being developed in Peru by adapting processing technologies to rural situations. A powder called 'garrofina' is produced from finely ground whole fruits with small, rural pod processing mills.

Coffee substitute has been made from *P. juliflora* in Brazil (e.g. Azevedo Rocha 1987), with the roasting of just the coarse pulp flour giving a better flavour than roasting the whole pods (Carrión 1988). Flour is roasted at 120°C until it becomes dark brown, during which time it agglomerates into larger granules requiring further grinding. The final product is used in the same way as filter coffee granules. Compared with other coffee substitutes such as roasted beans or cereals, it is generally well accepted by consumers and has an acceptable flavour. *Prosopis* coffee substitutes are caffeine free (Vieira *et al* 1995). Coffee substitutes or 'café de algarroba' are produced and successfully commercialised from *P. pallida* pods in Peru, packed in 250 g plastic bags at a convenient price under the manufacturers' own trade names (Cruz 1999).

Fuel

The uses of *P. juliflora - P. pallida* pods other than for food or feed have often been based on the high percentage of sugars primarily to produce liquid fuel. Attention has been paid to the potential of pods as a source of biofuels by processing the carbohydrates into ethanol. In the USA, Avgerinos and Wang (1980) assessed the potential for the direct fermentative production of ethanol from the pods of *P. glandulosa* and a *P. alba* X *P. velutina* hybrid. They used a mixed culture of *Clostridium thermocellum* and *C. thermosaccharolyticum*, able to break down both the sugars and celluloses in the pods. Up to 80% of the total carbohydrates present in the hybrid pods were utilised, with ethanol produced at 80% of theoretical yield (Avgerinos and Wang 1980).

Felker *et al* (1986b) estimated that in native stands of *Prosopis*, pods were a significant and unrecognised alcohol fuel resource. Potential ethanol production was estimated at 1100 l/ha/yr if only the sugars were utilised, or 1900 l/ha/yr if starch hydrolysis was also employed. The use of by-products from industrial processing of *Prosopis* pods for human food has also been suggested, such as using pod endocarps as fuel (Cruz 1999). *P. juliflora* pods have been suggested for use in the formulation of substrates and media for laboratory use (Bohra *et al* 1998).

3.2.3 Pod production

The age at first fruiting is variable, depending upon genotype and a range of environmental variables such as soil depth and quality, water status and exposure. Gomes (1961) found that, in its native range, the initiation of fruiting in *P. pallida* was dependent upon treatment, ecology and individual plant characteristics. Where introduced, *P. juliflora* and *P. pallida* trees generally commence fruiting in the second year after planting in Brazil (Lima 1987, 1994) and in Kenya (Otsamo and Maua 1993). Valdivia (1972) stated that, on average, trees began flowering and fruiting in the third year after planting in Brazil, whereas four years was more common in India (ICFRE 1993). Felker *et al* (1984) found that *P. juliflora* and *P. pallida* did not commence fruiting until 4-5 years after planting. This may be the result of the higher temperature requirements of these species not being met in sub-tropical USA.

Age at first fruiting depends on species. Trials have found that compared with *P. juliflora* and *P. pallida*, *P. chilensis* generally commences fruiting later, while *P. alba* and *P. velutina* fruit when younger in more sub-tropical sites (e.g. Felker *et al* 1984, 1986b). There is some variation between seed accessions of the same species. In Sahelian Africa, *P. juliflora* commenced flowering within the first year after planting under irrigated conditions, and flowering is seen to occur in some provenances in less than one year under non-irrigated field conditions. However, local site conditions are important in determining age at first fruiting, with early fruiting often associated with favourable conditions on research sites, such as better soils, protection from physical damage, and cultural treatments such as weeding and irrigation.

Gomes (1961) found that planting *P. pallida* at the onset of the rainy season resulted in trees that flowered in the second year after planting, whereas other trees flowered in the third year. Wild seedlings are often seen to begin flowering only after 3-6 years. Flowering and fruiting place a very high demand on the tree for energy, nutrients and water, and may not be initiated if site conditions are not suitable, or until roots have reached permanent ground water. In some sites, close spaced plantation trees were observed not to flower while single trees flowered profusely. Elsewhere, trees on exposed sites with very thin soils were reported not to have flowered in 15 years since planting. This is thought to result from unfavourable conditions, particularly lack of water (Pasiecznik and Harris 1998).

Yields of pods in the early years are generally very low compared with yields from mature trees and may not accurately reflect pod yield from a mature stand of *Prosopis* trees. A two year old tree may produce 2 kg of pods, 3 kg in the third year, 4 kg in the fourth year. In the fifth and subsequent years, the crown should be sufficiently well developed to see much larger increases in pod yields. Silva (1990b) stated that pod yields increased gradually until the trees were 15-20 years old, earlier on better sites, with pod yield in 2, 10 and 40 year old stands estimated at 2, 50 and 16500 kg/ha/yr respectively. However, Otsamo and Maua (1993) found no difference in pod yield with stand age. Pod production could be expected to remain approximately constant until trees reached an age of 50-100 years, but exact information on the maintenance of fruiting vigour with increasing age is lacking, particularly where introduced and very few trees if any have reached an old age. A sample of recorded and estimated pod yields from *P. juliflora* and *P. pallida* is given in Table 30, showing a large range of production. Lima (1987) noted that production from *Prosopis* spp. in Chile ranged from 10-160 kg/tree/yr and in Argentina from 5-100 kg/tree/yr.

As a tree fruit crop, the pods would be expected to have a seasonal production period. There are generally one or two main fruiting periods, with one yielding more than the other. However, in some regions, flowering and fruiting is continuous (e.g. Lima 1994, Goel and Behl 1996) (see 2.3.3). In more temperate climates, onset of flowering of some species is induced by warm temperature in the spring, with 27-30°C required for *P. glandulosa* (Lee and Felker 1992). In tropical, arid conditions, water availability is considered to be a key factor, although the phreatophytic nature of the trees makes them more independent of rainfall. Production

Table 30. Pod production of Prosopis *species per tree and per hectare.*

	Location	Per tree (kg/yr)	Per hectare (t/yr)	Stand density (trees/ha)	Remarks	Source
PP	Peru	60-80	5	100	selected trees	Valdivia 1972*
PP	Peru	5-100	-	-	-	Díaz Celis 1995
PP	Peru	47	1.6	-	mean 4 sites	Montenegro 1981***
PP	Peru		55	-	mean 6 sites	Estrada 1974***
PJ	Peru		6	-	-	Gomes 1961
PJ	Brazil	2.2		-	1-2 yr old	Azevedo 1955**
PJ	Brazil	-	2-8	-	-	Azevedo 1982**
PJ	Brazil	20-30	2-3	204	-	Azevedo 1982**
PJ	Brazil	-	6	45	-	Lima 1986
PJ	Brazil	5-111	2	400	-	Lima and Galvão 1984*
PJ	Brazil	5-193	-	-	-	Lima 1987
PJ	Brazil	78	-	100	13-17 yrs old	Lima 1994
PJ	Brazil	15	6-10	-	plantations	Silva 1990b
PJ	Brazil	300-420	-	-	best trees	Silva 1990b
PJ	Brazil	200	-	-	deep soil	Carvalho 1963*
PJ	India	80	-	-	good tree	Duque 1980*
PJ	India	19	-	-	-	Talpada 1985
PJ	India	37-75	-	-	-	Parkash and Hocking 1988
PJ	Kenya	-	2-6	1680	-	Otsamo and Maua 1993
PJ	Kenya	-	0.12	-	-	Webb 1988***
PJ	Africa	-	20-25	-	good yield	Von Maydell 1986

* - *in Silva (1990b)* ** - *in Lima (1994)* *** - *in Díaz Celis (1995)*

has, however, been more commonly recorded as being negatively correlated with rainfall(e.g. Lee and Felker 1992). In sub-tropical conditions, *Prosopis* species are sometimes observed to fruit only in alternate years, irrespective of rainfall (Simpson 1977). Fruiting may coincide with either wet or dry seasons and seasonality also has an effect on pod composition (Luna 1996, Kanzaria and Varshney 1998).

Site conditions also have a marked effect on pod production. Where soils are poor, or deficient in any required nutrient, pod production would be expected to be reduced. Soils that are highly alkaline and/or saline may be expected to produce only poor pod yields. Soil depth is also thought to have an effect on tree production, including fruit output, with yield being very low on shallow uplands in Brazil, India and the USA. An over-riding factor relating to site is the presence and depth of subterranean water. Highly productive trees are to be found on rich, deep, alluvial soils or on river banks. Trees in lowlands, valley bottoms, river and canal sides and other water collecting areas, are invariably noted as the best pod producers in any given locality. Tree productivity depends on plant health, with pod yields reduced by pest or disease infestations.

There are assumed to be genotype effects on pod production. In native stands in North America, certain stands and individual trees were noted as high yielding, and the harvest from these was reserved for members of privileged families (Felger 1977). Also, some trees and stands were identified as having particularly sweet or succulent pods, and seed of these could have been transported by humans over long distances. Large variations were noted between different *Prosopis* species and between different accessions of the same species in the USA (Felker *et al* 1981a). These were assumed to be due to genotype effects. There are clearly some differences between species, often between temperate and tropical species when compared in a single climatic region. Pods from *P. pallida* are generally noted to have high yields of sweet pods, whereas pod production from *P. juliflora* is very variable. Selection for increased pod production and increased yield has been undertaken on several *Prosopis* species in the USA, and programmes are underway in India, Peru, and have been developed for Brazil (Pasiecznik and Harris 1998) (see 4.3.3).

In Peru, *P. juliflora - P. pallida* trees typically commence pod production in the fifth year, the tree bearing twice a year with the main pod production in summer (December-March) and a second minor production season occasionally in the middle of the year (Grados and Cruz 1994). The productivity mainly depends on the age of the tree and on the soil quality. Some old trees produce up to 100 kg of pods/yr, while the average for adult trees is considered 40 kg/tree/yr. A dense forest is estimated to have 100 trees/ha, with an expected production of 4 t/ha (Díaz Celis 1995, Asencio Díaz 1997). In India, 40 kg/tree is estimated as mean pod production in arid north western regions.

Pod production has been estimated to be a substantial proportion of total biomass production on some sites, and this should be considered when assessing sustainability of production systems (Lima 1986, Pasiecznik and Harris 1998). Certainly with annual yields of 1-5 t/ha, if all pods are removed from the site, the high level of nutrients in the pods can lead to unsustainable nutrient harvesting. Introduction of superior lines or genetic improvement of existing material in some areas may not increase pod production if present production is already equivalent to estimated site productivity.

3.3 Foliage

3.3.1 Composition of leaves

The composition of the leaves of *P. juliflora* and *P. pallida* can be divided into basic extractives (proximate analysis) (Table 31) and mineral elements (macronutrients and micronutrients) (Table 32). Leaves are composed principally of lignin and cellulose in the cell walls to give rigidity to the leaf structure. Comparison of the proximate analysis of various authors show high levels of crude protein (14-26%) and crude fibre (21-25%), with ether extract (fat) of 3-9%, nitrogen free extract (carbohydrate) at 30-46% and highly variable levels of ash (1-16%) (Table 31). Elemental mineral content assessed by different authors was in approximate agreement. Nitrogen content was generally high, ranging from 3.1% to 5.6%, as was potassium (1.2-3.1%). Levels of phosphorus were generally low, 0.1-0.3%, with a single value of 0.9%. Calcium levels were 0.4-4.2% and magnesium content was 0.3-0.8%. Drumond (1990) found that *P. juliflora* had lower levels of macronutrients than six other *Prosopis* species tested. Leaf contents of Na, Cu, Fe, Zn and Mn have also been assessed but comparison of data derived using differing methods of analysis is not possible.

Table 31. Proximate analysis of* P. juliflora *and* P. pallida *leaves.

	Location	Dry matter %	Crude protein %	Crude fibre %	Ether extract %	Ash %	Nitrogen free extract %	Source
PJ	Brazil	-	18.5	21.2	5.6	-	-	Lima 1994
PP	Brazil	-	17.8	23.3	6.1	-	-	Lima 1994
PJ	India	-	26.3	24.8	8.5	1.4	31.8	Vimal and Tyagi 1986
PJ	S. Africa	-	19.0	21.6	2.9	8.5	29.7	Gohl 1981
PJ	Niger	38.1	13.7	22.9	4.8	15.9	42.7	Touzeau 1973
PJ	Kenya	-	21.7	21.0	4.8	-	45.8	Anttila et al 1993

Table 32. Mineral content of* P. juliflora *and* P. pallida *leaves.

	Location	N %	P %	K %	Ca %	Mg %	Na %	Source
PJ	Brazil	3.24	0.10	1.16	1.72	0.75	-	Lima 1994
PP	Brazil	3.13	0.10	1.35	1.49	0.75	-	Lima 1994
PJ	India	4.10	0.25	2.10	1.61	0.78	0.67	Singh *et al* 1988b
PJ	India	3.55	0.19	1.00	1.01	0.70	0.73	Singh *et al* 1990
PJ	India	3.31	0.30	2.11	2.25	0.38	4.08	Sharma 1968
PJ	India	5.57	0.90	3.11	1.01	-	-	Patel 1986
PJ	Niger	-	0.14	0.83	4.20	0.56	-	Touzeau 1973
PJ	Honduras	4.39	0.27	1.92	2.19	0.32	-	Hunter and Stewart 1993
PJ	Kenya	2.76	0.19	2.42	1.32	0.34	-	Maghembe *et al* 1983

The amino acids in leaves of several *Prosopis* species have been analysed by various authors (e.g. Carman *et al* 1974, Sankhla and Sankhla 1979) but show marked differences, possibly due to different methods of analysis. In general, leaves are rich in essential amino acids but low in sulphur containing amino acids (Sankhla and Sankhla 1979). Tannins, flavonoids and polyphenols are present in leaves of *P. juliflora* and *P. pallida* (Bragg *et al* 1978, Pancholy *et al* 1989, Lima 1994). Leaf tannin content is generally high, at 0.8% (Singh *et al* 1988b) or 1.9-2.0% (Lima 1994). Alkaloids and other chemical compounds are also present which are detailed later in regard to the use of leaves as a medicine (see 3.4.4).

3.3.2 Leaves as a resource

Animal fodder

Foliage of *P. juliflora* and *P. pallida* is rich in protein and minerals and is highly digestible, but the general unpalatability of the leaves to livestock severely limits the utilisation of this resource as an animal feed. Their unpalatability to livestock is widely noted where they have been introduced (e.g. Anttila *et al* 1993) and also in their native ranges (e.g. Stewart *et al* 1992). However, *P. pallida* leaves are noted to be a browse in Peru, where low branches are often stripped and trees are valued as a dry season fodder bank (Díaz Celis 1995). Condensed tannins are known to be present in the leaves of *P. juliflora*. These are thought to be the primary determinants of leaf palatability for browsing ruminants (Owen-Smith 1993). While generally unpalatable, livestock are know to occasionally browse the foliage in most locations. Because of the relative abundance of foliage of *P. juliflora* and *P. pallida* in many regions, and the high nutritive value, there is interest in the relative palatability of leaves to livestock.

The value of leaves as browse depends on livestock species, with palatability to stock in decreasing order being: (more palatable to) goats > sheep > camels > horses (unpalatable). However, during dry seasons or droughts when alternative sources of fodder are lacking, all livestock types will browse the foliage. Leaf age has a marked effect on intake, with leaf buds and young leaves being most palatable, possibly due to the low levels of tannins found in juvenile material. Palatability decreases as leaves mature and undesirable tannins, polyphenols and flavonoids are synthesised (Alves *et al* 1990). Dry, fallen leaves appear to regain some palatability, with livestock, particularly goats, often seen foraging under tree canopies. Unpalatable compounds may be removed from leaves prior to senescence or could be denatured during drying.

There are seasonal effects on the foliar concentrations of macronutrients (Lima 1990a, Garg 1993) and in the metabolic status of leaves (Sen and Mehta 1998) which could effect palatability. Seasonal effects on intake are, however, more likely to be due to seasonal variations in the availability of alternative, preferred browse species. Leaf mineral content has been shown to reflect the mineral content of the surrounding soil, with strong correlations found for *P. juliflora* (Sharma 1984), *P. alba* and *P. glandulosa* (Cline *et al* 1986). In saline soils or under saline irragation, there are changes in leaf metabolic status, including an accumulation of sodium in the leaves (Khan *et al* 1987). As such, soil type and nutrient status can influence leaf tissue nutrient levels and possibly palatability. Differences in the mineral content of foliage was also observed between *P. juliflora* trees of different diameter classes (Maghembe *et al* 1983).

Genetic differences in the palatability of species or provenances are known. While species of section Algarobia are generally unpalatable, some species are preferred, as noted when livestock enter a provenance testing field trial.

Lee *et al* (1992) assessed the relative preferences of livestock for various species and, along with unpublished field observations by the authors, unpalatability was noted in *P. pallida*, *P. juliflora*, *P. chilensis* and *P. glandulosa*, while *P. velutina* and *P. alba* were preferentially browsed. There may be variations between provenances of *P. juliflora* and *P. pallida* but because of the relative unpalatability of these species this has not been assessed.

Efforts have been made to make better use of the foliage as a feed resource. Dry matter digestibility of leaves of *P. juliflora* and *P. pallida* was found to be low by Lima (1994), at 56-59%, while other authors have found digestibility to be high. Digestible crude protein from *P. juliflora* leaves was found by Zech and Weinstabel (1983) to be 20.1%, the highest value among six common tree species in Burkina Faso. These authors also found that the content of most minerals was adequate as a feed, but phosphorus and sodium were deficient. Leaves have been mixed with other feeds as a cheap supplement to decrease feed costs while maintaining intake and live weight gains. In India, incorporation of *P. juliflora* foliage was possible, but the presence of *P. juliflora* foliage reduced intake at levels above 10% of the total feed (Shukla *et al* 1984). Chemical treatment of the foliage has been suggested to increase its value as a feed by increasing palatability.

Leaf compost

Prosopis species have an ameliorating effect on the soil under the canopy because of nitrogen fixation and because leaf litter incorporated into the soil improves the soil physical and nutritional status. A high mineral content and rapid decay of small leaves are favourable characteristics for the use of foliage as a soil ameliorant. In Peru, the fallen leaves of *P. pallida* are valued as a compost, known locally as 'puño'. Fallen leaves become abundant under some trees, forming a thick layer which is collected once it is partially decayed and added as a compost to agricultural fields (Alzamora 1988). Looking specifically at the use of foliage as a compost, Alzamora (1988) found leaves of *P. pallida* to contain 6-8% ash, 3.5-4.3% nitrogen, 45-47% carbon, 0.4-0.7% phosphorus and 1.0-1.4% potassium. In India, the use of *P. juliflora* leaves as a compost has been noted (e.g. Pasiecznik *et al* 1999), but no detailed data exist on its effects on soil fertility. Hussain *et al* (1990) observed that nitrogen released from the leaves of *P. juliflora* over 74 days was amongst the highest of nine species tested.

Constraints to the use of the foliage as a soil ameliorant are high labour costs, difficulties in collection and low accumulation because of livestock browsing or wind removal. As leaves contain a large proportion of the total levels of nutrients produced annually by the trees, continued leaf removed would have significant effects on the nutrient balance of the site. Leaf fall and decomposition are thought to play an important role in the positive effects of *P. juliflora* and *P. pallida* trees in reducing soil salinity and alkalinty (see 3.5.3). Regular harvesting of leaves from beneath the trees would thus reduce this ameliorating effect. However, use of shredded leaf and small twigs as a by-product from charcoal-making or timber production has been suggested.

Bio-control agent

Foliage and leaf extracts from *Prosopis* species have been noted to have bio-control properties. Possible active chemicals in the leaves are discussed in their use as a medicine (see 3.4.4). Extracts of *P. juliflora* are effective against some weed species, insects, nematodes, pathogenic fungi and viruses. Leaf extracts from *P. juliflora* have been found to inhibit germination in a number of species (Sankhla *et al* 1965, Sen and Chawan 1970, Goel *et al* 1989, Goel and Nathawat 1990), including some autotoxity (Warrag 1994). The use of *P. juliflora* leaves to control the invasive weed *Parthenium hysterophorus* has been assessed, with a noted reduction in seed germination (Dhawan and Gupta 1996). Germination was reduced to 21-22% with an aqueous leachate of *P. juliflora* leaves, and reduced to 7-9% with an aqueous extract (Dhawan 1995). Several *P. juliflora* leaf extracts were also effective against congress grass, another weed species (Dhawan *et al* 1996). Chellamuthu *et al* (1997) suggested that the allelopathic effect of *P. juliflora* may be due to the presence of phenolic compounds in the leaves.

A *P. chilensis* stem extract was 90% effective against the brown plant hopper (*Nilaparvata lugens*, Homoptera: Delphacidae) at low concentrations, and 'juliflorine' isolated from *P. juliflora* was found to have teratogenic effects on larvae, pupae and adults of the common house fly (*Musca domestica*) (Jahan *et al* 1990). Juliflorine was an effective insect growth regulator, producing morphological abnormalities similar to those produced by Dimilin (diflubenzuron) against larvae of *Aedes aegypti* (Diptera: Culicidae) (Naqvi *et al* 1994).

Ethanol extracts of *P. juliflora* leaves were effective against the peach potato aphid (*Myzus persicae*) but not against the diamond back moth (*Plutella xylostella*), while cold water extracts were not at all effective (Stein and Klingauf 1990). Chopped leaves of *P. juliflora* at 5 g/kg soil had a greater effect in suppressing populations of the nematode *Meloidogyne incognita* than all other species tested (Sundarababu *et al* 1990). Crude extracts from *Prosopis* species caused mortality of another nematode, *Meloidogyne javanica*, causal agent of root knot disease in okra. Use of leaves as a soil amendment significantly reduced knot galls on okra roots (Ehteshamul-Haque *et al* 1996a). Mixtures of *P. juliflora* plant extracts with those from *Paecilomyces lilacinus* were found to increase effectiveness against some nematodes and also against root infecting fungi (Ehteshamul-Haque *et al* 1996a, 1996b).

Leaf extracts of *P. juliflora* have been found to be effective against pathogenic fungi (see also 3.4.4). Positive results were seen against *Rhizoctonia solani*, cause of sheath blight of rice, root disease of okra and other important crop diseases (Sundarraj *et al* 1996). Cold water extracts of *P. juliflora* reduced germination of *Rhizoctonia solani* to 40%, and completely inhibited production of sclerotia at 10% concentration, with inhibitions also recorded at 2.5% and 5% concentrations (Ezhilan *et al* 1994). Cold water and hot water extracts of *P. juliflora* were effective in inhibiting mycelial growth of *Rhizoctonia solani*, and extracts maintained their fungitoxicity following treatment at 70°C for 10 minutes (Kurucheve *et al* 1997). Soil treatments with three *Prosopis* species including *P. juliflora* all significantly controlled the infection of *Fusarium solani*, *Macrophomina phaseolina* and *Rhizoctonia solani* on okra roots (Ehteshamul-Haque 1996b). *P. juliflora* extracts were also 65% effective against *Fusarium solani* (Vimala *et al* 1993).

Prosopis extracts were also effective against some virus diseases. A leaf extract from *P. chilensis* reduced infection of tomato spotted wilt topovirus, cause of mungbean leaf curl disease, by 96% (Manickam and Narayanasamy 1994). Yield of cowpea was increased with the application of a plant extract from *P. juliflora*, reducing the incidence of cowpea aphid-borne mosaic virus (blackeye cowpea mosaic virus) (Kannan and Doraiswamy 1993). *P. juliflora* leaf extracts are also used as a piscicide to kill unwanted or weedy fish in productive fresh water bodies. Srivasankar *et al* (1991) found total kill of fish within one hour with 200 ppm crushed leaf extract of *P. juliflora*, but no fish death was noted at lower concentrations. There was no residual effect, with 20 day old solutions causing no fish mortality. Srivasankar *et al* (1991) suggested the effect may be linked to the presence of alkaloids and that, because of its vast abundance, *P. juliflora* could be used as a stupefying agent reducing the dependence on other piscicides.

While the effects of leaves on soil fertility and some plant pests and diseases have been elucidated, no detailed studies on the effect of incorporation of leaves on agricultural productivity have been undertaken. However, the effects of such a bio-control agent on crop plant growth can be seen to be complex, with effects also on the numbers and diversity of soil micro-organisms under *P. juliflora* trees (Rao *et al* 1989). The potential of utilising fresh leaves or leaf extracts of *P. juliflora* and *P. pallida* as a valuable dual purpose bio-control agent and soil ameliorant for tropical agriculture has not been fully evaluated.

3.3.3 Foliage production

Total yields of foliage have been calculated directly from studies of biomass production and partitioning, and indirectly from regression analysis. Foliage production is dependent upon a range of environmental, climatic and genetic variables. Seasonality is important in leaf production. Non-seasonal variations in leaf production relate to general aspects of plant performance. High availability of moisture, good soil type and depth may increase crown size and total leaf area but may not necessarily lead to any increases in the rates of leaf turnover. However, under mature trees in sheltered locations, a deep mat of dry foliage can often be found, up to several centimetres thick (Alzamora 1988). It is not known how long this may have taken to accumulate.

P. juliflora and *P. pallida* are evergreen to semi-evergreen trees, with no marked period of leaf flush and leaf fall but some minor periods when leaf production or leaf senescence is more common. Lima (1994) found in Brazil that *P. juliflora* and *P. pallida* retained their leaves more than the other species of *Prosopis* tested. Leaf fall was more prevalent at the end of the dry season while leaf flush coincided with the first rains. Goel and Behl (1996) noted that in India, a period of *P. juliflora* leaf flush occurred in March and April, with a second, smaller flush from July to October.

Few attempts have been made to estimate the browse from standing trees, either from relationships with other tree parameters as a straightforward correlation, from regression equations, or from aerial photography or satellite imagery. Browse biomass is recognised as one of the most difficult of all vegetation components to measure, but analysis of the proportion of total biomass partitioned to leaves can provide a ratio that would allow an estimate based on calculations of woody biomass yields. Leaf area was found to correlate to leaf dry weight in *P. juliflora* (Burman *et al* 1995), though leaf volume was found to give a better correlation with weight by Lyon (1968, in Bryant and Kothmann 1979). In the USA, edible browse was predicted for *P. glandulosa* using crown volume, with the R^2 for the linear equation accounting for 68%, and the log-log regression accounting for 90% of the variability in edible biomass (Bryant and Kothmann 1979). Greater variability in leaf weight was seen in older trees, due to the lack of uniformity in growth or the degree to which they were browsed (Bryant and Kothmann 1979).

3.4 Plant extracts

3.4.1 Honey and wax

Flowers of *P. juliflora - P. pallida* are small, yellow and gathered on long inflorescences producing pollen and nectar that is high in protein and sugars. The proximate composition of the flower parts have not, however, been ascertained. Flowers of North American *Prosopis* species were eaten directly as a human food but this was only ever a minor use. The overwhelming use of flowers is for the supply of nectar and pollen as a bee forage for the production of honey. Honey from *P. juliflora* and *P. pallida* can also be processed into other products, or fermented into mead (honey beer). Wax is a by-product, used as an industrial and pharmaceutical raw material for the production of candles, furniture polish, creams and balms. Production can be from wild bees' nests collected from the branches of trees (Varshney 1996) but is more often from commercial hives in organised apiaries (Esbenshade 1980).

P. juliflora and *P. pallida* are the main source of pollen and nectar in many regions. Their ability to produce profuse numbers of flowers and flower regularly, even in drought years, often twice a year or almost continually, means that large bee populations can be maintained where woodlands or plantations are present. In Mexico, India and Hawaii particularly, commercial production of honey from *P. juliflora* and *P. pallida* has been developed. These industries are important to local economies, with the additional advantage that pod production is improved where hives are present (Esbenshade 1980, Varshney 1996). An often overlooked constraint to increased honey production in arid zones is water availability for bees, with a need to provide adequate quantities of fresh water near to each colony (Esbenshade 1980).

Many bee species visit the flowers (Simpson *et al* 1977) but only a few are of economic importance as honey producers. *Apis mellifera*, the common honey bee, is widely kept. In Gujarat, India, nests of the bee *Apis florea* are collected (Varshney 1996), while in Andhra Pradesh, *P. juliflora* is a nectar and pollen source for *Apis florea* and *Apis cerana* (Kalpana and Ramanujam 1990). In Brazil, the Africanized honey bee is domesticated. The foraging behaviour of bees has been studied. *P. pallida* was one of the three most visited tree species in Peru (Zevallos and Higaonna 1988), while in Brazil, *P. juliflora* was the second most important source of pollen for bees (Freitas 1994). In India, 52-95% of the pollen collected by *Apis florea* was from *P. juliflora* (Kalpana and Ramanujam 1990) while in another state, *P. juliflora* accounted for 90% of the honey produced (Varshney 1996). In Pakistan, Muzaffar and Ahmad (1991) noted *P. juliflora* as a major source of bee forage.

Honey is separated from the wax by straining through a cloth. Honeycombs are, however, sometimes heated in which case attention must be given to the possible production of toxic chemicals during heating. The honey produced by the various species of bee is noted as having excellent quality, being light in colour and flavour. In India, honey from *P. juliflora* was given an 'A' grade, and classed as one of the finest medicinal honeys (Varshney 1996), while in Hawaii, honey from *P. pallida* earns a price premium over honey from other species because of the high quality (Esbenshade 1980). In Brazil, however, the honey was said to be of an inferior grade. *Prosopis* honeys were declared adulterated in the USA, based on delta ^{13}C values being outside the range accepted there, but detailed analysis found that such high values are typical of *Prosopis* species, including *P. pallida* (White *et al* 1991). Furfural, a toxic chemical which can be produced during inadequate heat processing of honey, was detected in *P. juliflora* (Rocha 1990). The potential hazards of introducing new honey plants such as *P. juliflora* is discussed by Eisikowitch and Dafni (1988), suggesting that besides potential invasiveness, such species may attract native pollinators away from the native flora. Profuse production of pollen from *P. juliflora* has other potential drawbacks, being blamed for allergic reactions in the Middle East, India, the USA and elsewhere (see 3.5.2).

Limited information is available on the honey production per tree or per unit area. However, Burkart (1943, in Silva 1990b) estimated that bees may extract enough nectar and pollen from a single flowering tree to produce over 1 kg honey, which could yield an equivalent of 100-400 kg/ha/yr depending on tree density. Other data are more general, only relating to production over unspecified areas. Hawaii was estimated to be the largest honey producer in the world in 1930, producing over 225 t of honey/yr, primarily from *P. pallida*, with mean production (surplus) per colony estimated at 50-70 kg/colony/yr, and other estimates as high as 225-360 kg/colony/yr (Esbenshade 1980). Approximately 60 t of honey are produced annually from the collection of wild nests in Gujarat, India and 3 t/yr of wax has been produced and sold as a by-product (Varshney 1996), illustrating the great potential of honey production where woodlands and plantations are present.

3.4.2 Exudate gums

The exudate gum from *P. juliflora* and *P. pallida* appears as a viscous liquid exuding from the trunk or branches of the tree, before drying and becoming solid. The colour can vary from translucent to yellowish, generally amber, becoming darker with age. *Prosopis* gums are soluble in water with a low viscosity. They are odourless and have little taste, are non-crystalline and non-soluble in alcohol or ether (Rangel 1943, in Lima 1994). Where referring to *Prosopis* gums in the literature, it is important to differentiate exudate gums from seed (galactomannan) gums (see 3.2.1). The most important physical properties of exudate gum are light colour, solubility in water and high viscosity. The composition of *Prosopis* gum collected in Mexico was 11% moisture, 3.4% ash, 0.2% nitrogen, 0.6% methoxyl and 18% uronic acid (Anderson and Farquhar 1982). Sugar composition after hydrolysis was 3.8% 4-0-methylglucuronic acid, 14% glucuronic acid, 45% galactose, 24% arabinose and 13% rhamnose. The intrinsic viscosity of *P. juliflora* was assessed as 14 ml/g (Anderson and Farquhar 1982).

The sample of *P. juliflora* analysed by Anderson and Farquhar (1982) was found to differ considerably from exudates of other *Prosopis* species tested, by having a lower methoxyl content, a negative optical rotation, smaller nitrogen and arabinose contents and a higher proportion of rhamnose. While amino acid composition of exudates from five *Prosopis* species was analysed by Anderson *et al* (1985), neither *P. pallida* or *P. juliflora* was included. However, overall, amino acid composition was similar amongst species, and also to commercial gum arabic (from *Acacia senegal*). Commercial 'gum mesquite' from North American *Prosopis* species has also been analysed and found to be very similar to gum arabic (e.g. Anderson and Farquhar 1982, Anderson *et al* 1985). The samples analysed by Anderson and Farquhar (1982) and subsequently by Jurasek and Phillips (1993) showed that the sample of gum mesquite was probably from *P. glandulosa*. Commercial production of *Prosopis* exudate gum from South Asia and Africa could be assumed to be predominantly from *P. juliflora*.

Exudate gums have a wide variety of uses in the food, pharmaceutical, chemical and manufacturing industries. The gum of *P. juliflora* is used for sizing cloth and as a paper adhesive in India (Vimal and Tyagi 1986). The use of *P. juliflora* gum has been evaluated for use as a binder in tablet manufacture (Khanna *et al* 1997) and other pharmaceutical preparations. The gum has also been used as a stabilising agent for spray-dried encapsulated orange peel oil. Compared with gum arabic, *P. juliflora* emulsions were more stable but had a lower encapsulation capacity (80%), with no difference in flavour intensity (Beristain and Vernoncarter 1994). However, commercial gum mesquite or exudates from any *Prosopis* species are not permitted food additives in any of the regulatory listings (Anderson 1989). No toxicological study has been undertaken on the exudate gum of *Prosopis* species, but the mandatory tests required take 5-7 years and would cost over US$1 million. Considering the low present volume of trade, the chances of gum mesquite being accepted for food use are extremely slight (Anderson 1989).

The collection of the gum exudate is very time consuming and harvesting costs are a major constraint. A single person has been estimated to be able to collect 1-2 kg of *P. juliflora* gum/day in India (Tewari 1998). The trade in exudate gum has been increasing in India, with Gujarat state recording a total annual production of 850 t in 1989, with *P. juliflora* gum estimated to make up approximately 80% of that total (Tewari 1998). Seasonality of gum production was noted by Lima (1994) and Tewari (1998). *P. juliflora* gum exudation increased at higher temperatures and ceased completely at the beginning of the rainy season. Peak production occurred in India in April and May, extending to June where rains were later (Tewari 1998). In Brazil, gum production was also higher in the dry season, peaking from August to October (Lima 1994).

Total gum production per tree varies greatly, generally being very low in young trees and increasing with tree age. Lima (1994) found exudate gum production of *P. juliflora* and *P. pallida* began after the third year but was much lower than that of the other *Prosopis* species investigated, with a maximum annual yield of only 9 g and 49 g, respectively. The average annual gum yield from a mature *P. juliflora* tree was estimated to be 1 kg/tree/yr, with a range of 0.25-2.5 kg/tree/yr (Tewari 1998). There were large variations in yield between years, and a large difference in gum yields was also noted between provenances of *P. alba* and *P. chilensis* (Lima 1994). Annual variations were assumed to be associated with water availability, gum production increasing with increasing water deficit (Lima 1994), though Espejel (1980) found no correlation between climate and yield. Natural yields can often be quite low, with increases expected from artificially inflicted wounds. Gummosis has also been observed, that is thought to be related to fungal infections. Chemical treatments of trees are possible to improve gum output, and a method has been developed in India that has substantially increased production from a number of gum yielding tree species (Tewari and Harsh 1998).

3.4.3 Tannins and dyes

The tannins of *P. juliflora* and *P. pallida* are complex organic structures, comprising of phytogallotannins and pyrocatecollic tannins (Rocha 1990). Tannins of tropical woods tend to be of a cathetic nature rather than of the gallic type present in temperate woods (Doat 1978). Malhotra and Misra (1983, in Alves *et al* 1990) reported a new tannin in *P. juliflora* roots. Tannin content of the pods and leaves of *P. juliflora* and *P. pallida* have been assessed in relation to the food and feed value (see 3.2.1, 3.3.1), but it is the bark, stem wood and root wood that are generally used for extracting tannins primarily for use in curing leather. Tannin is generally obtained by boiling the macerated bark or wood but can also obtained as a by-product from the processing of timber for other chemical extractives (Parker 1982b).

The percentage of tannins in plant parts is variable but is generally highest in roots and bark. Tannins are present in the wood in various quantities (e.g. Gowda and Ramaswamy 1960). With *P. juliflora*, Kazmi and Singh (1992) found 3-8% tannin in bark and root wood, Patel (1986) found 3-8% tannin in bark and up to 9% in wood, while Vimal and Tyagi (1986) found 6-7% tannin tannin in root wood. Tannin contents increase as the tree gets older with considerable accumulations possible in dead tissue. Tan extract from all plant parts of *P. juliflora* is yellowish but generally of poor quality, possibly due to the presence of alkaloids. Tannin in *P. juliflora* roots was found to be unsuitable for tanning purposes by Vimal and Tyagi (1986). Tannins are also used in the petroleum industry, mixed with sodium hydroxide, to reduce the viscosity of drill mud, and also for making ink and conserving the fibres used in fishing nets.

There are a few references to the use of dyes specifically from *P. juliflora* and *P. pallida*, although dyes are prepared from other American *Prosopis* species. Several species of *Prosopis* have been used historically in the preparation of dyes, including the use of bark and gums in the USA (Felger 1977), roots to make a purple dye for cotton in Mexico (Martínez 1970, in Díaz Celis 1995) and a dye made from *Prosopis* branch wood of economic importance in Argentina. In India, Mohan (1940) and Vimal and Tyagi (1986) noted the use of *P. juliflora* pods to make a black dye used in the preparation of ink. The exact chemicals from *P. juliflora* and *P. pallida* involved as dyes are not fully understood but are thought to relate to the tannins and associated organic compounds with gums occasionally dissolved as a fixing agent. However, in areas where *P. juliflora* and *P. pallida* are found, there are often other species which have a higher percentage of better quality tannins which are used in preference.

3.4.4 Medicines

All parts of *P. juliflora* and *P. pallida* are used in the preparation of medicinal products to treat human ailments. There are many records of the use of these products from historical literature where *Prosopis* species are native and from recent descriptions where they have been introduced. In India, for example, an astringent decoction is made from boiling wood chips, a bark extract is used as an antiseptic on wounds, and gum is used to treat eye infections (Vimal and Tyagi 1986). In Brazil, *P. juliflora* flour is used as an aphrodisiac, syrup as an expectorant and tea infusion against digestive disturbances and skin lesions (Rocha 1990).

Because of their noted bactericidal and fungicidal effects, *Prosopis* extracts are widely used to treat four main groups of affliction; eye infections, stomach disorders, skin ailments and superficial wounds. Against optical and dermatological ailments, *Prosopis* extracts form a protecting antiseptic coat over lesions allowing tissues below to regenerate (Rocha 1990). Against diarrhoea and stomach disorders, there is a constipating action and the formation of a protective coat over inflamed mucous membrane, preventing the action of irritants and decreasing toxin absorption (Rocha 1990). In Guatemala, *P. juliflora* is used to treat sexually transmitted diseases (Caceres *et al* 1995). Anticarcinogenic effects have also been reported.

Of the many chemicals with effects on human health that have been isolated from *P. juliflora* and *P. pallida*, most work has concentrated on alkaloids, flavonoids and tannins. Several groups of piperidine alkaloids have been isolated from *Prosopis* species. Full analysis of the alkaloids has been carried out for several *Prosopis* species, including *P. africana* (Neuwinger 1996) and *P. cineraria* (Jewers *et al* 1976). The alkaloids juliflorine, juliprosine, juliprosopine, julifloricine and julifloridine have been isolated from *P. juliflora* (Vimal and Tyagi 1986). A diketone, prosopidione was isolated from *P. juliflora* leaves by Ahmad and Sultana (1989), and a cytotoxin patulitrin was found by Merzabani *et al* (1979, in Ahmad and Sultana 1989). Many flavonoids and tannins have also been isolated (Rocha 1990). An extensive list of other chemical compounds that have been isolated from *P. juliflora* bark, pods and roots is given by Vimal and Tyagi (1986).

A mixture of alkaloids from *P. juliflora* has significant inhibitory effects on gram positive bacteria (Ahmad *et al* 1988, Aqeel *et al* 1989). The minimum inhibitory concentration (MIC) of julifloricine for the gram positive bacteria was 1 µg/ml for *Staphylococcus aureus*, *S. epidermidis*, *S. citreus*, *Streptoccus pyogenes* and *Sarcina letea;* 5 µg/ml for *S. faecalis*, *S. pneumoniae*, *S. lactis*, *Cornynebacterium diphtheriae*, *C. hofmanii* and *Bacillus subtilis* 5 µg/ml, but there was an almost insignificant effect on gram negative bacteria such as *Aeromonas*, *Enterobacter*, *Klebsiella*, *Proteus*, *Pseudomonas*, *Salmonella*, *Shigella* and *Vibrio* spp. (Ahmad *et al* 1988, Zainal *et al* 1988, Aqeel *et al* 1989). A water-soluble mixture of alkaloids from *P. juliflora* leaves was more active against gram-positive bacteria than three commercial antibiotics bacitracin, chlormycetin, gentamicin or trimethoprim (Ahmad *et al* 1988).

As a fungicide, julifloricine was more effective than miconazole but less effective than econozole, two commercially available fungicides, against *Candida albicans* and *C. tropicalis* but not effective against dermatophytic fungi and viruses (Zainal *et al* 1988, Aqeel *et al* 1989). Water soluble alkaloids, mainly juliprosine and isoprosine were less active than econazole against *Allescheria boydii*, *Aspergillus* (three spp.) and *Candida* (two spp.) but more active than griseofluvin against *Allescheria boydii*, *Aspergillus* (three spp.), *Trichophyton violaceum*, *T. simii*, *T. tonsurans* and *Microsporum ferrugineum* (Ahmad *et al* 1989). Alcohol extracts of *P. juliflora* leaves inhibited *Neisseria gonorrhoea* (Caceres *et al* 1995). The fruits of *P. juliflora* contain patulitrin, which is effective against lung carcinomas (Ahmad *et al* 1988). *P. juliflora* extracts had a low antigiardiasic activity against trophozoites of *Giardia duodenalis* (Ponce-Macotela *et al* 1994).

The antifungal, antibacterial and general antimicrobial activity of plant extracts of *P. juliflora* is well established, but there are concerns as to their toxic effects. An immune response was induced in mice injected by two plant protein extracts of *P. juliflora* (Lima *et al* 1990). Julifloricine was non-lethal to mice in doses up to 1000 µg/25 g of mouse (Aqeel *et al* 1989). Topical 1% juliflorine was non-lethal to rabbits at a concentration of 2.5% but produced irritation and inflammation, lethargy, prostration and weakness (Aqeel *et al* 1991). The LD_{50} of julifloricine was 33 mg/kg in rabbits and 17 mg/kg in mice (Aqeel *et al* 1991). Cytotoxic effects were also observed with extracts of *P. juliflora* by Merzabani *et al* (1979 in Ahmed and Sultana 1989), and alkaloids were reported to cause haemolysis of rat and human erythrocytes (Kandaswamy *et al* 1989). Crushed leaves of *P. juliflora* are known to be used as a suicidal agent in India (Srivasankar *et al* 1991) and the incidence of poisoning is common in rural areas reflecting its abundance (Kandaswamy *et al* 1989). Rocha (1990) also identified the presence of the toxic chemical furfural. Tannins present are irritants of internal organs and can also bind proteins making them indigestible (Rocha 1990). Constraints to the use of *P. juliflora* extracts as a source of medicinal compounds are the presence of such irritant and potentially toxic chemicals, and further work would be required before making any recommendations for the use of *Prosopis* plant extracts for medicinal use.

3.5 Physical benefits

3.5.1 Live fencing and shelterbelts

There are many examples of the use of *P. juliflora* as a living fence. Densely planted trees are used to prevent the access of livestock to agricultural fields and homestead compounds, and widely spaced or even single trees are used to delineate field and farm boundaries. *P. juliflora* and *P. pallida* are generally medium sized to large trees and thus visible from a distance, and long lived, giving durability as boundary markers. Erect forms are preferred, although they may be lopped. *P. juliflora* is commonly used as a living fence where it has been introduced in Sahelian Africa (Madany 1991), the Middle East (Hussain *et al* 1994) and India (Muthana and Arora 1983). Thorny, multi-stemmed forms are particularly desirable for this purpose and the unpalatable foliage is a positive advantage. Living fences are effective against cattle, horses and camels but have to be particularly dense, especially close to the ground, to prevent the entry of sheep and goats. All these trees can provide additional benefits with the production and harvesting of tree products and through soil improvement. Side branches can be cut for firewood, maintaining the height of the fence and its value also as a shelterbelt.

Shelterbelts of *P. juliflora* and *P. pallida* are planted around fields in many semi-arid regions to reduce wind speed. This reduces wind-induced soil erosion, decreases desiccation by reducing transpiration and consequently increases plant and animal production. Shelterbelts can comprise one or more rows of trees, commonly three but up to ten. In India, shelterbelts of *P. juliflora* were found to have a positive effect in reducing soil erosion compared with other species and control plots. Gupta *et al* (1983) noted a 36% reduction in the magnitude of wind erosion behind *P. juliflora* shelterbelts. Shankarnarayan and Kumar (1986) noted a decrease in area wind speeds of 33-38%, 17-26% and 12-21% at distances of 2, 5 and 10 times the height of the trees, with consequent reduction in the quantities of soil removed by erosive forces. In Sudan, wind speed was reduced by an average of 14% inside *P. juliflora* plantations, and with reductions up to 36% at high wind speeds (El Fadl 1997).

3.5.2 Shade and the urban environment

Planting *P. juliflora* and *P. pallida* trees or protecting naturally regenerated seedlings for shade is widespread. They are found around houses, schools, stations or any place where people tend to sit or congregate in both rural and urban situations. They are also commonly planted as roadside trees in many arid and semi-arid areas and, if not coppiced for fuel, provide desirable shade for pedestrians and their animals. Large projects such as hotel complexes and golf courses in arid and semi-arid regions often incorporate *P. juliflora* and *P. pallida* in the landscaping as single trees, tree rows or even pruned hedges. *P. juliflora* and *P. pallida* are very common urban trees in many tropical cities in arid and semi-arid areas, both where native (Díaz Celis 1995) and where introduced (Muthana and Arora 1983, Biondi 1990).

Although *P. juliflora* and *P. pallida* do not have all the qualities required of urban trees (Biondi 1990), they are very popular because of their adaptability to a wide variety of sites and soils, their tolerance to damage and pruning, and particularly because of their low water requirements. Broad crowns and permanent greenery provide shade to pedestrians, and the fine bipinnate foliage, masses of yellow flowers and long yellow pods are attractive. In general, they are low maintenance trees. They have high survival rates and rarely require replanting. They are unpalatable to livestock and therefore are not browsed by roaming animals, although they generally require some protection when young. They are resistant to most pests and diseases and tolerant to pollution. They are nitrogen fixing, requiring no fertilisation, and require little or no watering.

However, their fast growth rates and great height are not ideal, with *P. juliflora* trees over 20 m tall reaching power lines and requiring drastic pruning (Biondi 1990). The wide, irregular canopies of trees are also less favoured, but these problems can be overcome by regular cutting. Single trees in parks, squares or other open spaces are often left unpruned, but street trees require pruning. Some rows of street trees are lopped at a height of 2-3 m, a practice giving a desirable crown form while minimising management input. A twisted or crooked trunk, low branching and thorniness are undesirable features found with some *P. juliflora* and *P. pallida*. Very undesirable features noted with *P. juliflora* in Brazil include superficial roots which damage pavements and structures, and tree instability allowing them to be overturned by wind in the rainy season (Biondi 1990).

A further problem recently identified is the allergenic nature of *P. juliflora* pollen. It was the main constituent of airborne pollen in Kuwait City (Halwagy 1994) and was also detected in Delhi (Malik *et al* 1991) and in Saudi Arabia (Kwaasi *et al* 1998). Hypersensitivity reaction to *P. juliflora* pollen was observed in 46% of patients in Saudi Arabia (Suliaman *et al* 1997) while several cases of anaphylactic reaction have also been reported (Mansfield and Goldstein 1981) and the potential danger of ingestion of pollen by allergic individuals was noted. However, allergenic proteins in *P. juliflora* pollen were found to degrade over time and following chemical and high temperature treatment (Sridhara *et al* 1992). Although allergic reactions to *Prosopis* pollen are encountered in the USA, they are still popular street trees, whereas in Saudi Arabia, research confirming the highly allergenic nature of the pollen has led to *P. juliflora* not being recommended for urban environments.

P. juliflora trees fulfil aspects of the functional and aesthetic roles required in landscaping in rural and urban contexts. Biondi (1990) considers that the use of *P. juliflora* in urban forestry is very limited. Owing to its superficial root system and tending requirements it is not recommended for street planting but presents no problems in open spaces. Díaz Celis (1995), however, considers *P. pallida* a suitable tree for urban situations because of its shade and low maintenance. An important consideration often overlooked in tropical settings is the production of resources by urban, landscaping or roadside trees. Prunings are a source of firewood and the pods are either browsed by livestock or collected as a feed for stalled animals or for sale, providing valuable resources or incomes for urban dwellers with little or no access to other types of fuel or fodder.

3.5.3 Soil stabilisation and soil amelioration

There are many instances where *P. juliflora* and *P. pallida* have been planted where soil fixing or improvement is an important consideration. They have proved particularly suitable for stabilising sand dunes and easily erodable soils (e.g. Rao 1951, Prajapati and Nambiar 1977). This is because of their ability to survive and grow on poor sites that few other species will tolerate, and the extensive lateral root system which binds soil particles, particularly in the upper 60 cm. Induced changes in the microclimate from the shade and shelter provided, offers physical protection and, combined with improved soil conditions, this favours the growth of other herbaceous species furthering the control of soil erosion. Many plantations have been established primarily to stabilise sand dunes (Sharma and Gupta 1989, Misak and Draz 1997), prevent the incursion of sand in towns, roads and fields, e.g. in Mauritania (Velde 1983), the Middle East (Wood *et al* 1975) and India (Muthana and Arora 1983), and stabilise earth bunds such as on canal sides or between fish ponds. Where soil erosion is a major problem, *P. juliflora* and *P. pallida* trees have been planted to reduce further degradation, such as on steeply sloping sites in catchments or on contour bunds (Spaak 1990), or where gulleying has occurred (Chinnimani 1998).

P. juliflora and *P. pallida* are often planted on sites deemed too poor to support other more productive land uses, and have been shown to improve soil quality significantly within 15 years (e.g. Singh 1996). The ameliorating effects involve reducing soil salinity, neutralising alkaline soils and improving soil nutritional status and physical properties. These are primarily due to complex interactions between the effects of nitrogen fixation, incorporation of leaf litter, changes in microclimate, and changes in the floral, soil faunal and soil microbial populations. An improvement in soil quality by *P. juliflora* trees has often been reported (e.g. Aggarwal and Lahiri 1977, Sharma and Gupta 1989, Aggarwal 1998) (see 2.4.4).

Plantations aimed primarily at soil reclamation have been established in saline and alkaline soils of India (e.g. Singh and Singh 1993) and Pakistan (e.g. Khan *et al* 1986) (see 2.4.4). Barren or unproductive soils can be profitably returned to agriculture via bio-remediation during a single rotation of *P. juliflora* (e.g. Patel 1986, Singh 1996). Reclamation is quicker and more effective when *P. juliflora* is planted in combination with grasses, with *Cenchrus ciliaris* and *Leptochloa fusca* most effective (Singh 1995). *P. juliflora* and *P. pallida* are also occasionally used in the reclamation of industrial sites such as quarries and tolerate otherwise polluted soils such as mine spoils and industrial waste sites (e.g. Jha 1992). *P. juliflora* has been found to be very effective in taking up toxic chemicals from polluted soils in India (e.g. Senthilkumar *et al* 1999).

3.5.4 Biodiversity and carbon sequestration

P. juliflora and *P. pallida* woodlands are important habitats for a variety of plant and animal species (e.g. Mooney *et al* 1977, Hardy *et al* 1999), several of which are collected or hunted for human uses, have become endangered and require protection. Many such woodlands have suffered as a result of fuelwood collection or the expansion of agricultural land. While no plantations have been established specifically for the purpose of wildlife conservation, some native *Prosopis* stands have been conserved primarily for this reason. Wildlife benefits from ameliorated environmental conditions and the physical protection offered by the trees. In the USA, *P. glandulosa* woodland and scrubland is maintained as a refuge for wild game and occasionally stocked with exotic game, specifically for commercial hunting purposes. *P. juliflora* is also an important source of food for wild animals where it has been introduced, such as for large wild mammals in Gujarat, India (Chavan 1986, Prajapati and Singh 1994).

Some areas of native *Prosopis* woodland or dominated ecosystems such as the UNESCO Biosphere site in La Monte, Argentina, have been given special protected status, while several national reserves throughout the native range of *P. juliflora* and *P. pallida* include these species as a major vegetation component. The genetic diversity of the trees themselves is conserved, as are the other ecosystem components. The positive benefits of maintaining or increasing biodiversity on a global level by protecting existing *Prosopis* woodlands or establishing others is stressed, while also considering the negative aspects of *Prosopis* as an invasive weed and its negative impacts on biodiversity, e.g. in Brazil (Pasiecznik and Harris 1998) and India (Jadhav *et al* 1993).

Prosopis trees and woodlands world-wide may account for a significant amount of sequestered carbon, though tree species in arid and semi-arid zones are not considered when calculating carbon balances at present. Felker *et al* (1990) estimated that carbon stored as woody biomass was equivalent to 2-20 t C/ha in *P. glandulosa* stands in the USA, with an additional 1.4-18.4 t C/ha sequestered as reserves of soil carbon, assuming 25% canopy cover (Geesing *et al* 1999). While such data is expected to vary greatly between sites and species, they indicate the considerable quantities of carbon stored in woody biomass and soil reserves. Even a single rotation of *P. juliflora* or *P. pallida* would lead to significant amounts of total carbon sequestered. Using the figures above, it may be estimated that *Prosopis* plantations could sequester carbon in excess of 1000 kg/ha/yr, with a yet unseen value in the emerging global market for 'carbon credits'. Arid zones presently contain the lowest levels of carbon in the world on a per hectare basis, and it is necessary to consider the role of arid zone forests in carbon sequestration on a regional and global level.

Chapter 4
Husbandry and management

4.1 Nursery propagation

4.1.1 Propagation by seed

Seed collection and storage

Seed should be collected only from trees that have been identified as having desirable characteristics, such as high yields of sweet pods, lack of thorns, erect form and freedom from pests and diseases. The fruiting period of *P. juliflora* and *P. pallida* varies throughout the year and can be seasonal or almost continuous. Pods can be collected from the trees or gathered off the ground. Pods that have been on the ground for more than a few days should not be collected as they are more likely to have seeds that have reduced viability or to have been destroyed by predators. In many regions, insects can destroy a substantial percentage of the seed crop. Collection of the best seed generally involves collecting pods that can be picked easily off lower branches, or fall when boughs are shaken. A hooked stick or rope thrown over the tree or branch can be used to avoid injury from thorns, and sticks can be used to remove pods that remain on the tree even after shaking.

Only the largest, undamaged pods should be collected, rejecting discoloured pods or those showing signs of herbivory, such as the exit holes of bruchid beetles. This is the first selection procedure. Collection is facilitated by large numbers of long pods and, when picked from the tree, a large number of pods per hand (i.e. the number from a single inflorescence). Access to the trees and tree form are very important. Pods are more easily collected from plants with a tree form, with a broad crown facilitating access to principal branches and access under the canopy. The amount and type of undergrowth also affects accessibility. Pods are collected easily from bare ground and, where weeds are present, cultivation around seed trees with a tractor drawn disc harrow has been recommended in the USA prior to pod maturity. In weedy invasions of dense, multi-stemmed *Prosopis*, or where there is substantial undergrowth including other woody species, some clearing would be required in order to access the trees and allow for an adequate harvest. *Prosopis* pods are gathered into sacks weighing up to 30 kg when full.

Pods are transported to a central processor, storage unit or nursery, where they are often dried before storage or processing. Sun drying is sufficient for some processing methods, and is achieved by laying pods out thinly on the ground during three consecutive sunny days. If left overnight, however, pods are likely to re-absorb some moisture and gathering in of the pods is recommended each evening. Traditional drying methods used in the Americas included covering sun dried pods with hot ashes from a fire, sometimes with periodic turning (Felger 1977). This would also kill the seed feeding insects which could otherwise destroy a store of pods. Insects can also be killed by freezing, roasting or toasting, or immersion of the pods in cold water (Díaz Celis 1995).

Heat-treatment to reduce the moisture content to approximately 8% also prevents the high sugar content pods 'sticking' during mechanical processing (Cruz 1999). Grain dryers blowing air through stacked pods have been used successfully for drying *Prosopis* pods to 10-12% moisture content in 2 days. Several wood-fired ovens and driers have been designed for drying *P. juliflora* and *P. pallida* pods, generally for human or animal feed (e.g. IPA 1988, Cruz 1999). Some large processors can dry batches of several tonnes of *Prosopis* pods to acceptable moisture levels in a single day. A second selection procedure may minimise secondary infection by removing all pods with visible bruchid exit holes.

Optimal conditions for storage of *Prosopis* seed, along with many other tropical legume seed, is refrigeration at 0°C (Díaz Celis 1995) or 4°C (Ffolliot and Thames 1983). Dusting of the pods with fungicides and, particularly, insecticides is generally recommended. Naphthalene and paradichlorbenzene were suggested for use in *Prosopis* seed stores in India by Griffith (1945), who found that these chemicals were effective and had no detrimental effect on seed germination even at high concentrations. Muthana and Arora (1983) recommended fumigation and Luna (1996) suggested carbon disulphide, hydrocyanic acid and naphthalene. The incorporation of neem (*Azadirachta indica*) leaves in seed and pods stores at rates of 10-20 g neem leaf powder or 2-3 ml neem oil/kg of seed has been suggested (Tewari *et al* 2000). A large number of traditional, bio-control methods for controlling insect pests in seed stores is given by Johnson (1983).

Pods have been stored in rooms and barns, either ventilated to keep pods dry and free from fungal attack, or sealed to prevent insect infestation (see 3.2.2). Pods are often placed in large sacks to facilitate transport. However, it is generally recommended that for nursery use, seeds are extracted before storage. These will have a much smaller volume, and should be stored in sealed metal tins or plastic bags. Dry pods can be stored for years if kept dry and free from insects and animals. Whole *Prosopis* pods have been stored for over 15 years in sub-optimal conditions, with some insect damage and variable temperatures and humidities, and the extracted seed still had viability of 40-80% (Pasiecznik and Felker

1992). However, Killian (1990) noted reduced viability of seed stored in pods rather than as cleaned seed.

Seed extraction

Whole pods, pods broken into segments or seed in their endocarps can be used to propagate *Prosopis*, but resulting seed germination and emergence is generally poor. Removal of the mesocarp and exocarp can be most simply achieved by soaking pods in water for 1-14 days (Saxena and Khan 1974) or leaving freshly collected pods in sealed bags and allowing the mesocarp to be broken down by fungal attack (Díaz Celis 1995). Controlled fungal action, although effective in seed extraction, was damaging to the seed (Kandaswamy and Venkata-Rao 1956). Pods can also be mixed with cow dung for 14 days before removal (Luna 1996). Following any of these treatments, the mesocarp pulp can be easily washed off, leaving seed still enclosed in their endocarp shells. The mesocarp may also be removed by lightly pounding the pods, or rubbing between coarse material such as sand or coarse cloth. The endocarps are rigid and fibrous and require opening to obtain clean seed. Manual extraction of seed is a very time-consuming operation with a knife or other cutting implement, and is greatly facilitated using batch methods.

Endocarps can more easily be separated after soaking in acid or alkaline solutions. Soaking is much more effective if a small amount of sodium hydroxide (NaOH) is added to the water, followed by rubbing between two folds of a coarse cloth to loosen the endocarps (Saxena and Khan 1974). Pimentel (1982) suggested soaking in a 4% solution of NaOH. Endocarp removal was also facilitated by soaking pod parts in a mild solution of hydrochloric acid (HCl) for 24 hours and washing, although all seed were killed with a 24 hour soak in concentrated HCl (Vasavada and Lakhani 1973). Valdivia (1972) found soaking with 5% HCl and rubbing with sand effective. Muthana and Arora (1983) recommended shaking in concentrated H_2SO_4 for 5 hours to completely destroy the endocarps, while a 30 minute soak was also effective (Saxena and Khan 1974, Souza *et al* 1983). However, owing to the corrosive nature of concentrated acids, use of mild alkaline solutions is recommended. Seed extracted using either acid or alkaline chemical methods may show improved germination (Saxena and Khan 1974).

Feeding pods to stalled livestock may allow clean seeds to be collected from faeces (e.g. Gomes 1961, Muthana and Arora 1983). This system is recommended for obtaining large numbers of clean seed where machinery and labour are limiting. Clean seeds are, however, not always used in large nurseries in Africa and Asia, and processing involves only removing the mesocarp and then sowing seeds in their endocarp shells. In these cases, pod soaking or feeding methods that remove the pulp and improve germination are used. Feeding or milling may be preferred as the pods then have a feed value rather than the mesocarp being wasted.

Some form of mechanical extraction, generally a modified form of existing machinery used to thresh or grind cereals, is often preferred over manual or chemical methods (e.g. Souza *et al* 1983). Equipment used includes some form of rotating wheel or drum combined with mesh screens and/or air blowers to separate pod parts and produce clean seeds. Flynt and Morton (1969) described an early modified grain thresher used to separate seeds of North American *Prosopis* pods. Pasiecznik and Felker (1992) were able to process 2 kg of pods/h, yielding 0.25 kg of clean seeds from a number of *Prosopis* species with a modified meat grinder and seed separators. Smaller quantities can be cut by hand. The seed yield by weight from dry *Prosopis* pods is approximately 10-15% by hand or small machines (Pasiecznik and Felker 1992).

Large scale threshers are also used to separate seeds in India (Kanzaria and Varshney 1998), Peru (Cruz 1999) and Argentina (Galera *et al* 1990). Some of these have been developed for milling pods into flour for animal feed but can also be used to separate clean seed (e.g. Grados and Cruz 1996). These larger machines can process over 50 kg of pods/h, more than enough to supply the seed for a large afforestation campaign. Smaller machines, such as those tested by Flynt and Morton (1969) and Pasiecznik and Felker (1992) are also suitable for large nurseries. Although a small amount of seed is destroyed during mechanical processing, coincidental scarification during the process leads to improved germination of seed.

Germination pretreatment

It is preferable if more than 90% of seed sown in the nursery germinates in a synchronised manner within seven days. The hard seed coat of *P. juliflora* and *P. pallida* prevents water uptake and subsequent germination, even when seed has been removed from the pod and endocarp (e.g. Killian 1990, Diagne 1996) (see 2.3.3). Scarification of the seed coat to aid water permeability and encourage germination, known as pretreatment, is usually required. However, in some circumstances, pretreatment is not required. Fresh seed have been seen to exhibit high germination rates without treatment, probably as a result of the seed coat not yet hardening (e.g. Ffolliot and Thames 1983, Luna 1996). Also, mechanically processed seed and seed collected from animal faeces may germinate without further treatment. Old seeds often germinate without pretreatment, probably because the seed coat has weakened over time. Seed in the middle of the pods have a higher viability than seeds in the distal or proximal ends (Killian 1990).

Pretreatment can be classified into heat, chemical and mechanical treatments. Seed from all species of section Algarobia tested are similar in their size, morphology and responses to pretreatment. Standard techniques have been developed using accepted seed testing methodologies (e.g. Catalán and Macchiavelli 1991). Most tests involve the germination of seeds on filter paper, although there is a noted variation in germination of *P. juliflora* seed on a sand medium (e.g. Torres *et al* 1994) or in soil (e.g. Harris *et al* 1996a). Sowing seeds into nursery bags introduces other factors such as sowing depth which affects germination and seed emergence. However, germination tests indicate approximately 10% germination of untreated seed, increasing to 50% with old or damaged seed and to over 90% with fresh or pretreated seeds.

Heat treatment of seed generally involves immersion of seeds in hot water and is often recommended as a simple and effective pretreatment. Pouring boiling water onto seeds and leaving to cool for 24 hours has been recommended for *P. juliflora* and *P. pallida* and used successfully with other *Prosopis* species (Catalán and Macchiavelli 1991). However, Pasiecznik *et al* (1998) found this method gave germination of only 52% with *P. juliflora*. Leaving the seed to soak for up to 5 days in the same water did not further increase final germination significantly (Pasiecznik *et al* 1998), but improved synchronisation, with a high proportion of the total germination occurring within 24 hours of removal from the water (Harris *et al* 1996a).

Scalding of seeds by leaving them immersed in actively boiling water for 5-10 seconds was found to increase germination, but longer periods of scalding led to seed mortality (Pasiecznik *et al* 1998). Incubating seed at unnaturally high temperatures can break dormancy, with *P. juliflora* seeds incubated at temperatures up to 60°C for 12-24 hours exhibiting improved germination (Tewari *et al* 1998). *P. juliflora* seed heated to 90°C for 7 days had a germination of 48% while 95°C was lethal (Sacheti 1996) and seed of a number of *Prosopis* species showed decreased germination following a dry heat of 60°C for 24 hours (Lópes and Avilés 1990).

Chemical treatments that improve germination mostly involve acids that weaken the seed coat. Sulphuric acid (H_2SO_4) is effective with *P. juliflora* and *P. pallida* (e.g. Muthana 1988, Silva 1990b, Tewari and Harsh 1998). Maximum germination rates of over 95% were achieved with *P. juliflora* seed by a 15 or 30 minute soak in 97% (concentrated) sulphuric acid, or a 30 minute soak in a 60% solution (Pasiecznik *et al* 1998). Large heats of reaction are noted following washing of acid treated seed in cold water which may also improve germination. Hydrochloric acid (HCl) has also been used but with less success.

Passage through the digestive tract is known to assist in the breaking of seed dormancy. The high rate of *P. juliflora* and *P. pallida* seedling emergence from animal faeces shows that not only are seeds cleaned, but that some weakening of the seed coat has occurred. Pasiecznik *et al* (1998) found a slight increase in the germination of clean *P. juliflora* seed following passage through a cow, while Danthu *et al* (1996) found germination rates much higher, as has been seen with other *Prosopis* species (e.g. Peinetti *et al* 1993). Different animals are known to have different effects on germination, with cattle having the most beneficial effects, followed by goats, while ingestion by sheep, camels and pigs leads to reductions in germination (Harding 1991, Danthu *et al* 1996) (see also 2.3.4). While these effects are often assumed to be due to the action of stomach acids, other chemicals in the gut may also have weakened the seed coat.

Mechanical scarification techniques have been assessed for their effectiveness in breaking *P. juliflora* and *P. pallida* seed dormancy. All methods aim to puncture or weaken the hard seed coat allowing water to enter. Seeds can be cut individually with a blade, scissors or nail clippers, to remove a portion of the seed coat. Abrasion by manually drawing the seed across a sheet of sandpaper is also very effective. Burning with a hot iron is the standard method of pre-treating small batches of seed at DANIDA (Stubsgaard 1990). Such techniques are highly effective, equal to the best chemical treatments, with over 95% germination found in most studies. However, treating seeds individually is time consuming. Pasiecznik *et al* (1998) found that a maximum of 1200 seeds/h could be individually scarified. Also, as the seeds are small, they are difficult to handle individually, and minor damage to fingers can occur.

Batch scarification involving mechanical means would be preferred for pretreating seeds, but little has been done to develop and promote the use of appropriate equipment. Machines for milling pods tend to increase the germination of seed, presumably by mechanical scarification during processing. Rotating drums with *P. juliflora* seed alone, or with sand or small stones, have been suggested for batch pretreatment. Simply pounding seeds with sand was also effective but less easy than using a drum or container for the seeds (Nambiar 1946). Firing seeds at a hard surface also improved germination markedly (Stubsgaard 1990). Shaking *P. juliflora* seed in a square tin for 10-15 minutes increased germination to over 95% (Nambiar 1946). Bandyopadhyay *et al* (1990) found that gamma radiation decreased the germination of *P. juliflora* as radiation dose increased from 1 kR to 16 kR. Other unsuccessful pretreatments have included soaking in cold water and stratification at low temperatures.

While heat treatments are not as effective as chemical or mechanical scarification, the use of boiling water is a safe, simple, cheap and straightforward technique which leads to acceptable levels of germination (over 50%). Acid scarification is very effective and simple but also more expensive and somewhat dangerous. Mechanical scarification is equally effective but can often be time consuming and thus more expensive when undertaken manually.

Mechanical scarification techniques that can be applied to large samples of seed are preferable, such as those using a rotating or shaking drum or container. The choice of pretreatment will depend on availability of labour, chemicals or equipment, and on the quantity and value of the seed to be used. For small seed samples, manual extraction and mechanical scarification is adequate, while for larger amounts of seed, either mechanical scarification by batch treatment, or boiling water treatments are recommended. Soaking of seed produced by any of these methods for at least 24 hours will improve the rate and sychronisation of germination but not final germination.

4.1.2 Vegetative propagation

Rooted cuttings

While concentrating on *P. juliflora* and *P. pallida*, references will be made to literature available on other *Prosopis* from section Algarobia sharing similar characteristics, although some differences in the rooting response of different species has been observed. Vegetative propagation of *P. juliflora* by stem cutting was first reported by Kaul (1956), who noted that cuttings took a long time to sprout, needed frequent watering and were subject to termite attack. Felker and Clark (1981) achieved over 80% rooting with shoot cuttings of *P. alba*, *P. articulata*, *P. chilensis*, *P. glandulosa*, *P. pallida* and *P. velutina*. Lima (1988) found *P. juliflora* (20%) more difficult to root than *P. alba* (44%), *P. chilensis* (54%) or *P. pallida* (54%) although the *P. juliflora* stockplants were 6 months older than those of the other species. In contrast, Harris *et al* (1996a) found in one trial, that cuttings of the *P. juliflora - P. pallida* complex exhibited much higher rooting percentages (over 70%) than those from seven other species from section Algarobia (under 30%). Significant differences were observed in the rooting performance of stem cuttings of three clones of *P. juliflora* in non-mist propagators (Wilson *et al* 1990), indicating intraspecific as well as interspecific variation in rooting ability.

Propagation by stem cuttings has generally proved more difficult with material from mature field trees than from juvenile plants. However, success has been observed with the use of larger cuttings 30-120 cm long and 1-2 cm in diameter (Vilela 1988 in Díaz Celis 1995, Sandys-Winsch and Harris 1991). Felker (1991) stated that cuttings root with very low success from mature field trees no matter what the rooting environment, giving typical figures of under 1%, although this may be due to the small cutting lengths used. Klass *et al* (1985) observed a loss of rooting ability with repeated cuttings, which De Souza and Felker (1986) considered might be due to a decrease in nutrient status of the stock plants. Rooting was considerably improved by fertiliser application to the stock plants, and was linked to the relative concentrations of nutrients, with unbalanced nutrients including high N giving slightly higher rooting. Attempts to root juvenile *Prosopis* have used stem cuttings of differing sizes, from small cuttings 3-8 cm long, used by Leakey and Longman (1988) and Klass *et al* (1985), to 15-25 cm long cuttings used by Arce and Balboa (1990) and Harris *et al* (1996a). The position of the cutting on *P. juliflora* stock plants was significant, with a higher rooting frequency from lower nodes (Dick *et al* 1991).

Various techniques have been employed to root *Prosopis* stem cuttings, including growth chambers, mist or non-mist propagators and open or sealed nursery bags. Several experiences in India, Africa and Brazil have shown that *P. juliflora* can be successfully propagated from stem cuttings placed in open nursery bags or beds without misting (Lima 1990b, Goel and Behl 1994). While rooting is possible using open bags, rooting percentages are invariably very low and much improved with a plastic covering or misting, due to increases in relative humidity in the air around the cuttings. Sandys-Winsch and Harris (1991) obtained very high rooting of long, mature cuttings of *P. juliflora* in an enclosure, while Klass *et al* (1985) reported that a polythene enclosure system routinely gave acceptable rooting percentages of *P. alba*.

Simple designs for appropriate non-mist propagators have been published (Leakey and Longman 1988; Leakey *et al* 1990) and these have been used with great effect in several tropical countries, including the successful propagation of *P. juliflora* stem cuttings in Kenya (Wilson *et al* 1990) and Cape Verde (Harris *et al* 1996a). Dick *et al* (1991) reported a marked increase in rooting of *P.juliflora* cuttings when a non-mist propagator replaced conventional misting techniques, owing to improved humidity and decreased susceptibility to rotting. Wojtusik and Felker (1993) considered that high light intensity is very important for rapid rooting and that misting is required to ensure that dehydration does not occur. A simple design for a solar-powered misting system was very successful for rooting *P. juliflora* cuttings in Haiti (Wojtusik *et al* 1994). The medium used in the propagators is also very important to rooting, with media that allow aeration, such as sand, gravel and vermiculite proving more successful than soil and manure which restrict the oxygen availability. Locally available volcanic pumice was an effective medium for rooting *P. juliflora* cuttings in Haiti (Wojtusik *et al* 1994) and Cape Verde (Harris *et al* 1996a).

Auxins are known to play a significant role in stimulating root initiation in stem cuttings of woody plants. While Dick *et al* (1991) and Lima (1988) achieved 80% success in rooting *P. juliflora* cuttings without hormone treatments, most reports are of very low rooting with untreated controls. Leakey *et al* (1990) recommended IBA (indole butyric acid) while Sandys-Winsch and Harris (1991) used NAA (naphthalene acetic acid) to root *P. juliflora* cuttings. Harris *et al* (1996a) found both IBA and NAA to be effective for rooting of a number of *Prosopis* species including *P. juliflora*, but that IBA induced rooting in some species where NAA was not at all effective. High rooting response from *Prosopis* species is commonly seen with IBA treatment only (e.g. Caceres 1983 in Díaz Celis 1995, Klass *et al* 1987, Arce and Balboa 1991). Lima (1990b) found a mixture of IBA and IAA (indole acetic acid) most effective for *P. juliflora* cuttings and Felker and Clark (1981) found a mixture of IBA, NAA and thiamine to be the most effective in rooting a variety of *Prosopis* species. Several studies have identified the need to use fungicides to prevent rotting of cuttings but care should be taken in selecting the type and concentration of fungicides as some can inhibit rooting (Klass *et al* 1987).

There have been several reports of seasonal variation in the rooting ability of *Prosopis* cuttings (Felker and Clark 1981, Klass *et al* 1985, Arce and Balboa 1991) with marked effects noted specifically on the rooting of *P. juliflora* and *P. pallida* (Lima 1990b, Goel and Behl 1995, Harris *et al* 1996a). Seasonal rooting responses appear to correlate with seasonal cycles of dormancy or active growth. Klass *et al* (1985) have shown that environmental conditions influenced the rooting of *P. alba*, with no rooting at 20°C and optimum rooting at 35°C. Very high light intensities were found to be more effective by Klass *et al* (1985) and Wojtusik and Felker (1993), while Arce and Balboa (1991) obtained success with relatively low light intensity. Optimum photoperiod for rooting cuttings was found to be 12 or 16 hours (Klass *et al* 1985, Arce and Balboa 1991).

The potential of air layering as a technique for vegetatively propagating plants from mature field-grown trees has probably been undervalued (Harris 1992, Goel and Behl 1994). Felker (1991) concluded that air layering has serious limitations because of the low success rate, long rooting periods and limited number of suitable branches. However, the successes in India (e.g. Goel and Behl 1994, Tewari and Harsh 1998) suggest that the method may be useful to obtain vegetative material for later propagation by other means. Stem cuttings taken subsequently from air layered material should be compared with cuttings from field trees to see if air layering achieves rejuvenation of such mature material. Vegetative propagation from root suckers appear unsuitable for *P. juliflora* and *P. pallida*, although some root suckering (5%) was noted with *P. juliflora* (Goel and Behl 1992).

Rooting from stem cuttings is the favoured method of propagating vegetatively, producing acceptable levels of rooting while minimising management input, but techniques still require refining if economically viable methods of mass production are to be developed. It is more likely, however, that vegetative propagation will be used in bringing selected germplasm from the field in to the nursery, allowing for subsequent multiplication and the production of small numbers of selected, clonal plants for out-planting as seed orchards.

Grafting

P. juliflora was found to be graft compatible with other species of section Algarobia (Wojtusik and Felker 1993, Harsh *et al* 1996). It was inferred that 100% survival would be possible with healthy stock plants and an experienced grafter. Of four graft types attempted by Wojtusik and Felker (1993), cleft grafting was the most successful, was easy to perform and produced uniform grafts. However, Pinto (1991, in Harris 1992) found only a 5% success rate in cleft grafting 30 year old *P. chilensis* trees, while grafting of 5 year old trees produced 25% success rate, and double 'English' grafting was 50% successful. Micro-grafting in the laboratory using stock plants at their cotyledon stage of development produced a success rate of 73% (Pinto 1991 in Harris 1992). Using mature field trees, Aguirre and Wrann (1985) found the grafting of *P. chilensis* on to itself to be 25% successful and the grafting of *P. tamarugo* onto itself to be 80% successful. Scion budwood from selected trees from the *P. juliflora - P. pallida* complex was successfully cleft grafted onto greenhouse rootstocks in the USA (Wojtusik and Felker 1993) and onto nursery seedlings as rootstocks in India (Harsh *et al* 1996). However, cleft grafting of several *Prosopis* species including *P. juliflora* was unsuccessful when carried out in the nursery with stock plants and scions of various ages (Harris *et al* 1996a).

The experiences from the USA (Wojtusik *et al* 1993) and India (Harsh *et al* 1996) show that grafting techniques are appropriate for the isolation, multiplication and dissemination of improved planting material. Selected material was taken from field trials and grafted in a greenhouse for further distribution (Wojtusik *et al* 1993). Grafted plants that have naturalised rootstocks and fast growing, erect and thornless budwood, originally from Peru have been produced and planted in India (Tewari and Harsh 1998). The potential value of grafting is to produce material with rootstocks tolerant to local conditions and budwood with desirable characteristics such as thornlessness, erect form and high pod production and there is also the possibility of topworking, using grafting to improve existing stands (Felker 1991).

In vitro *propagation*

There are reports of regeneration of complete plants from *P. juliflora* shoot tips (Walton *et al* 1990) and nodal explants (Batchelor *et al* 1989, Yao *et al* 1989, Nandwani and Ramawat 1991). Many of the factors that affect the production of whole plants *in vitro* are those that influence the rooting of conventional cuttings. Different species respond differently to the same culture conditions. For example, the relative success with which Walton *et al* (1990) regenerated plants from shoot tips was *P. glandulosa* (100%), *P. alba* (94%), *P. juliflora* (74%), *P. chilensis* (67%), *P. cineraria* (9%) and *P. tamarugo* (4%). Ramawat and Nandwani (1991) concluded that rooting could be induced in *P. tamarugo* and *P. juliflora* with relative ease compared with *P. cineraria*. Regeneration from juvenile nodal explants or shoot tips from *P. chilensis* was always better than from *P. tamarugo* and rooting responses and plantlet regeneration were always better (Jordan 1987).

The age of the stock plant from which explants are taken influences the success of regeneration. Walton (1990) reported a decline in *in vitro* rooting of *P. chilensis* shoot tips with age from 4 to 20 weeks old. Arce and Balboa (1991) obtained 80% regeneration from nodal and apical segments of 1-4 month-old juvenile material grown in pots, compared with 60% from rooted cuttings and none from field collections. Despite these observations, there are reports of regeneration from 10 year-old, field-grown *P. juliflora* by Nandwani and Ramawat (1991). Tabone *et al* (1986) showed that explant size had an effect, with 20 mm explants of *P. alba* always producing far greater shoot growth than 5-10 mm explants. Batchelor (1990) found that the top six nodes of *P. juliflora* and *P. chilensis* were most suitable for micropropagation, with 15 mm being the minimum explant size required.

A wide range of media has been used to achieve both shoot growth and root initiation. Where simple regeneration from a node or shoot tip is required, an auxin to stimulate rooting may be all that is necessary, sometimes with a low concentration of a cytokinin, usually kinetin. Walton *et al* (1990) regenerated whole plants *in vitro* from shoot tips of six *Prosopis* species with IBA. Nandwani and Ramawat (1991) rooted *P. juliflora* shoots on a medium with NAA or IBA and found that rooting increased with increasing concentrations of these hormones. Arce and Balboa (1991) obtained complete regeneration from nodal and apical segments of *P. chilensis* with NAA and cysteine, while Jordan (1987) obtained plant regeneration from nodes of *P. chilensis* with NAA and kinetin and from *P. alba* with NAA alone. Nandwani and Ramawat (1991) found that a cytokinin was essential for *in vitro* shoot growth of *P. juliflora*. Batchelor (1990) found IBA and kinetin to be effective for shoot elongation and regeneration of whole plants from *P. chilensis* nodes, while complete plants could be regenerated from shoot tips with IBA and benzylamino purine.

The nitrogen nutrition of *Prosopis* explants is important. Ammonium ions in the medium were inhibitory to shoot production while glutamine or nitrate were satisfactory nitrogen sources for short incubations (28 days) but only glutamine for longer periods (55 days) (Tabone *et al* 1986). Antioxidant treatments have been used in an attempt to counter the browning of explants and medium which has been attributed to phenolics (Jordan *et al* 1987, Batchelor 1990). Hammond (1991) reported improved rooting of *P. chilensis* juvenile shoot tips when silver thiosulphate, an inhibitor of ethylene action, was incorporated into the medium. Batchelor (1990) found no difference between high and low light intensity with *P. chilensis* shoot tip cultures, while *P. juliflora* showed a slight improvement with high light intensity. Jordan (1987) showed that root and plantlet formation from nodes of *P. alba* and *P. tamarugo* was greater at 30°C than 20°C. Batchelor *et al* (1990) found *P. chilensis* to be sensitive to the type of culture vessel, with glass containers much more successful than plastic ones, with the release of inhibitors from the plastic considered a possible cause. Multiple shoot formation has been reported, with up to seven shoots per node produced from *P. juliflora* (Nandwani and Ramawat 1991), *P. alba* (Tabone *et al* 1986) and *P. chilensis* (Batchelor 1990) cultured with cytokinins and auxins in combination.

There have been only a few limited attempts to obtain *Prosopis* plants via organogenesis from protoplasts, tissue explants or callus, in order to propagate plants or to generate further genetic variation for selection. Nandwani and Ramawat (1991) observed callus formation in *P. juliflora* explants from stems, cotyledons, hypocotyls and inflorescences, but in all cases callus did not survive after subculture on any of the media tested. Direct organogenesis from *P. chilensis* hypocotyls, callus production and root regeneration was achieved, but only one out of a total of 800 hypocotyl explants showed shoot organogenesis, and after 35-40 days in culture the callus began to deteriorate despite transfer to fresh medium (Batchelor 1990). Jordan (1987) and Jordan *et al* (1987) obtained *P. chilensis* and *P. tamarugo* callus and cultured liquid cell suspensions of *P. chilensis* with indications of aggregates and possible proembryonic structures after subculture.

All of the individual stages for *in vitro* micropropagation of *Prosopis* have been achieved in short-term experiments. Production programmes have not been established, however, because *Prosopis* species have proved recalcitrant to sustained *in vitro* culture. After a period in culture the explants tend to become chlorotic and suffer from leaf abscission and shoot necrosis (Yao *et al* 1989). Tabone *et al* (1986) also found that after 5-6 weeks in culture, shoots of *P. alba* also became necrotic and after 8 weeks were dead. Felker (1991) concludes that tissue culture propagation of *Prosopis* has not proven useful in any process related to asexual propagation as new shoots can be produced but these die after about 12 weeks in culture. Nandwani and Ramawat (1991) comment that many laboratories all over the world have worked on regeneration of *Prosopis* species but abandoned the work because of either the recurrent contamination problems or recalcitrance to regeneration. *Prosopis* can be vegetatively propagated *in vitro*, but unless micropropagation can offer positive advantages over conventional vegetative propagation by stem cuttings, the very much higher labour input, technical level and capital costs are unlikely to make it an attractive alternative.

4.1.3 Nursery husbandry

Cultural techniques

The raising of *P. juliflora* and *P. pallida* material for planting involves a nursery to give protection and control over the plants when they are juvenile and most sensitive to external factors. Nurseries vary from the most primitive, possibly consisting of a few tens of recycled containers containing seedlings, surrounded by cut, thorny branches as livestock protection, to large, high technology, controlled environment greenhouses. However, most nurseries fall in between, capable of raising from one thousand to several hundreds of thousands of plants per year in fixed beds, using relatively little technology. The location of the nursery is of fundamental importance, having to be relatively close to where the plants will be out-planted. The availability of water is also essential, particularly in the arid and semi-arid zones. Access to the planting sites, roads, the labour required and general amenities also need to be carefully considered.

The important features of a nursery are a good layout and adequate plant protection. A well designed nursery layout allows good access to all parts and minimises handling leading to lower labour requirements and less plant damage. Young plants need to be protected from injurious animals, pests, diseases and environmental stresses. Livestock are a persistent hazard and a continuous, livestock-resistant fence is essential. A living fence, or one made from dead, thorny branches can be used, but barbed wire or wire mesh, either on their own or to reinforce natural fencing materials is often used. Employing a guard is also recommended to protect against livestock and theft of equipment.

Although shading from the sun is not essential for seedling establishment, assuming water is not limiting, some form of solar protection is often recommended. Locating nurseries under tree canopies is feasible for smaller nurseries with netting suspended across a basic frame used for larger nurseries. A living fence or specially planted rows of trees can act as a shelterbelt, or windbreaks can be made and erected from a variety of local materials on exposed sites. Where less shelter from the sun and wind is available, more frequent watering is required to maintain high growth rates. Water use efficiency during irrigation depends upon the irrigation system employed and the bed system in use, and all systems are variously suited to raising plants of *P. juliflora* and *P. pallida*.

Production of planting material must be timed to be ready for out-planting at the beginning of the rainy season, to maximise soil water availability for the plants during initial field establishment. The optimum nursery establishment period is dependent on species, cultural treatment and propagation method. Planting material of *P. juliflora* and *P. pallida* is produced almost entirely from seed raised in polythene bags and seedlings require only a relatively short nursery establishment period. However, the variability of the climate in arid regions dictates that seedlings often remain in the nursery for longer periods of time and poorer field establishment is seen with the planting of seedlings with root systems that have been allowed to out-grow the containers used. Seedlings have high initial growth rates with height increments in excess of 10 cm/month under normal nursery conditions and over 20 cm/month under optimal conditions. Basic nursery management techniques involve preparing media, pot filling, sowing, watering, replicating, weeding, hardening off and selecting, before planting out. These will not be dealt with in detail in this section, as they are not specific to *P. juliflora* and *P. pallida* and are adequately covered in general publications. *P. juliflora* and *P. pallida* seedlings have no special requirements in forestry nurseries and are generally more resilient than seedlings of many other species to environmental stresses and damage from improper handling.

Sowing is recommended 2-3 months before the expected onset of the rainy season by Moreira *et al* (1982), 3-4 months by Delwaulle (1979) and 3-6 months by Silva (1990b) and Lima (1994). In India, however, either a short nursery period of 2-3 months is used, or plants are potted up into larger containers for out-planting after 9-12 months (e.g. Muthana and Arora 1983, Luna 1996), with *P. juliflora* seedlings at heights of 30-45 cm and 90-120 cm respectively. Pasiecznik (1998) found that *P. juliflora* and *P. pallida* seedlings had reached heights of 50-85 cm in 3 months prior to planting. Root damage can be reduced after 3 months in the nursery by moving containers, placing containers on an impermeable layer, air-pruning or use of larger containers, thus extending the period for which seedlings can be kept in the nursery. Stump cuttings often over 2 cm thick have also been used successfully, pruned to approximately 10-20 cm shoot length and 10-15 cm root length (Jha and Choudhary 1990).

Sowing of clean seed rather than seed in pod segment is advisable. Sowing depth of approximately 1 cm is recommended by many authors, and germination and emergence is significantly reduced at greater depths, with no seedling emergence observed with seeds sown 5 cm deep (e.g. Mutha and Burman 1998). Seeds can be sown directly into bags or into beds for transplanting into containers once emerged. A knowledge of expected seed germination aids in decision making concerning the numbers of seeds to be sown in each nursery bag. If seed in endocarps are used, at least six seed capsules should be sown per bag to account for low germination, and germination will also take much longer (Azevedo 1961, Muthana 1988). Sowing of seed in endocarps is often carried out because of difficulties in seed extraction. With boiling water treated seed and germination rates of around 50%, three seed per bag is recommended, which should ensure at least one seedling in most nursery bags. When two or more seedlings appear in a single bag, extra seedlings can transplanted into empty bags. This replication process results in minimal losses with *P. juliflora* if undertaken by experienced nursery staff. When acid or mechanical scarification pretreatments have been applied that suggest germination rates of over 95%, one seed per bag is adequate.

Covering nursery bags with moistened dry grass increased the rate of emergence of *Prosopis* seedlings (Harris *et al* 1996a) and was found to give significantly taller seedlings of *P. juliflora* after 120 days than those covered with nothing, sand, sawdust or rice straw (Passos and Ferreira 1991). Watering is required more frequently when seedlings are very young, in more exposed conditions, with more free draining potting media, following stressful events such as replicating and moving nursery bags, and during hotter weather. Water quality is generally important, but less so for raising plants of *P. juliflora* which are tolerant of saline irrigation water (Muthana and Jain 1984) and alkaline conditions (Goel 1987). *P. juliflora* and *P. pallida* seedlings are, however, sensitive to competition from weeds, and poor early establishment and growth is expected where nursery beds and bags are not regularly weeded. Rooted cuttings, or plants resulting from other vegetative propagation techniques can be raised following similar nursery practices. One exception is the raising of bare-rooted stock, which is unsuitable for hot, arid regions. Percentage survival of bare-rooted stock is less than half the survival of seedlings raised in nursery bags (Kaul 1956).

Potting media and containers

The medium must provide an adequate supply of nutrients to facilitate rapid plant growth during the nursery stage, good water holding capacity and good drainage. Where the local soil is predominantly clay, a standard mix employed is equal parts of soil, sand and animal manure, or two to three parts of soil to one part manure. The manure must be well decomposed so as not to 'burn' the young roots. Sand provides drainage. Ingredients must be well sorted or sieved to remove all stones, twigs and clumps, and mixed well. Different mixtures are suitable for different species, but *P. juliflora* and *P. pallida* are not sensitive to media type.

The nursery container in general use is the standard 'poly bag', approximately 10 cm wide and 25 cm long when full, made of black polythene with several drainage holes at the base. In India, clay pots were commonly used in earlier decades, as were earthen bricks and galvanised metal tubes, but now they have been mostly replaced by the ubiquitous polythene bags. A common problem noted from the raising of fast growing *P. juliflora* and *P. pallida* seedlings in the nursery arise from roots out-growing their containers and either growing into the soil and becoming broken when moved, or spiralling round at the base of the bag leading to root-balling. If not cut off, the roots may continue to spiral even when planted in the field leading to very poor field establishment and eventual plant mortality. To reduce the incidence of root-balling and root damage, it is best to undertake field planting at around 3 months of age before the roots out-grow the bags. Failing this, bags should be moved regularly, or larger bags used.

The use of longer pots has been suggested for use with tap-rooted legume trees, to avoid damage to the principle root and aid field establishment. Cardboard root tubes, 4-5 cm wide and 40-50 cm long when full have been used successfully to establish *P. alba*. These were suitable for machine planting and being biodegradable could be planted with the tree without removal (Felker *et al* 1988). Root trainers have been suggested as essential for the production of high quality nursery stock with no problem of root balling or root damage. These are plastic or cardboard 'cells', often with some form of vertical ridging that prevents spiralling of roots. Plastic cells can be opened, minimising root damage at planting. Many of the types now available on the market are reusable. These are more expensive that polythene bags, even if reused, and have been used more for the production of high value tree crops. Also, the cells are generally smaller than polythene bags and the resulting seedlings are smaller. It is thought that for low value trees such as *P. juliflora* and *P. pallida*, polythene bags will continue to be used as the most cost effective container for raising seedlings.

Of increasing importance in dry zone forestry is the observed value of rhizobial and mycorrhizal associations to tree survival and growth. Native soil micro-organisms such as rhizobia and mycorrhizal fungi are incorporated in the potting media whenever local soil is used, which is recommended. If inoculation with exotic strains is desired, then these must be introduced to the substrate by other means. *P. juliflora* is known to form symbiotic relationships with a range of indigenous rhizobia and, in several trials, the performance of plants inoculated with exotic strains did not exceed that of non-inoculated plants. Possible reasons put forward to explain this include native rhizobia out-competing the exotic strains, that trees develop a symbiotic relationship only after time, and that the dry or saline conditions found in the field do not facilitate nitrogen fixation (Pasiecznik *et al* 1993) (see 2.4.5). However, inoculation of nursery media with exotic strains was found to markedly increase the growth of *P. juliflora* in the field by Basu and Kabi (1987), with increases in growth of 30-150% also seen with *P. juliflora* by Diagne (1996). Inoculation with mycorrhizal fungi has also been shown to be effective in the nursery and in early field establishment (Diagne 1992), and the practice shows much potential for increasing productivity.

Pest and disease control

Physical protection, adequate hygiene and regular observation are required to reduce the deleterious effects of pests and diseases on seedling health and growth. Sound fencing or individual tree protection can protect against livestock, wild animals, rodents and other animals. Alternatively, guards and their dogs can prove very effective. Netting against birds is rarely required. Good hygiene is very important, and soil sterilisation is often recommended for nursery media, with soil solarisation recommended by Tewari *et al* (2000) as a low cost alternative to chemical treatment. Soil cleaning prior to use must remove insects and their eggs, larvae and pupae, and woody or other material than could harbour potential pests and pathogens. Regular attention should be given to removal of diseased plants and immediate treatment where possible. Natural predators should be encouraged wherever possible.

Generally, *P. juliflora* and *P. pallida* seedlings are more resistant to pests and diseases than seedlings of other species, including other *Prosopis* species, with few observed losses at the nursery stage. Small animals have, however, been known to damage many seedlings if left unwatched. Lizards have been reported as pests of *P. pallida* in Peru (Díaz Celis 1995). Grasshoppers and locusts have been known to destroy nursery seedlings of *P. juliflora* and *P. pallida* in India, as well as mature trees, but incidences in the nursery are not common, and no feasible control method is proposed. Other insect pests include ants, termites and cochineal beetles. Treatment with insecticides is recommended, while several bio-control agents for use against termites are used. A few diseases are known to affect *P. juliflora* and *P. pallida* in the nursery. Damping-off fungus (*Phytopthera infestans*), a common problem with many species, is virtually unknown on *Prosopis*, but collar rot (*Macrophomina phaseolina*) and root rot (*Fusarium* sp.) can cause serious problems to *P. juliflora* seedlings during the rainy season in India (Srivastava and Mishra 1998).

4.2 Field establishment

4.2.1 Site preparation techniques

Plantation design

The planting design and the plant spacing (tree density) to be employed is dependent upon site and climate, the land use system intended and the desired use of tree products (Table 33). *P. juliflora* and *P. pallida* are suitable for planting in a variety of locations including very arid sites, sites with poor, saline or alkaline soils, and stony sites unsuitable for other species. Being trees which produce generally low value products, they are recommended for planting on sites where other, more valuable species cannot be grown. The main restrictions to the planting of *P. juliflora* and *P. pallida* are on sites that suffer from frost, high rainfall, thin soils, on impermeable hard pans or very saline or alkaline soils. Very low rainfall, when combined with low relative humidity or a lack of permanent sub-surface water, will limit growth and may lead to mortality after several seasons.

Trees can be planted singly or in rows or blocks. A spreading crown and root system suggest that problems may arise with trees planted close to buildings or other vegetation (Biondi 1990). Trees are planted 0.3-0.5 m apart in single or multiple rows as a living fence, up to 3 m apart as a shelterbelt or still further apart for erosion control on contours or as boundary markers. In plantations, trees are planted in rows or equidistant across the site. Planting density is measured in trees per hectare. Dense stands (400-4000 trees/ha) are preferred for firewood production in woodlots or plantations, as short rotation biomass and for soil reclamation, whereas lower density stands (100-400 trees/ha) are used for pod production and silvopastoral systems. In India, very dense plantations (up to 10000 trees/ha)are used for firewood production and site reclamation on good sites with irrigation (Singh 1996), whereas in Brazil 2500 trees/ha is recommended for firewood plantations (Silva 1990b). Plant spacings employed in India for different *P. juliflora* plantations depending on desired end use are presented in Table 33.

General methods

Site preparation can involve spot, row, or whole-site cultivation. The technique chosen for a particular site will be dependent upon the site (slope, soil type and depth), tree density, desired end products, land use system intended and the availability of labour, machinery, capital and infrastructure. Agricultural machinery has been used for site preparation, predominantly in experimental and small scale plots of *P. juliflora* and *P. pallida*. In accessible sites without very stony and shallow soils, the use of machinery for site preparation has been shown to be economically viable (e.g. Singh 1996, Felker 1991). Mechanical site preparation techniques have been developed for commercial use in the Americas specifically for *Prosopis* species (Felker 1999). However, most sites to be planted with *P. juliflora* and *P. pallida* are still prepared by hand.

Standard afforestation techniques, described by Kaul (1956) and Goor and Barney (1976), can be used to plant *P. juliflora* and *P. pallida*. General techniques include weed control and cultivation. Unwanted woody shrub species and other weedy plants are controlled by mechanical or chemical techniques. Whole site or strip application of herbicides have been recommended for weed control, and found to be cost-effective for establishing *Prosopis* plantations in the USA (Felker *et al* 1984) and Argentina (Felker 1999). Mechanical means may involve brush cutters or flail mowers for bushy growth (Felker *et al* 1999). Hand clearing is more practical on sloping ground and may be preferred for employment generation, but mechanical and chemical techniques have proved more cost-effective for commercial *Prosopis* plantations (Felker *et al* 1999).

For maximum conservation of soil moisture, whole site cultivation is recommended (Felker *et al* 1986a), although this is only feasible on relatively level sites and is often prohibitively expensive. Cultivation the year before planting was found to increase the growth of *P. alba* and *P. glandulosa* in the USA (Felker *et al* 1986a) owing to significant conservation of moisture deeper in the soil profile and to the improved weed control facilitated by whole site cultivation. Row or whole-site cultivation is often carried out by a tractor with cultivator, harrow or plough, or by hand along contours on sloping sites. Spot preparation involves the digging of planting holes at the desired spacing, usually carried out by hand, but tractor powered augers have also been used to prepare planting holes for *P. juliflora* (Singh 1996).

Attention should be paid to erosion control, and to the need to prevent surface run off during and after rainfall events, and to channel as much water as possible to each planting hole. Various rainfall harvesting techniques have been successful for establishing *Prosopis* (e.g. Pasiecznik 1989, Kaarakka and Maua 1993). Contour bunds and microcatchments are the two common forms of soil water conservation for sloping ground and are generally prepared by hand. The holes into which seedlings are planted vary in size, but are generally 40 x 40 x 40 cm, as recommended by Kaul (1956), but smaller holes of 30 x 30 x 30 cm and larger holes 60 x 60 x 60 cm have also been recommended for *P. juliflora* and *P. pallida*, depending upon cultural practices, site and climate.

Site-specific techniques

Site preparation techniques used for establishing *P. juliflora* and *P. pallida* plantations vary between sites types. Tewari *et al* (2000) described site-specific techniques for preparing bare land for establishing plantations of *P. juliflora* on eight different site types found in India. These sites types are typical of many areas in which *P. juliflora* and *P. pallida* are planted around the world, and as such are summarised below. These include: sandy plains, sand dunes, shallow sandy soils, rocky and semi-rocky terrains, heavy clayey soils, alkaline soils, saline soils/brakish water areas, and ravines (Tewari *et al* 2000).

1) In sandy plains, little land preparation is required for out-planting *P. juliflora*. Planting pits of 50 x 50 x 50 cm are recommended, within a saucer-shaped basin 1 m in diameter. Soil for back-filling should be mixed with 4-5 kg manure and 50 g neem cake for termite control.

2) For shifting sand dunes, a specific three-step process is suggested. First, the area to be planted should be protected from biotic interference, with three-strand barbed wire fencing recommended. Micro-windbreaks should then be built from any locally available material against the

Table 33. Spacing requirement for various types of* P. juliflora *plantations recommended in India.

Plantation type	**Purpose** **Main**	**Secondary**	**Spacing** **Row to Row**	**Plant to Plant**	**Density** (trees/ha)
Afforestataion of degraded land	land/soil conservation	fuel wood production	3 m	3 m	1111
Sand dune stabilization	land/soil conservation	fuel wood production	5 m	5 m	400
Energy plantation	fuel wood production	(a) charcoal making	(a) 3 m	1 m	3333
		(b) pod/seed production	(b) 2 m	2 m	2500
Fodder production	pod production	(a) fuel wood production	(a) 6 m	4 m	416
		(b) seed collection	(b) 5 m	5 m	400
Timber production	timber	pods for fodder and seeds	10 m	5 m	200
Seed orchard	improved seed	pods for fodder	6 m	6 m	278
Hedge row	live fences	shelter, erosion control	0.3-0.5m	0.5m	n/a
Agroforestry and agri-silviculture	fuel and fodder	production of associated crops	10 m	10 m	100
Silvo-pastoral	fuel and fodder	production of grasses/animals	10 m	5 m	200
Road and river sides, field boundaries *	aesthetic value, wind break, soil conservation	pods for fodder	single row	3-5 m	n/a
Shelterbelts **	soil/moisture conservation, reducing wind speed	pods for fodder, shade for livestock	3 m	3 m	n/a

* *If plantation plan is for two or more rows, then keep row to row distance 3 m. However, planting should be done in a staggered manner.*

** P. juliflora *for inner and outer rows in three row shelterbelt and for second inner and second outer row in five row shelterbelt.*

n/a *not applicable*

dominant wind direction, 2 m apart at the top of the dune and 5 m apart on the dune slope and heel. Finally, pits of 40 x 40 x 40 cm are dug one day prior to planting and 2-3 kg manure incorporated with imported soil for back-filling if available.

3) In shallow sandy soils, pits 60 x 60 x 60 cm are excavated, in 1 m diameter saucer-shaped basins on flat land, or in cresent-shaped microcatchments or behind contour ridges on sloping ground. Microsites are selected where soil depth is not limiting. If a calcareous layer is present, it is broken with a crowbar or tractor-mounted auger.

4) In rocky and semi-rocky terrain, skill is required to select suitable microsites during plantation design. Pits 60 x 60 x 60 cm are dug within individual crescent-shaped bunds 15 cm high. Soil for back-filling should be of good quality, and half should be an imported mix of preferably one part pond silt to two parts sand, with 4-5 kg manure.

5) In heavy clayey soils, which often have a very thick calcareous hard pan deep in the soil profile, test pits are first dug at least 3 m deep at several locations to assess the presence and depth of the hard pan. If the hard pan is less than 1.5 m deep, a tractor-mounted auger is used to break through it, but if it is more than 1.5 m deep, the auger can compact soil on the sides, and manual digging and use of a crow bar to break the hard pan is recommended. Planting pits should be 60 x 60 x 90 cm deep, and imported sand and 2-3 kg manure should be mixed with the soil for back-filling.

6) In alkaline soils, a tractor-mounted auger should be used to prepare planting holes over 1 m deep which also break through the hard pan. Gypsum (3 kg) and manure (8 kg) are mixed with the soil for back-filling, though these quantities should be increased on very alkaline soils.

7) In saline soils and brackish water areas, trees are planted on raised bunds, which should be 1 m high, and 1 m wide at the base and 0.75 m wide at the top. The operation is labour intensive, as bunds have to be constructed manually, but can be facilitated by first cultivating by tractor on flat sites. Pits 45 x 45 x 45 cm should be excavated at the top of the bunds, and 2 kg gypsum ($CaSO_4$) and 4 kg manure mixed with the soil for back-filling, using more on increasing saline sites.

8) Ravine lands are seriously eroded, alluvium soils with parallel gulleys from less than 2 m deep to over 6 m deep. Emphasis should be on first preventing soil movement and checking further gulley extension and then reclaiming eroded land. Branch cuttings of shrubs should be planted amongst brushwood gulley plugs and soil bunds at the beginning of the rains to slow water and soil movement. Towards the end of the rainy season, pits 30 x 30 x 30 cm should be dug between the bunds in saucer-shaped basins 1 m in diameter. No soil amendments are required.

4.2.2 Planting and establishment

Nursery stock

Planting commences as soon as possible after the first significant rainfall event, generally assumed to be greater than 50 mm. Trees are distributed and some soil is returned to the planting hole, with any soil amendments as required. Containers are removed and, with minimal disturbance to the root ball, the tree is placed in the hole. Remaining soil is applied and then firmed down. If the plant roots are seen to spiral in the base of the bag, these should be cut off with a knife. Other roots or stems can also be removed at planting, though unnecessary damage to the plant at this sensitive time is not recommended. It is important to stress the need for a well-trained work team or adequate supervision, to ensure that holes are not left unplanted, and that seedlings have their container removed and are planted with the root collar at ground level.

Fertilisers, manures or composts can be used to increase nutrient supply or overcome a particular nutrient deficiency in the site, and are often incorporated into the planting hole at the time of planting (e.g. Tewari *et al* 2000). However, the ability of *Prosopis* to fix nitrogen and tolerate poor soils means that fertilisation is not often essential for growth and has been observed as having no effect on the growth of *P. juliflora* (Basu and Kabi 1987). Water is more often limiting to growth. Amendments to neutralise the high pH and provide the plant with deficient nutrients have proved successful in establishing *P. juliflora* in highly alkaline soils, with combinations of gypsum and farm yard manure improving survival and tree growth (Singh and Singh 1993, Singh 1996).

Water is required if there is insufficient soil moisture and can be added to the base of the hole prior to planting or superficially after planting. Where flood irrigation is possible, the site should be allowed to dry out prior to planting to improve access, but trees should be irrigated immediately afterwards. Irrigation can then be undertaken as frequently as required. Drip-line irrigation has been used on experimental and ornamental *Prosopis* plantations. Irrigation by hand is often impractical and prohibitively expensive (Anttila *et al* 1993). *P. juliflora* and *P. pallida* seedlings have survived and grown well with no rain in 15 months post planting (Harris *et al* 1996b).

Seedlings of *P. juliflora* and *P. pallida* are sensitive to competition for light and moisture during early establishment. Hand clearing for at least 1 m around the planting hole at the time of planting is generally recommended to minimise weed competition (e.g. Ribaski 1990). Once the tree has been planted, physical protection can be offered against animals and for shade and shelter, particularly on sand dunes (e.g. Velde 1983, Tewari *et al* 2000). Mulching with stones and/or uprooted vegetation provides a cheap, simple and effective means of reducing evaporation around the planting hole and is recommended where suitable materials are readily available. Beating up may also be required soon after planting, replacing trees that may have died due to root damage, insect or rodent attack or planting shock before the end of the same rainy season.

While planting of *P. juliflora* and *P. pallida* is carried out almost entirely by hand, mechanical transplanters have been used successfully to plant *Prosopis* seedlings in the USA and Argentina, raised in long paper plant-bands (Felker *et al* 1988, Felker 1999). Felker (1999) undertook a full economic analysis of establishing *Prosopis* in Argentina. This included two discings, sub-soiling and a herbicide treatment a year before planting, and marking out with applications of pre-emergence herbicide, insecticide and rodenticide at planting. Sweep cultivation, staking and pruning of trees are the tending activities, followed by beating up and cultivation, herbicides and pruning at yearly intervals for the first four years. Additional pruning was also costed in for years 10, 15 and 20 (Felker 1999). The total estimated cost including overheads for all these establishment and tending operations was US$2135/ha.

Management of natural regeneration

Protecting or transplanting naturally regenerated seedlings and promotion of natural regeneration can be employed to establish *P. juliflora* and *P. pallida* seedlings. Such selective wilding retention and wilding transplants offer the potential for establishing seedlings without the need and costs involved in raising stock in the nursery. Where seedlings (or wildings) establish naturally on non-agricultural land they are left to grow, often cut for firewood, but rarely killed or removed. On annually cropped land, seedlings are killed by ploughing, but on land cultivated by hand, the destiny of seedlings is dependent upon the farmer or land owner. On rainfed land in Cape Verde, it was noted that many farmers removed some *P. juliflora* seedlings but left well-spaced plants (e.g. over 5 m apart), while *P. juliflora* seedlings were always be removed from irrigated land (Pasiecznik 1998).

Naturally regenerating *Prosopis* seedlings can also be propagated through wilding transplants. These can be dug up, carefully retaining as many of the roots as practically possible, and transplanted to the desired location at the beginning of the rainy season. Seedlings are generally taken from close to a mature tree known to possess superior characters, normally high yields of sweet pods and lack of thorns. This offers possible genetic improvement in pod sweetness and thornlessness, though outcrossing and environmental considerations means this by no means certain. Selective wilding retention and wildling transplants have been observed by the authors as methods of propagating *P. juliflora* and *P. pallida* seedlings in parts of Mexico, Peru, Argentina, Brazil, West Africa and India.

Natural regeneration in an area without significant numbers of mature *Prosopis* trees can be promoted through the introduction of livestock purposefully fed *Prosopis* pods (El Houri 1986, Muthana 1988). The seed, largely cleaned and pretreated during passage through the animal, is deposited in faeces across the chosen site. Successful rates of establishment have been achieved by feeding *P. juliflora* pods to stalled cattle before letting them out to graze an area where seedling establishment was desired. If carried out at the beginning of the rainy season, this was deemed an efficient and cost-effective method of stand establishment in India (Muthana 1988), and successful establishment of several *Prosopis* species was also achieved in Argentina, with an estimated two seedlings germinated per kg of pods fed (Marmillon 1986).

Direct seeding

Direct seeding does not require the use of a nursery and involves a variety of techniques that are modifications of natural regeneration. Pods of selected trees are collected and either broadcast or placed in shallow holes or trenches and covered with soil, but resulting seed germination and establishment is very low. Percentage establishment can be improved by soaking pods in water for several days, or by sowing endocarp segments or, better still, clean and pretreated seeds. The short rainy season, however, often offers insufficient time for the seedlings to become well established before the dry season begins. If possible, the site should be cultivated one year in advance in order to maximise the conservation of soil moisture available for plant growth in the following year. Direct seeding was a common method for establishing *P. juliflora* in India but is now largely replaced by the planting of nursery stock (Muthana and Arora 1983). In Argentina, direct seeding has proved successful for establishing a number of *Prosopis* species (Marmillon 1986).

To ensure a rapid and synchronised germination, seed should be pretreated prior to sowing. Spot or row sowing has been used with some success to establish seed of *P. juliflora* and *P. pallida*, with seed sown thickly at the beginning of the rainy season. Row cultivation and direct seeding can be carried out to establish contour vegetation strips, living fences and shelterbelts. A method used in India to establish *P. juliflora* is the construction of ridges and furrow intermittently across a site into which three rows of seed are sown. One row is sown on the top of the ridge, one half way down and one near the base of the furrows, ensuring the survival of at least one row, as the bottom row is killed in very wet years and the top row killed in dry years. If the whole site has been cultivated, seed can be broadcast. Aerial seeding has been carried out over large areas of India with some success and, although survival is very low, the large areas that can be covered and the low cost of seed still make this a viable method of propagation in inaccessible regions (Sharma 1985).

4.2.3 Plant protection

P. juliflora and *P. pallida* are generally more tolerant than other tree species to damage from rodents, livestock, insect pests and diseases. While few are lethal to the trees, several can significantly reduce overall survival and growth rates in plantations, and affect production in naturalised or native stands of trees. Pests and diseases affecting seedlings in the nursery have been discussed earlier (see 4.1.3). Control methods involve fencing against livestock, baiting for rodents and chemical treatments against insect pests. However, the high cost of such control methods often precludes their use in *Prosopis* plantations. Where certain problems cause major damage, replanting with more resistant species, accessions or selected individuals is recommended.

Rodents

At planting and immediately thereafter, rodents pose a serious threat to the survival of *P. juliflora* and *P. pallida* seedlings in some regions. In India, rats, squirrels and other small mammals can completely destroy whole plantations of *P. juliflora* (Muthana and Arora 1983, Rana and Jain 1984). Rodents eat the cotyledons, young leaves and buds, and gnaw at the roots, base of the stems and even the trunks of trees 2-3 m high, leading to plant mortality. Control methods involving baiting with poisons applied to grain have proved effective and are recommended for establishing *P. juliflora* plantations in northern India (Rana and Jain 1984). However, potentially harmful effects on other animals, both livestock and wildlife, must be considered. Lizards are also a problem pest in establishing plantations in Peru (Calderón 1986). Individual tree guards made from wire mesh have proved effective against small mammals (Pasiecznik 1989), but physical barriers such as tree guards and rodent-proof fencing are likely to be uneconomical for establishing plantations of *P. juliflora* and *P. pallida* in most situations. Where damage to seedlings is widespread, use of alternative species or other methods of control should be investigated.

Livestock

Mature foliage of *P. juliflora* and *P. pallida* is generally unpalatable to livestock, but the young, green shoots and buds are more palatable and damage to young seedlings is common when other sources of forage are unavailable. Goats and sheep browse *P. juliflora* and *P. pallida* more than cattle, horses and camels (see 3.3.2) and wild animals can also cause significant damage. Juvenile seedlings of *P. juliflora* and *P. pallida* are more tolerant than those of many other tree species to browsing damage, but damage of the terminal bud will lead to the formation of generally undesirable multi-stemmed forms. Physical protection with stone walls, fences, oil drums or vehicle tyres, can be used with single trees or rows planted in towns or around dwellings. Plantations can be fenced, or livestock otherwise restricted from entry into plantations to increase seedling survival and aid early growth and establishment, although complete protection is very difficult as animals often breach or jump fencing. As with rodent protection, individual tree guards and well maintained fencing is generally prohibitively expensive for large plantations.

Livestock can, however, also have a beneficial effect in seedling establishment by their role in controlling weeds, thus reducing competition for light and moisture, and by adding nutrients to the site through dung deposition. Once the upper crown of *P. juliflora* and *P. pallida* trees are high enough to avoid browsing damage, stock should be allowed access to plantations. While some breaking of branches and bark stripping has been recorded, the damage is generally regarded as minimal. There are noted differences in the palatability of several provenances of the *P. juliflora* - *P. pallida* complex and unpalatable selections could be planted where browsing is likely to be damaging to young plantations. Lee *et al* (1992) identified several trees grown from Peruvian seed, amongst a trial containing many *Prosopis* species and seed sources, that remained unbrowsed following the accidental entry of goats.

Pests and diseases

Many invertebrates inflict damage on *P. juliflora* and *P. pallida* seedlings and mature trees. Most are insects, but nematodes have been recorded from soil under the canopies of *P. juliflora* and may be harmful. Insect pests of *P. juliflora* are presented in Table 18 (see 2.4.5) and some country-specific lists are available for Peru (Díaz Celis 1995), Brazil (Arruda *et al* 1990, Lima 1994) and India (Singh 1998, Yousuf and Gaur 1998). Some insects that cause widespread damage such as seed feeding beetles, mostly of the family Bruchidae, are not harmful to the health of the tree itself.

Ants and termites are only damaging to seedlings and young trees of *P. juliflora* and *P. pallida*. They attack roots and leaves reducing growth rate, but termites, particularly, can cause widespread mortality in young *Prosopis* plantations. Termites are a serious pest in young *P. juliflora* plantations in India but can be effectively controlled with the use of chemical insecticides (Muthana and Arora 1983) or biological treatments (e.g. neem, Tewari *et al* 2000) applied to the base of the planting hole or mixed with the planting soil. Other insect pests injurious to *P. juliflora* and *P. pallida* trees include defoliators, sap suckers, flower eaters, seed feeders and wood borers (Table 18, 2.4.5).

Twig girdlers are found throughout the Americas and are important pests of several *Prosopis* species, ring-barking branches up to 3 cm in diameter and causing the proximal end of the branch to die and fall to the ground (Felker *et al* 1983b, Lima 1994). While rarely fatal, killing the terminal shoot promotes a shrubby form and repeated infestations severely impede growth and establishment. *Oncideres limpida* can become a serious pest in Brazil (Arruda *et al* 1990), being the only one of four species of twig girdler found to affect only *P. juliflora* and *P. pallida* in a plantation of six *Prosopis* species (Lima 1994). Control of these insects involves burning fallen branches to kill the eggs laid there.

Psyllids are another major problem in the Americas, attacking buds and significantly reducing tree growth. They were effectively controlled on *P. glandulosa* with the application of insecticides (Felker *et al* 1983b). While affecting *Prosopis* in the Americas, these psyllids have not yet been recorded in any frequency elsewhere. The possibility that an injurious psyllid could begin to seriously damage *P. juliflora* and *P. pallida* world-wide, similar to the damage caused globally to *Leucaena leucocephala* cannot be discounted. Locusts, grasshoppers and larvae of various species have also been reported and can cause completely defoliation but they are not fatal to mature trees and no control methods are suggested.

Beetles of several species cause damage by boring tunnels through the wood of living trees and dead wood. The sapwood is very susceptible to insect attack, while the heartwood is more resistant. Beetles have been recorded on several American *Prosopis* species whose timber is of commercial value (Fiorentino and Bellomo 1995), and the formation of tunnels or galleries can render the wood worthless as a timber. Chemical treatments have been recommended for some of the insect pests, but application is generally not economic. Biological control agents have been identified for potential use against several insect pests (Johnson 1983).

Several diseases attack the stem, branches and leaves of *Prosopis* (Lesney and Felker 1995, Srivastava and Mishra 1998). Some diseases were observed in young *P. juliflora* plants in India, notably the root rot *Fusarium* spp. and the collar rot *Macrophomina phaseolina* (Srivastava and Mishra 1998) (see also 4.1.3). In older *P. juliflora* trees in India, the leaf blights *Colletotrichum capsici*, *C. cymopsicola* and *Ravenelia spicigera*, a twig blight *Diplodia prosopides* and a stem canker *Botryodiplodia theobrmae* were observed (Srivastava and Mishra 1998). Cankers and tip-dieback in *P. glandulosa* in the USA were identified as caused by *Lasiodiplodia* sp. and *Pestalotiopsis* sp. (Lesney and Felker 1995) and stem cankers have been observed on *P. pallida* in Peru (Díaz Celis 1995) although they are not thought to restrict growth. No control methods have been suggested, possibly because of the low severity of attacks and limited effects on tree growth.

4.3 Stand management

4.3.1 Land use systems

In this section, *P. juliflora* and *P. pallida* stands are classified into native woodlands, naturalised stands, firewood plantations, agroforestry systems and weedy invasions. Weedy invasion are of sufficient importance to be dealt with in a separate sub-section (see 4.3.3). These classifications can be sub-divided by the density and form of the tree component, the management system applied and the system outputs. Ten distinctive stand types have been identified (Table 34) and the form of the trees and understorey approximating to selected stands are presented (Figure 21). Each stand type has a principal output, secondary products and other minor outputs with potential for increased production. Ranges in plant densities for each stand type have been estimated (Table 34). While accepting that there is some overlap between several of the ten stand types in terms of density and outputs, some classification is required for describing the system and assisting in the formulation of management options. It is hoped that this will allow for the improvement in understanding and management of *Prosopis* based land use systems.

Native woodland

Native woodlands exist only from Peru to Mexico (see 2.4.1). Plant density varies considerably, from dense stands, generally found in saline or coastal areas with greater than 2000 trees/ha, to scattered, mature trees more often found in upland and inland sites with densities as low as 5-10 trees/ha. Where abundant, *P. juliflora* and *P. pallida* can occur in almost pure stands and, when scattered, they are often separated by other tree species. Associated species are listed for Peru and Central America in Tables 15 and 16 (see 2.4.5). There is limited information on tree density in the native range but in northern Peru the density of *P. juliflora* and *P. pallida* ranges from 40 to 200 trees/ha (Díaz Celis 1995). While it may be expected that native stands are uneven-aged, seedlings tend to establish more frequently in wetter, more favourable years. Where the very wet years occur periodically and are marked in their intensity, as with the 'El Niño' weather phenomenon in the Americas, stands may be predominantly even-aged, corresponding to these high rainfall years.

As well as variable tree densities, native woodland can be found with very different tree and stand forms, vegetation associations and site types. These differences make it difficult to standardise management systems. The shrub forms of *P. juliflora*, more common in Central America and the Caribbean, particularly along the coast, are not amenable to management other than occasional cutting or coppicing for firewood. While these plants do produce pods, their sweetness varies considerably and yields are generally poor. Single trees are often managed, whether within native stands, isolated on farmland, along roads or around settlements. Pods are picked for fodder, branches are pruned for firewood and larger trunks may be used for construction. Of most interest are the management systems applied to the extensive dry areas of Peru, Ecuador, Colombia and Venezuela, containing open to dense woodlands in which *P. juliflora* and *P. pallida* often dominate.

In some areas of northern Peru and Ecuador, *P. juliflora* and *P. pallida* may appear in almost pure woodlands which used to occur over vast areas. Many of these have undergone severe over-exploitation for fuelwood since the arrival of colonists and the remaining woodland is much depleted (see 1.4.1). These woodlands occur predominantly in dry coastal and inland sites in Peru and Ecuador and contain mostly *P. pallida* but also *P. juliflora* and hybrid forms. These woodlands are an essential resource for rural inhabitants in these regions, with the ubiquitous *Prosopis* trees providing food, firewood, animal feed, fencing and timber. It is in this region that most use is made of the pods as a human food, playing a valuable role in family nutrition and in providinga cash income. Pods are gathered by hand for sale or conversion to food products. *P. juliflora* and *P. pallida* woodlands are a valuable grazing resource, particularly during the dry season (Gomes 1961). Pods are extensively browsed by livestock although some are collected and stored or processed for animal feed. Trees are also harvested for firewood, wood for charcoal, fence posts and construction timber.

Little systematic management is applied to these woodlands, which are harvested on an extensive basis. As demand for fuel for industry and urban populations increased, so did pressure on these woodlands as sources of wood and charcoal (see 1.3.3). Indiscriminate harvesting of *P. juliflora* and *P. pallida* has occurred on a large scale, but recently an increasing awareness of the need for sustainable harvesting has led to more controlled use of these resources. Projects have been established to promote sustainable management and maximise the use and value of tree products. Local government controls some of the harvesting of fuelwood and pods from common lands, and some replanting of areas and controlled grazing to promote natural regeneration is taking place. More work is required on the identification and conservation of superior trees and stands in this region, and in optimising management systems.

In Colombia and Venezuela, *P. juliflora* is a common component in the savanna-like landscapes found in dry montane valleys and on parts of the Caribbean coast. Here, trees are seen mainly as a source of dry season fodder or forage from the pods. Several studies analysing animal production

Table 34. Classification of* P. juliflora *and* P. pallida *stand types and system outputs.

Stand type	**Density (trees/ha)**	**Fuel**	**Poles**	**Logs**	**Forage**	**Fodder**	**Food**	**Game**	**Other**
Native or naturalised stands									
Dense infestation	>2500	xx	-	-	-	-	-	x	-
Weedy thicket	1000-2500	xx	xx	-	xx	-	-	xx	x
Closed woodland	200-1000	xxx	xx	x	xx	-	xxx	xx	xx
Open savanna	10-200	xx	xx	xx	xxx	xx	xx	x	xx
Managed stands									
High density single rotation	2500-10000	xxx	xx	xx	-	-	-	-	x
Short rotation coppice	1000-5000	xxx	xx	-	-	-	-	-	-
Closed plantations	400-625	xxx	xx	x	xx	x	-	x	x
Extensive or controlled grazing	100-625	xx	x	x	xxx	-	x	x	x
Open understorey management	25-200	xx	x	x	xx	xxx	x	-	xx
Integrated agroforestry	25-625	xx	xx	xxx	xx	xx	xx	-	xx

Fuel - firewood (domestic), fuel wood (industrial), charcoal, converted biomass
Posts - fence posts, poles and small roundwood for light construction
Logs - trunks over 20 cm in diameter and over 1 m long, suitable for sawmilling
Forage - browsed pods and/or forage understorey
Fodder - collected pods and/or cut and carry fodder
Food - processed pods and/or honey
Game - hunting of wild animal using trees as cover
Other - medicines, fibres, wax, tannin, dyes, exudate gums, physical benefits

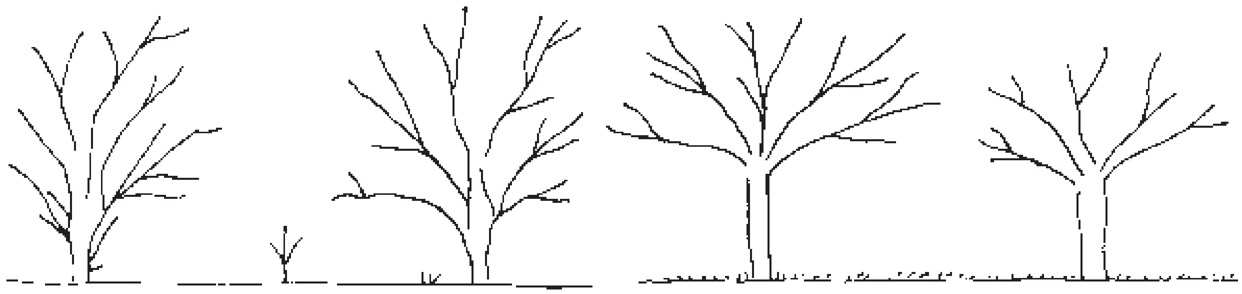
xxx *- principal output*
xx *- secondary output*
x *- minor product*
\- *- not an output*

in the dry zones of these countries have noted the value played by trees, including *P. juliflora*, in the provision of animal nutrition (e.g. Díaz Celis 1995). While the leaves are said to be palatable to some animals, the pods are recommended for feeding to all livestock, including rabbits and chickens (Díaz Celis 1995). However, *P. juliflora* is noted as a weed in some areas, invading water courses, agricultural and pasture land, possibly because of uncontrolled stock movements that can disseminate seed widely (see 1.4.2). Some cutting for firewood and fence posts also occurs, and the trees are a valuable source of honey, as cover for game and for medicines, tannins, dyes and gums. They can be managed as an agroforestry system, though this is often only practised on an extensive basis.

More detailed studies have been undertaken on the stand dynamics of other native *Prosopis* species in the USA, Mexico, Argentina and Chile. Felker *et al* (1990) describe native stands of *P. glandulosa* in the USA with 6-19000 trees/ha, and Felker (1991) divided them into weedy stands (over 4000 trees/ha), closed stands (400-4000 trees/ha) and open stands (under 400 trees/ha), and stated that each has different management requirements. What is a weedy invasion or a dense stand varies depending upon the land use system

Native and naturalised stands

Managed stands

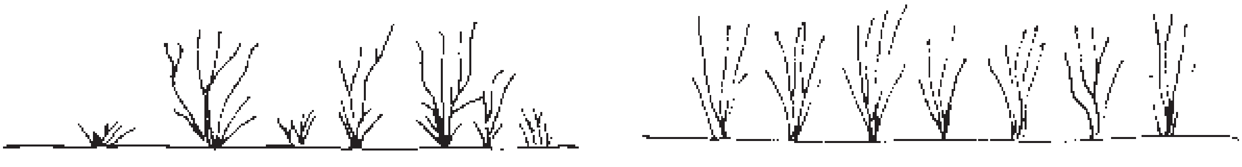


Open savanna
<100 trees/ha

Open silvopastoral
100 trees/ha

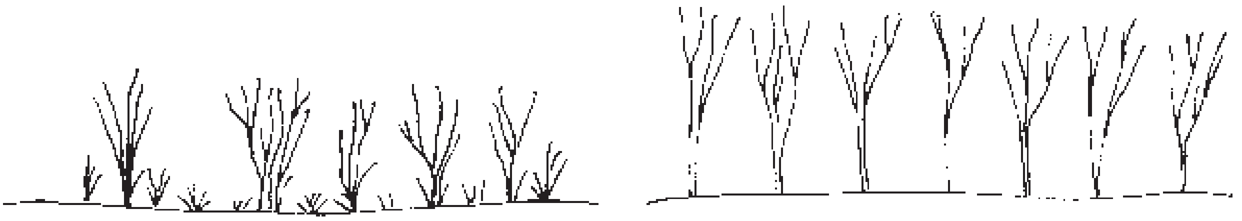
Closed stand
~400 trees/ha

Extensive or controlled grazing
400 trees/ha



Weedy thicket
~2500 trees/ha

Short rotation coppice
2500 trees/ha



Dense infestation
>5000 trees/ha

High density single rotation
~5000 trees/ha

Figure 21. Schematic representation of tree and stand form for selected stand types where* P. juliflora *and* P. pallida *are the dominant components. Scale width of each subfigure is 16 m.

present and the attitude and opinions of land owners and farmers. It is not just the density, but also tree form and age which affects classification of such stands. In the USA, detailed studies of native stands of *P. glandulosa* by El Fadl *et al* (1989), Felker *et al* (1990), Meyer and Felker (1990), Cornejo-Oviedo *et al* (1991, 1992), Patch and Felker (1997), Villagra and Felker (1997) and Patch *et al* (1998) have looked at all *P. glandulosa* stand types and aspects of their management.

Naturalised stands

Naturalised stands are found where *P. juliflora* and *P. pallida* have been introduced and have escaped into the wild. They tend to occur along water courses, on common lands, on urban and rural waste land and also on and around pasture and cultivated land. In places, sometimes over extensive areas, stands have become very dense, impenetrable thickets which require specific management interventions (see 4.3.3). Naturalised stands occur in most countries where *P. juliflora* and *P. pallida* have been introduced, and are common in dry areas of Brazil, Sahelian Africa, the Middle East, Pakistan and India. In other regions such as southern Africa and Australia, they are generally classified as weedy invasions rather than naturalised stands (see 1.4.2). Stands can be even or uneven aged, but comprise smaller diameter classes than will be found in native stands.

While most trees arise from natural regeneration, some trees in the landscape, particularly around settlements and along paths and roads or in and around fields, have been planted by land owners acknowledging the value of trees and their products. In other instances, seedlings of *P. juliflora* and *P. pallida* are protected and encouraged to establish, while others are weeded out as wilding management (see 4.2.2). These naturalised trees are mostly a source of firewood and animal fodder. Wood is harvested either by coppicing or, where a tree form is desired, by cutting side branches or cutting mature trees at approximately 2 m above ground level. Fence posts and some small construction timber is also produced. Pods are an important source of animal feed particularly during the dry season (e.g. Silva 1990b) and are often collected from the trees or the ground below and fed to stalled livestock (see 3.2.2). Extensive grazing is practised under trees when present over large areas. When well established, naturalised stands can be managed in a similar fashion to native woodlands, as they serve similar functions such as cover for game and provision of various resources on an extensively managed basis.

Firewood plantations

Firewood plantations are high density plantations established primarily for the production of firewood for local domestic use, fuelwood for industrial or urban uses, or bio-fuels for the generation of power and electricity. They are almost always established in pure blocks and are, by definition, even-aged. However, differences in growth rates between individual trees may lead to large differences in tree size. A higher intensity of management is applied and growth rates are expected to be higher than those of trees in naturalised or native stands. The aim is to maximise production of woody biomass at minimal cost. Density can vary from 400 trees/ha (5 x 5 m spacing) on poor and/or arid sites to 10000 trees/ha (1 x 1 m spacing) on fertile and/or irrigated locations. Wider spacings allow more light at ground level promoting weed growth but also allows the possibility of under-grazing. Three management systems have been identified that are applied to plantations of *P. juliflora* and *P. pallida* planted principally for fuel: single rotation stands, short rotation coppice and open stands.

Single rotation stands involve planting at high density with the aim of clear felling at an appointed age, usually 10-20 years. This system has been employed successfully in northern India where it has also been used for reclaiming highly alkaline and saline soils (Singh *et al* 1988a). Following clear felling, stumps can be removed and the land returned to agricultural use (Bhojvaid *et al* 1996). In irrigated plantations, Singh *et al* (1990) found that biomass production of *P. juliflora* was higher at a stand density of 10000 trees/ha than at 5000 trees/ha. Singh (1996) calculated the economic viability of this system. For production of firewood alone, good internal rates of return were generated over a 15 year rotation. The reduction in pH and soil salinity, and the increase in soil nutrient status and physical properties that follows a 15 year rotation of *P. juliflora* has been quantified (Singh 1996). Soil improvement following such an extended ‘tree fallow’ has not been calculated in economic terms and would add to the profitability of the system. The increasing interest in the value of *P. juliflora* as a timber in India has led to the sale of trunks from some sites as saw logs, greatly increasing profitability. In high density plantations, trunks tend to be straight with few branches and are more suitable for sawing. In northern India, several plantations have been established by the state on common land, with responsibility passed over to the local villages after several years. These stands will produce only limited pod yields. They may be converted to coppice stands by stump retention or to other stand types following thinning.

Short rotation coppice stands, which are coppiced at set intervals (normally 1-5 years), are common for producing firewood, fuelwood and charcoal. Coppice stands should be divided into blocks such that at least some parcels are available for harvesting each year. These are also planted densely (up to 10000 trees/ha), but slightly wider spacings improve coppice regrowth per tree. Under-grazing of livestock is not possible. Pod production is negligible because of frequent harvests. Coppice stands are often established on flatter, more productive sites, and production can be greatly increased by irrigation. Fertilization is recommended because of the frequent harvests. Although many plantations are tended and harvested by hand, coppice plantations allow the use of mechanical harvesters, such as those developed for use on *P. glandulosa* in the USA (Ulich 1982, Felker *et al* 1999). The wood harvested from such stands can be used and sold as firewood, processed into charcoal or converted to a bio-fuel (see 3.1.2).

Open stands are found on poorer sites, planted at typical densities of 400 and 625 trees/ha (5 x 5 m or 4 x 4 m spacing, respectively). The aim is to produce firewood on a rotational basis every 5-10 years, with some parcels harvested each year to maintain a continuous harvest. Livestock production is a secondary output. Wider spacings and less frequent firewood harvests allow for an increase in the growth of understorey forage species and increased pod production. The harvesting and grazing of such plantations should be controlled to maximise outputs of desired stand products. The harvesting system varies from complete coppicing of trees to pruning of the trees to one or a few erect stems. A mixture of management interventions may be used on the same stand, depending on tree size, form and spacing. This allows the development of some erect trees with broad crowns with the potential to produce valuable pod yields. These can be thinned out to wide-spaced stands (100-200 trees/ha) with the main objective of pod production.

Agroforestry systems

The possible agroforestry systems involving *P. juliflora* and *P. pallida* as the tree component are silvopastoral systems on poorer, more arid sites and agrosilvopastoral systems where adequate rainfall and soil fertility allow the seasonal cultivation of agricultural crops with grazing during the dry season. Agrosilvicultural (or silvoarable) systems, i.e. those excluding livestock, are rarely found in arid and semi-arid zones except in irrigated areas, where it may be expected that *P. juliflora* and *P. pallida* would be replaced by more valuable tree species. *Prosopis*-based agroforestry systems are managed with either animal production or agricultural crops as the principal outputs, with firewood, posts or timber as secondary products. Along with the many other possible products from *P. juliflora* and *P. pallida* trees, system design and management should also consider social needs and site productivity as well as markets for system outputs and socio-economic limitations.

Silvopastoral systems are those that have been established primarily with the aim of maximising animal production through the provision of pods and yields of understorey forage, with some secondary production of poles, posts and firewood. While open stands planted for firewood production at 400-625 trees/ha are often classified as silvopastoral systems, the small spacings do not maximise pod production, which is an important consideration where *Prosopis* trees are included. Pod production in a *P. juliflora* plantation of 625 trees/ha peaked 4-5 years after establishment, thought to be because of insufficient distance between trees, canopy closure and the poor site limiting pod yields (Lima 1994). Insufficient spacing, restricting crown development and water and nutrient availability, is considered a reason for poor pod productivity of *P. juliflora* plantations at higher densities. Wider spacing increases crown diameter and pod productivity per tree, while also allowing sufficient light and moisture to support understorey vegetation, and spacings of 25-100 trees/ha were recommended by Silva (1990b) and Moreira *et al* (1982).

Three silvopastoral management systems have been identified for *P. juliflora* and *P. pallida* plantations: extensive grazing, controlled grazing and understorey management. The principle advantage of incorporating *Prosopis* species into silvopastoral systems is the production of pods as a dry season animal feed. Pods can be collected from any of the systems, but collection is facilitated by restricted grazing. Gathering is carried out by hand and pods are fed to stalled livestock as part of a mixed ration, either as whole pods or after processing, and either immediately or following storage. Extensive grazing allows unrestricted access for livestock to fallen pods and natural vegetation, and is practised on sites of low productivity. Controlled grazing involves restricting access to blocks of trees by fencing or guarding, and rotational grazing allows time for regeneration of ground vegetation and possible accumulation of pods. Livestock that feed almost entirely on the pods of *P. juliflora* and *P. pallida*, however, may suffer from digestive disorders during the dry season when alternate forage is unavailable.

Understorey management is aimed at increasing the production of alternative forage species. This involves either existing vegetation or the planting or seeding of forage species, and possible irrigation, fertilization, or tractor cultivation in the alleys. Fully integrated systems have been developed which involve the planting of forage species and management of the understorey component as well as the *P. juliflora* or *P. pallida* tree component. In Brazil, a silvopastoral system has been developed that incorporates prickly pear cactus (*Opuntia ficus-indica*) in the alleys between rows of *P. juliflora* at 10 x 10 m spacing. Systems, including alternate rows of *P. juliflora* and *Opuntia*, have been recommended for use as a high yielding forage bank. *Opuntia* is sensitive to over-grazing and is thus more often harvested, mechanically or by hand and fed to stalled stock. The phyllodes (hands, pads or palms) of *Opuntia* are planted at densities of 800-2000 plants/ha within *P. juliflora* plantations (100 trees/ha). The application of manure is recommended on planting, and because of frequent harvests, at 3-5 year intervals thereafter.

Forage grass species are sown between rows of *P. juliflora* trees in silvopastoral systems in Brazil and India. In Brazil, buffel grass (*Cenchrus ciliaris*) is sown following cultivation with a disc harrow. Grass establishment and growth is good, with production estimated at approximately 10 t/ha/yr (Ribaski 1990). However, survival of *P. juliflora* was much reduced when planted with buffel grass, and weeding for 2 m around the stem base of the trees was required to improve tree survival to acceptable levels (Ribaski 1990). In India, systems have been developed that include Karnal grass (*Leptochloa fusca*) as the forage component in alleys between rows of *P. juliflora*. The grass establishes well with irrigation, although growth of the *P. juliflora* trees is reduced compared with trees without grass (Singh *et al* 1988b, Singh 1996). Forage yields have been estimated to be 12 t/ha/yr, comparing favourably with yields from better or wetter sites. This system is suitable for highly alkaline sites following addition of soil amendments, increases the rate of soil amelioration compared with *P. juliflora* trees alone, and is an economically viable land use option for similar sites (Singh and Singh 1993). After 5 years, the soil is sufficiently reclaimed to be able to replace Karnal grass with more palatable and productive species such as *Trifolium* spp. (Singh 1996).

Silvoarable systems have also been attempted with *P. juliflora*, and agricultural crops have given acceptable yields in irrigated conditions when planted between rows of *P. juliflora* in India (Singh 1996). In rainfed conditions, *P. juliflora* is generally viewed as a highly competitive and demanding species, with crop yields decreasing with increasing proximity to rows of trees. However, competition with neighbouring crops can be reduced by a number of management interventions, particularly pruning (see 4.3.2). *P. juliflora* is also used as a tree fallow in southern India, where land is cleared and cultivated for 2-3 years before seedlings are allowed to re-establish on the site, which is then left under *P. juliflora* for 4-5 years (Jambulingam and Fernandes 1986). Large improvements in soil fertility have been observed following 5 years of *P. juliflora* tree fallow in Tanzania (Jonsson *et al* 1996).

Agroforestry systems can produce a variety of tree products from a stand of trees independent of the understorey component. Bee hives can be located in or around plantations, making use of the copious flowers to produce high quality honey. Reports of very high yields of honey have been recorded from stands of *P. pallida* in Hawaii, where the process of bee foraging was also noted to increase pod production through improved pollination (Esbenshade 1980) (see3.4.1). Honey is produced in many areas where *P. juliflora* and *P. pallida* are native or have been planted in wider spacings that facilitate flower production. Gum collection may be a profitable activity, although the high labour required for gum harvesting means this may only be economic in denser plantations and where labour costs are low (see 3.4.2). Plantations can also be harvested for other products such as leaves (see 3.3.2), fibres, dyes, tannins (see 3.4.3) or medicines (see 3.4.4).

P. juliflora and *P. pallida* trees produce a variety of wood products, each having different characteristics, different market values and which are produced from different management systems. Any woody material can be used or sold as firewood, though prices may vary depending on the length and thickness of pieces. Long straight lengths, such as those arising from coppice shoots may fetch a higher price as fence posts or poles for construction than for firewood but are also very suitable for conversion to charcoal. Larger trunks, such as occur in older stands or following repeated pruning to a single stem, may fetch the highest price as saw logs, thus increasing returns from plantations of *P. juliflora* and *P. pallida*. Agroforestry plantations can have mixtures of trees of various forms managed for different products, and all these types of wood products can be produced as well as pods, honey and gums from integrated management systems.

4.3.2 Management interventions

Irrigation

Lack of rainfall after planting may mean that irrigation is essential to maintain adequate seedling survival. *P. juliflora* and *P. pallida* have shown high rates of survival and growth during early establishment, even with very little rainfall (Lee *et al* 1992, Harris *et al* 1996a, Harsh *et al* 1996). Life saving irrigation is, however, deemed necessary in some cases. In India, Tewari *et al* (2000) recommended watering each *P. juliflora* seedling with 2-3 litres every 20 days, while Muthana and Arora (1983) recommended watering *P. juliflora* with at least 9 litres every 16 days. Several irrigations during the first year are suggested but, while possible on experimental sites, are rarely practical on large scale plantations.

Watering by hand is usually impractical and the high cost of tube or pipe irrigation makes these methods uneconomic on large scale plantations. Flood irrigation is more frequently used in Asia, where it is applied to *P. juliflora* plantations as often as possible to maximise shoot growth. Economic studies on raising firewood plantations in India have shown the viability of flood irrigation in several cases (e.g. Singh *et al* 1988b, Singh 1996). Ojala *et al* (1993) produced an economic analysis of the cost benefits of flood irrigation on dense plantations in Kenya and concluded, however, that for the production and sale of fuelwood, irrigation is only marginally economic and viability was highly dependent upon the cost of water. Maximum water use efficiency is assumed to occur only after canopy closure, with higher water losses to transpiration in younger plantations (Singh *et al* 1988b) (see 2.4.3).

Cost of water can be much reduced by using sea water or saline well water that is otherwise unsuitable for other purposes, directly or mixed with fresh water. *P. juliflora* plantations have been raised successfully with saline water in Pakistan (Khan *et al* 1986), India (Muthana and Arora 1983) and the Middle East (Ahmad *et al* 1996). *P. juliflora* and *P. pallida* have physiological adaptations for tolerating excess sodium ions (see 2.4.3). While they can tolerate salinities equivalent to sea water (Felker *et al* 1981b, Rhodes and Felker 1988), they do so with much reduced survival and vigour with more than 50% sea water or equivalent salt concentrations. The use of saline water may also limit the availability of other plant nutrients and suppress nitrogen fixation. Even at low salt concentrations in soil or water, increased levels of sodium ions are found in all plant parts, particularly the leaf (e.g. Khan *et al* 1986). Further studies on the effects of saline irrigation water use on soil and tree product quality are required.

P. juliflora and *P. pallida* have shown a tolerance to pollutants and nutrient imbalances as well as salt, and waste water has been used for irrigating *P. juliflora* plantations in the Middle East. Abohassan *et al* (1988) found no increase in tree height of *P. juliflora* due to monthly irrigation with sewage waste water but noted increased diameter increments and some differences in wood quality. Waste water or sewage sludge from urban or industrial areas is of low or no cost, can be a health hazard and often needs to be disposed of. Irrigating plantations with such waste can also provide valuable nutrients often lacking in desert soils, as fertilisation is very rarely applied post-planting. Annual applications of phosphorus did not significantly increase tree growth in native stands of *P. glandulosa* (Villagra and Felker 1997). However, Patch and Felker (1997) found that phosphorus application positively affected basal area of *P. glandulosa*. In high yielding short rotation biomass plantations, the removal of nutrients will probably necessitate fertilisation to maintain yield, which could be provided by irrigation with sewage sludge.

Weeding

Where there are predominantly herbaceous weeds, hand clearing around the base of trees should be carried out at least annually, but clearing of the whole site in this manner is time consuming. The growth of weeds can also be reduced by applying a mulch of stones or other readily available material on the soil surface around the base of the tree. This will also increase soil water retention. Spot or strip applications of herbicides have been also used successfully against a range of broadleaved weeds and grasses in *Prosopis* plantations (Felker *et al* 1986a). Tractor cultivation of alleys between trees or rows of trees with a disc harrow is effective where site access allows. Weed control involving cultivation is preferred over chemical methods because of the advantages of reduced dependence on external chemicals and possible effects in conserving soil moisture.

Controlling larger weeds, understorey scrub, unwanted shrubs and trees is more of a problem in native and naturalised stands than in plantations. Clearing to ground level is first required to assist in site access. Hand cutting and clearing is a very time consuming operation, made unpleasant by the thorns present on many species to be removed. However, clearing with hand tools and chainsaws is still the most commonly practised technique. Tractor mounted flail mowers have also been used successfully to cut, chip and remove all stems up to 10 cm in diameter in dense weedy stands of *P. glandulosa* (Ulich 1982, Felker *et al* 1999). Also, ‘chaining’ has been found to be effective on trees of all sizes, with a heavy chain being pulled between two, slow-moving Caterpillar tractors. Many woody weeds coppice when cut, so tree and shrub stumps must either be removed or otherwise killed. Hand removal of stumps of *P. juliflora* and *P. pallida* is a time consuming operation but sometimes preferred as the roots make high quality charcoal. As stump removal, or ‘grubbing’, is a difficult operation, various chemicals have been tested for their efficacy in killing or preventing regrowth in stumps of *Prosopis* (e.g. Villagra and Felker 1997). Chaining, if carried out in both directions, can break roots on all sides of the tree and facilitate whole tree removal. The most effective but costly intervention for removal of stumps is root ploughing, with a heavy plough shear cutting roots to a depth of up to 50 cm deep. Simple methods to reduce coppice regrowth are to make the cut very close to ground level and remove as much bark as possible from the stump (Tewari *et al* 2000). Techniques for land clearance and woody weed control are covered in detail in the management of weedy invasions (see 4.3.3).

Thinning is included here as a weeding operation, and the process of removing unwanted *P. juliflora* and *P. pallida* seedlings or trees is similar to that employed for understorey, brush and weed control. Thinning is infrequently carried out in plantations of *P. juliflora* and *P. pallida*, but high density firewood plantations can, however, be converted to lower density stands (100-625 trees/ha) suitable for agroforestry systems by the removal or killing of selected trees. Thinning is, however, an important initial intervention when implementing management systems in native or naturalised stands. Cornejo-Oveido *et al* (1991) recommended the thinning of dense *P. glandulosa* stands as the most important management intervention, and it was calculated that annual production of utilisable biomass increased as stand density decreased. An optimum stand density for *P. glandulosa* was estimated at approximately 100 trees/ha (Cornejo-Oveido *et al* 1991, Felker 1991). In Argentina, Marmillon (1986) recommended thinning native *Prosopis* stands to 30-50 trees/ha to maximise productivity.

Pruning

Unlike traditional timber species, which are often cut only once at final harvest, multi-purpose and often multi-stemmed coppicing species such as *P. juliflora* and *P. pallida* are cut frequently during their lifetime. Not only is cutting required to obtain harvests of timber products, but location, frequency, timing, quality and severity of cut can be expected to have an impact on overall tree performance and also to affect competitive interactions with neighbouring plants. However, firewood and fodder tree species are often planted with little aftercare, with trees left to take a sub-optimal multi-stemmed form. Pruning is an intervention which can be instantly applied to such trees with immediate effects.

The term pruning is used to describe the removal of selected stems, including singling (removing all side branches to leave only a single stem), crown pruning and root pruning. Other cutting operations employed in the management of *P. juliflora* and *P. pallida*, that involve the wholesale removal of all stems at a prescribed height or position on the tree, include coppicing, lopping and pollarding, and are also detailed here. Plantations established for short rotation biomass or specifically for the production of posts or poles are coppiced close to ground level. In some cases, however, the number of coppice shoots per stump is also reduced by selective pruning. Pruning (singling) aims to improve tree form and increase production of saw logs and understorey vegetation through the selective removal of branches. Trees with broad crowns and short boles tend to yield more fruit. Crown pruning can increase pod production but is rarely practised on *P. juliflora* and *P. pallida*.

Coppicing is probably the most commonly used technique, particularly on wasteland or common ground and on short rotation firewood stands. *P. juliflora* and *P. pallida* are amenable to such a practice, coppicing well and resprouting vigorously after cutting. Very little mortality of stumps is observed, but regrowth is dependent upon the season of cut, cutting frequency, the height of cut and subsequent management of resprouts. Sugur (1988) and El Fadl (1997) noted seasonal differences in regrowth of *P. juliflora* coppice shoots corresponding to periods of high rainfall. Management of short rotation coppice for biomass and fuelwood generally involves cutting frequencies of less than 12 months on the best sites, or up to five years under poor conditions. Sugur (1988) observed no significant differences with different cutting intervals but recommended cutting every 3-6 months. However, management often necessitates longer cutting intervals, with 2-5 years common for charcoal and a ten year rotation for saw logs from *P. juliflora* in Haiti (Roig 1990).

In short rotation coppice and with trees on common land, the cut is often made close to ground level to maximise the harvest of wood. However, height of the cut above the ground significantly influences the total biomass produced during subsequent coppice regrowth. El Fadl (1997) found that cutting at ground level severely reduced the ability of *P. juliflora* to resprout. While cutting at 10 cm, 30 cm or 50 cm height each produced the same number of coppice shoots, cutting at 30 cm gave the highest total biomass yield. Roig (1990) noted that *P. juliflora* coppice stands in Haiti are generally cut at a height of 50 cm. The number of resprouts are occasionally pruned to concentrate growth in selected shoots only, with Roig (1990) noting thinning to six, four but more commonly two shoots per stump. In Kenya, pruning coppice shoots of *P. juliflora* to six, four and two stems affected stem thickness but had no significant effect on total volume produced (Ojala *et al* 1993).

Pruning to a single stem, or singling, is occasionally carried out on various *Prosopis* species to produce an erect tree form with a clear, well-defined bole. Singling can be carried out at any stage in the growth of a plant but, with planted seedlings, first pruning is recommended in the first two years. Subsequent prunings can then be undertaken at 1-5 year intervals, producing firewood from the pruned branches. Pruning increases total biomass production, increases the annual diameter increment and final yield of the main trunk, improves accessibility within the site and improves the growth of understorey vegetation. Following pruning of *P. juliflora* trees in a plantation in Sudan, annual diameter increments of 1.3 cm and 2.3 cm were recorded in the first and second years, compared with 0.3 cm and 0.9 cm, respectively, in unpruned trees (El Fadl 1997). In native stands of *P. glandulosa* in the USA, pruned trees had annual diameter increments of 1.25 cm, significantly greater than the 0.50 cm/yr increments observed in the unpruned trees (Cornejo-Oveido *et al* 1991).

Although an ability to coppice well is advantageous for the management of *P. juliflora* and *P. pallida*, this also leads to the production of a large number of undesirable side and basal shoots following pruning. To reduce resprouting from cut branches of *P. juliflora*, Tewari *et al* (2000) recommended that rather than cutting right back to the trunk, a short stump should be left from which the bark is removed. Treatment of cuts with NAA proved effective in suppressing resprouting and suckering in *P. glandulosa*, (Meyer and Felker 1990), while Patch *et al* (1998) found that resprouting was significantly reduced by chemical treatments, although some also had a negative effect on subsequent tree growth. A plastic sheet wrapped around the trunk was very effective against resprouting from wounds but did not prevent sprouting from the tree base and was more costly than chemical treatments (Patch *et al* 1998).

Detailed investigations of the effects of pruning on the growth of *P. juliflora* were undertaken in Sudan by El Fadl (1997). Trees pruned to three stems had a larger basal area than trees pruned to either one or five stems, but there was no difference in vertical tree height between the treatments. Pruning intensity, or the amount removed at each pruning, was also found to affect tree growth. Removing all side branches up to one half (medium intensity) or three quarters (high intensity) of total tree height resulted in significantly greater growth than pruning to one quarter (low intensity) of tree height or no pruning at all (El Fadl 1997). Where *P. juliflora* trees are found in and around agricultural fields, some farmers carry out a high intensity pruning to greater than three quarters of tree height, leaving only a tuft of leaves at the top or a very small crown (e.g. Pasiecznik 1998). The frequency of pruning also affects tree growth, with annual pruning producing a greater volume of *P. juliflora* biomass than less frequent pruning (El Fadl 1997). Pasiecznik (1998) observed annual pruning of *P. juliflora* trees in agricultural fields in Cape Verde, coinciding with the seasonal planting of agricultural crops. Thus in practice, the timing as well as the frequency of pruning may be dictated by other land use activities rather than by a desire to maximise biomass production.

Following the removal of side branches, the plant concentrates growth in the main bole and leader, and increased increments in bole diameter are to be expected. However, it was observed that annual increments in the total above ground biomass are also increased in pruned trees, suggesting a physiological response to the management intervention (El Fadl 1997). A reduction in crown size reduces the total leaf area from which water can be transpired and should improve drought tolerance. Loss of photosynthetic potential is not necessarily proportional to pruning intensity, as foliage on lower branches is photosynthetically less active, and green stems of *P. juliflora* and *P. pallida* are also thought to compensate for loss of leaf area. Leaves in different parts of the tree crown have slightly different functions and characteristics. In the upper crown, 'sun' leaves are efficient in the production of sugars and actively photosynthesise, whereas the lower branches of trees tend to contain 'shade' leaves which are photosynthetically less active. These shade leaves are less efficient at photosynthesis and appear to exhibit lower water use efficiency during photosynthesis and respiration than sun leaves in several tree species (El Fadl 1997). El Fadl (1997) concludes that the improved performance of *P. juliflora* trees in Sudan following pruning is due to the increased water use efficiency of the pruned trees.

There are mixed reports of whether *P. juliflora* and *P. pallida* favour or hinder the growth of other plants growing under their crowns or in close proximity. While possessing deep tap roots, *P. juliflora* and *P. pallida* also have broad, lateral root systems known to extend for many metres beyond the crown and to be very efficient at drawing water from the soil, even at very low water potentials (Prajapati *et al* 1971) (see 2.2.2, 2.3.3). Severing the surface roots of trees grown near to agricultural crops may be achieved consciously by digging a trench, deep ploughing or sub-soiling along a row of trees on a field margin. This may be carried out incidentally during ploughing around trees in seasonally cultivated fields. Such root pruning may be a means of reducing competition for water, but competition for light may also be an important consideration. In Nigeria, Jones *et al* (1998) found that crown pruning of *P. juliflora* significantly reduced total root numbers and increased the yield of an adjacent sorghum crop.

Reducing competition, or maximising complimentarity between tree and crop components is an important aim of agroforestry management. Tree species that are designated as suitable for agroforestry, and particularly dryland silvoarable systems, such as *P. cineraria* and *Faidherbia albida* are known to possess a dominant tap root with few surface lateral roots that would otherwise compete with neighbouring crop plants (e.g. CTFT 1988, Sandison and Harris 1991). These also tend to be species that are regularly pruned or lopped, generally for fodder. Root form, particularly of lateral roots, may be less influenced by genetic control and more by management intervention than is presently accepted. Pruning significantly reduces the number of *P. juliflora* lateral roots and below ground competition for water and nutrients (Jones *et al* 1998). Growth and water use efficiency of *P. juliflora* benefit from the selective removal of lower leaves (El Fadl 1997). Further work is required to confirm these results in a variety of environments but, from present knowledge, pruning of all *P. juliflora* trees is strongly recommended to increase tree growth and also to minimise negative influences on adjacent agricultural crops.

4.3.3 Management of weedy invasions

Eradication programmes

Prosopis species are recognised as problem woody weeds in many countries world-wide (Table 3, 1.4.2). However, most of the invasive weeds on which control has been used are the more temperate species *P. glandulosa*, *P. velutina* and *P. ruscifolia*. While *P. juliflora* is also a noted weed in several tropical countries, major control programmes have not been implemented, and examples will refer to the genus in general. The global problem of *Prosopis* species as weeds and how they affect land use is detailed earlier (see 1.4.2). The ecology of *Prosopis* as weeds, relating particularly to factors concerning the spread and succession of species, are also detailed elsewhere (see 2.4.5).

This section deals with three of the recognised methods for the control of *Prosopis* species: mechanical, chemical and fire. Mechanical and chemical methods have been applied most often to date while biological control and fire are credited as factors that limited the spread of *Prosopis* prior to the arrival of man (Jacoby and Ansley 1991). The more recent increased interest in use of biological control and cultural techniques, involving changes in land use, will be dealt with separately from standard mechanical, chemical and fire techniques. Major regional eradication and control programmes have been undertaken on *Prosopis* species in their native ranges, principally in the USA and Argentina, and also where introduced, principally Australia and South Africa.

The presence of *Prosopis* invading rangeland in southern USA, and threatening the livelihoods of ranchers since the early years of this century led to the call for its eradication. There, for over 60 years, researchers and ranchers have worked together in an attempt to rid themselves of the menace of *Prosopis* invasion. However, no efficient and cost effective methods have been found. A wealth of literature exists on eradication programmes developed using mechanical and chemical techniques in the USA, and tested in the field against mainly *P. glandulosa* with limited success (see Cadoret *et al* 2000). This information was well summarised in Jacoby and Ansley (1991) and forms the basis for evaluating the feasibility of eradication and control. Similar but less intensive eradication programmes have been implemented in Argentina, Paraguay, South Africa, Sudan, Pakistan and Australia. The term eradication has gradually been replaced with that of control, as it became clear that total kill and exclusion of *Prosopis* from a site once invaded, if possible, could not prevent further encroachment and reinvasion.

Hand clearance was the first method used to deal with *Prosopis* as a weed in the Americas. Work teams were sent into invaded pasture, all trees were felled and all seedlings and stumps uprooted. While obtaining a harvest of firewood and possibly fence posts and poles, and being very effective, the operation was too labour intensive and expensive for the land owner to consider carrying it out on anything but a small scale. Hand clearing remains practical only for small land holdings of high value, such as for agriculture, or where labour is relatively cheap. Hand clearing can also be used in conjunction with some mechanical or chemical methods, such as chemical stump treatment. In Pakistan, hand grubbing was cheaper than chemical stump treatment (Khan 1961). Mechanical grubbing can be carried out with tractor operated machines, but effectiveness is limited by tree size, and grubbing is more cost effective in lighter infestations.

Mechanical site clearance involves tractor operations developed for removing trees, which have to sever roots below ground level to ensure tree kill. These include root ploughing and chaining, which are often the most effective mechanical means. For root ploughing, using a moldboard plough pulled behind a Caterpillar tractor, large trees must first be felled by hand. This treatment can remove stumps up to 50 cm in diameter without difficulty and has a treatment life of 20 years or more (Jacoby and Ansley 1991). Other advantages are that only a single pass is required. Whole site cultivation leads to improved soil water conservation, and there is a chance to reseed with improved forage species. The soil should be neither too wet nor too dry for effective root ploughing.This method is, however, one of the most expensive control treatments and is recommended only on deep soils which have a high potential for subsequent increased forage production (Jacoby and Ansley 1991).

Chaining involves the pulling of a heavy chain between two slow moving caterpillar tractors, with the effect of pulling over larger trees and uprooting them. A second pass in the opposite direction ensures that roots on all sides are severed to ease tree removal (Jacoby and Ansley 1991). Soil moisture is again important, with dry surface soil that is moist below giving the optimal conditions. Too dry and the tree stem breaks leading to coppicing, too wet and damage is caused to the soil and understorey (Jacoby and Ansley 1991). Smaller unbroken trees have to be removed by other means. While an expensive treatment, it is effective where there are many mature trees. It is most widely used following herbicide application to remove dead standing trees. Clearance with a biomass harvester produces wood chips that can be sold for energy production offsetting the operational costs (e.g. Felker *et al* 1999).

Chemical treatments involve the use of herbicides to kill trees, with the most effective being stem or aerial applications of systemic herbicides. Effectiveness is dependent upon chemical uptake, which in *Prosopis* is limited by the thick bark, woody stems and small leaves which have a protective waxy outer layer. Formulation and application of chemicals for trees of mixed ages and sizes within a stand is difficult. Many herbicides and herbicide mixtures have been tested. Until the banning of its use in the 1980s, 2,4,5-T was the herbicide of choice in the USA (Jacoby and Ansley 1991) and Australia (Csurhes 1996). While 2,4,5-T and 2,4-D provided excellent supression of top growth, few trees were actually killed and such chemical treatments had to be applied periodically to ensure that forage yields were maintained. Infested sites often needed spraying every 5-7 years. The most effective chemical for high tree kill of *P. glandulosa* in the USA is clopyralid, but dicamba, picloram and triclopyr have also been successfully used either alone or in combination (Jacoby and Ansley 1991). In India, ammonium sulphamate was successful in killing *P. juliflora* trees and as a stump treatment (Panchal and Prabhakar-Shetty 1977).

Fire, probably one of the original management tools used in American grasslands, has undergone limited assessment for controlling *Prosopis*. Young seedlings are sensitive to fire but older trees become increasingly protected by thick bark as they mature and will resprout rapidly after fire. Fire can, however, be used successfully as a management tool for preventing the re-establishment of young *Prosopis* seedlings while also improving forage production. Fire has been used in conjunction with other methods in the development of integrated eradication programmes. For example, spraying with herbicides produces dead wood, which will ignite and support a sustained fire with more likelihood of killing remaining trees.

Mixed mechanical and chemical methods have proved more effective than either alone in several cases. Several integrated programmes that mix mechanical, chemical and fire have had reasonable success but are costly and require a high level of management input. However, methods of eradication as attempted for over half a century in the Americas have proved very expensive and largely unsuccessful in the long term. Total tree kill may be possible with some treatments, but adequate techniques for preventing re-introduction of seeds and re-establishment of trees have yet to be developed. The potential environmental damage from widespread use of herbicides must also be taken into consideration. It has been accepted that using these techniques, eradication is not possible, and at best only some form of control is feasible.

Biological control

The high cost and poor success of mechanical and chemical eradication techniques have led to the investigation of alternative means of control. Several biological control programmes have been developed and implemented that use species of seed feeding bruchid beetles. In the native range, bruchid beetles can destroy substantial amounts of seed produced (see 2.3.4), thus severely limiting the potential for invasion. The advantage with bruchids is their observed host specificity, with many species found to feed only on *Prosopis*, and some only on single species (Kingsolver *et al* 1977) (see 2.4.5). Other insect species known to have a deleterious effect on native and exotic *Prosopis* in the

Americas, mainly twig girdlers and psyllids, have also been suggested as possible biological control agents. The twig girdler *Oncideres limpida* attacks *P. juliflora* in Brazil (Lima 1994), while *Oncideres rhodostricta* was seen as a serious pest of *P. glandulosa* in the USA (Polk and Ueckert 1973). Psyllids are known to severely affect the growth of *Prosopis* (Hodkinson 1991) and have been suggested for use in controlling invasions. Many other insect species have been noted as being damaging to *Prosopis* species (Table 17, section 3.3), and several have been noted as potential biological control agents. However, less is known about the host specificity of these insects and further work is required before any attempt at their use in controlling *Prosopis*.

Species of bruchid beetles have been successfully introduced as part of control programmes in South Africa, Australia and Ascension island. Much initial work centred around identifying suitable species from the native range and testing their efficacy and host specificity on *Prosopis* and other native and exotic plant species. This work was hampered by taxonomic problems within the genus, with many of the weed trees belonging to unidentified *Prosopis* species or hybrids. In both Australia and South Africa, it is not the *P. juliflora - P. pallida* complex that has invaded the widest areas and poses the greatest threat, but *P. glandulosa*, *P. velutina* and *P. glandulosa* X *P. velutina* hybrids. However, *P. juliflora* was identified as the main weed species in Ascension island (Fowler 1998). Panetta and Carstairs (1989) identified *P. juliflora* in Australia and tentatively identified *P. pallida*, confirmed by Perry (1998), and the same two species are also present in South Africa (Zimmerman 1991) although the taxonomy is less well studied there.

Most work on biological control of *Prosopis* to date has been carried out in South Africa, where several programmes are underway. The seed feeding insects *Mimosetes protractus* and *Neltumius arizonensis* were introduced to eastern South Africa in conjunction with the bruchid beetles *Algarobius prosopis* and *A. bottimeri* for the control of invasive *Prosopis* species. *Neltumius arizonensis* and *Algarobius prosopis* were successful in establishing themselves in large numbers and having a significant effect on *Prosopis*, whereas the other species were only found in low numbers (Hoffmann *et al* 1993). Maximum damage to seed was where grazing was controlled, as the multiplication and progress is hampered by livestock devouring pods before they are destroyed by the insects.

The same two bruchid species were also introduced to Ascension island in an attempt to control *P. juliflora* which is present on 80% of the island, often in dense thickets. Two other species, one a psyllid and the other a mirid, were identified as attacking *P. juliflora* in Ascension island and were thought to have been introduced accidentally from the Caribbean. The mirid *Rhinocloa* sp. causes widespread damage and is thought to lead to substantial mortality of trees (Fowler 1998). In Australia, *Prosopis* infestations are at a relatively early stage and extreme care is being employed in the selection of suitable biological control agents, following the long history of problems caused there by plant and animal introductions. Insect species continue to be tested for their efficacy and host specificity as possible biological control agents of *Prosopis* species in Australia (e.g. van Klinken 1999).

Prosopis species continue to spread widely in parts of their native ranges where many insects species including bruchids, twig girdlers, psyllids and other injurious pests are common components of the ecology. These regularly attack *Prosopis* but the trees have adapted to infestation by these pests and are still able to become invasive weeds over large tracts of land. While some success has been seen in the control of exotic *Prosopis*, following the introduction of bruchid beetles and other insects, it appears that biological control alone may be insufficient. Introducing biological control agents against exotic *Prosopis* will only lead to a new ecological balance and must be integrated with other cultural methods if an effective means of control is to be developed.

Biological control could also include the use of animals, other than insects, to eat and kill *Prosopis* seed. The factor common to most *Prosopis* invasions include over-grazing with cattle, which spread *Prosopis* seed widely. *Prosopis* seed tend to pass undamaged through cattle and seed found in faeces have much improved germination compared with uningested seed (Peinetti *et al* 1993, Danthu *et al* 1996) (see 2.3.4). In contrast, sheep and goat destroy most *P. juliflora* seed ingested (Harding 1991, Danthu *et al* 1996). Marked differences were noted in the germination of ingested seed following passage through different animals by Mooney *et al* (1977), who noted that seed germination was 82% with horses, 69% with cattle but only 25% with sheep. *P. flexuosa* seed were killed completely followed ingestion by pigs (Peinetti *et al* 1993). Replacing free ranging cattle with other livestock, particularly sheep or pigs, possibly in conjunction with other control methods, could drastically reduce spread of *Prosopis* species.

Studies on succession suggest the possibility of ‘ecological control’, by leaving succession to take its natural course (see 2.4.5). The invasion of *Prosopis* species into rangeland has been observed and studied for over a century in the USA (e.g. Archer 1995), and for long periods in South America (e.g. D’Antoni and Solbrig 1977) and India (e.g. Chinnimani 1998). Long term ecological observations and the use of models have indicated that dense thickets associated with the problems of invasion are only a temporary stage in the process of succession. Initial stages of invasion involve the introduction of small numbers of *Prosopis* trees, which eventually produce seed and act as centres of dissemination (Archer 1995). *Prosopis* stand density increases if land use systems allow the establishment of seedlings, leading to the formation of dense thickets where conditions allow. Chinnimani (1998) showed that, eventually, *Prosopis* density declines as other species become established, and, if left to take a natural course, a new vegetation complex will occur with *Prosopis* as only a minor component (see 2.4.5). Felker *et al* (1990) observed that self-thinning occurred in stands of *P. glandulosa* over time. The dense thickets identified as weedy invasions in many countries may only be indicative of the early stage of invasion and if left alone, ecological control may naturally reduce *Prosopis* numbers.

Conversion to agroforestry systems

Weedy invasions of *Prosopis* have a serious effect on local economies but may also become a valuable resource for local populations. *Prosopis* trees can provide many products for local use and are always valued by some sections of the community. Problems of weedy invasions exist primarily on pasture and grazing land. *Prosopis* are thus disliked by large land owners, ranchers and herders, because of reduced forage yields associated with invasions and problems of access in dense, thorny stands. However, the trees provide valuable firewood and pods for the landless and small farmers in rural areas who may depend, to some extent, upon these raw materials for their survival. The dichotomy of how *Prosopis* can be a weed and a valued tree species at the same time is dependent upon the level of poverty of the people using the land (Pasiecznik 1999). Richer families who cook with gas and do not own livestock quickly forget the value of *P. juliflora*, whereas rural farmers are invariably aware of its importance (Pasiecznik 1998).

The need for eradication was replaced by control when it became apparent that total eradication was impossible. Several agroforestry systems including *P. juliflora* and *P. pallida* as the dominant component have been described (see 4.3.1), and integrated land management options are proposed as a sustainable solution to the problem of weedy invasions. The aim is to treat dense infestations to convert them to economically viable and sustainable agroforestry systems. Such systems have already been evaluated with *P. glandulosa* in the USA (e.g. Felker 1991) but could be applied equally to weedy invasions of other *Prosopis* species in other parts of the world.

The most promising agroforestry systems include *Prosopis* as the tree component with native or possibly introduced forage plants as an understorey. Tree density is a very important factor in defining the system (Table 33, see 4.2.1), with preferred densities in agroforestry systems being 400-625 trees/ha (5 x 5 m or 4 x 4 m spacing) or even as low as 25-100 trees/ha (20 x 20 m or 10 x 10 m spacing). System choice and management interventions will vary according to site and desired end products. Most important are animal products, but food, firewood, fuel, posts, timber and other raw materials may be included. Following conversion, such systems require management of the tree and understorey component to prevent further establishment of *Prosopis* seedlings. Systems have been devised that produce all of the above outputs on a single unit of land, showing internal rates of return far in excess of any alternative land use possible for such a site (Felker 1991).

Weedy invasions of *Prosopis* can be successfully adapted to agroforestry systems by a conversion process. This conversion requires three main management interventions; thinning, pruning and treatment of understorey. Weedy thickets with 1000-2500 trees/ha and dense infestations with over 2500 trees/ha need to be thinned to 100-625 trees/ha. This thinning operation is the most problematic and most costly aspect of conversion and limits the uptake of such a system. The use of a tractor mounted flail mower to cut rows through the stand can be a most economical means of initial thinning, with harvested biomass sold to offset some of the cost of the operation (Felker *et al* 1999). The aim is to leave rows of undisturbed *Prosopis* at least 1 m wide and at 5-10 m intervals across the site. Clearing by hand is a laborious and unpleasant task owing to thorns and difficult access, and rows of thorny brash must be left on site. However, with this methods, most of the nutrient-rich foliage is also retained on site adding to soil fertility. All the tree stumps also need to be killed, both of *Prosopis* and other woody weed species. This can either be achieved by hand or mechanical means or by chemical stump treatment as described earlier (see 4.3.2). In India, the *Prosopis* infested land is sold to charcoal makers, who will also remove tree stumps if requested.

Following initial systematic thinning to a stand density of approximately 500-1000 trees/ha, a secondary selective thinning is required to create a desired final density in the range 100-625 trees/ha. While trees do not necessarily have to be equally spaced, leaving open rows 5-10 m apart will facilitate access and increase the number of understorey management options possible with tractor operations. Trees with desirable characteristics and at defined spacings should be marked, and all others removed and stumps treated or removed. Trees should be selected for their large size, erect form, straight trunk, pod production, lack of thorns and good tree health. Selected trees are then pruned to improve form, by removing any basal shoots and side branches to at least one half of tree height for timber production, leaving a clear bole preferably over 2 m. For pod production, a shorter bole and broader crown is preferred. Treatments can be applied to reduce resprouting from the tree base and wounds (see 4.3.2).

Conversion to an extensive or controlled grazing silvopastoral system is then complete. Converting *P. glandulosa* stands in the USA from 356 trees/ha to 192 trees/ha produced 32.7 m^3/ha of woody biomass, of which an estimated 55% was firewood, leaving 18m^3/ha of solid wood for use as a timber from the thinning operation (Cornejo-Oviedo *et al* 1992). Felker *et al* (1990) noted that because of small tree sizes, there was no timber produced from stands with densities above 3000 trees/ha, but as stand density decreased to 470 trees/ha, timber volume increased rapidly. Further periodic pruning maintains tree form and the value of sawlogs as a system output. In trees that have a single bole of 2 m height, rotational harvesting of all branches above this height will continue to provide firewood and fence posts, though to the detriment of pod production. Pods can be browsed or collected as a source of food or fodder. Incorporating bees into the system would produce honey and wax and increase pod production, and the trees could be a minor source of other raw materials (see 3.4). Further thinning of trees in later years can also be carried out, or trees can be removed entirely from the site and the land returned to agriculture (e.g. Bhojvaid *et al* 1996).

Recruitment of *Prosopis* seedlings is prevented or very much reduced under the crown of mature *Prosopis* trees (Simpson 1977). Correct management of understorey vegetation, maintaining ground cover and preventing over grazing, will also restrict recruitment through effective competition. Maintenance and improvement of soil fertility is also thought to reduce the competitive advantage that woody legume seedlings have over other species (Geesing *et al* 1999). Controlled burning, inter-row cultivation, collection of pods and grazing of livestock such as sheep and pigs which kill ingested seeds, can also be used to prevent further seedling recruitment. Livestock production can be significantly improved if conditions allow for understorey management. Planting of productive forage species has proved to be economic in several countries, and interplanting with agricultural crops may be possible on better soils in higher rainfall zones.

Mean annual diameter increments of pruned and managed *P. juliflora* trees in excess of 2 cm/yr have been recorded under arid conditions (El Fadl 1997). Such rates of timber production are impressive, comparable to those seen in commercial hardwood plantations, and further investigation over the whole rotation is required. Trees can be selectively felled or the stand cleared when trunk mid-point diameters exceed 20-25 cm, though much higher timber recovery at the sawmill will be achieved with *Prosopis* logs of over 30 cm diameter (Rogers 1986). Coppice regrowth can be thinned to single stems and the cycle repeated. Alternatively selected trees could be replanted or stumps could be removed and the land converted to open pasture or agriculture. Such an integrated agroforestry system, with a rotation length of 20-40 years, if established on open ground, has been shown to be profitable when using only the saw logs for timber as the system output (Felker 1999). Further work is required on the economics of conversion from a dense *Prosopis* infestations.

Changes in land use systems during the spread of *Prosopis* (e.g. D'Antoni and Solbrig 1977, Fisher 1977) are likely to be over-riding factors affecting the spread of *Prosopis* as a weed. However, few cultural control programmes have been proposed or attempted (Jacoby and Ansley 1991) even though some change in land-use management appears necessary for the effective control of *Prosopis*.

4.4 Exploitation of the resource

4.4.1 Sustainable harvesting

The principle of good system management is to maximise yields of desired outputs while maintaining site productivity. This requires an understanding of nutrient flows, rates of production and harvest frequency. Extensively managed systems are more likely to be sustainable but at relatively low productivity. Increasing levels of management, shorter rotations and more frequent harvests can improve total yields, but an improved knowledge of system dynamics is then required to calculate optimum productivity with the external inputs available. In agroforestry systems, there are several possible outputs from the site besides those from the trees themselves, and often complex interactions between components in terms of nutrient cycling. Over-grazing, or unsustainable harvesting of the understorey forage component is a common problem in arid zone agroforestry systems that include *Prosopis* as the tree component. In areas where cultivation is possible, unsuitable cropping practices are also found. Both lead to a reduction in soil fertility and possible increases in soil erosion. However, it is the harvesting of products from the *P. juliflora - P. pallida* tree component that will be detailed here.

Harvesting includes all operations that remove a tree product from the site and includes preliminary on-site preparation that facilitates extraction of the product. Harvesting of wood products generally includes the separation of the wood from small twigs, side branchlets and foliage, and cutting branches to the desired lengths. However, mechanical biomass harvesting removes the entire above ground portion of the tree including nutrient rich foliage. Pods are gathered off the ground or directly from the trees into large sacks, and insect infested pods and others unsuitable for feeding can be selected out at this stage and left on site. Exudate gum, wild bees nest and other tree products rarely undergo any on-site transformation prior to removal from the site.

Nutrient content of harvested product, amount removed and frequency of harvest determining total nutrient removal. Certain nutrients may become limiting following repeated harvest. Over 50% of the above-ground nutrients in *P. juliflora* are in the foliage (Maghembe *et al* 1983), which should be allowed to return to the soil. Regular harvesting of the leaves may seriously deplete soil nutrient reserves and limit the potential of plantations to reclaim soils. While 35% of the nutrients were found in the stem wood (Maghembe *et al* 1983), this is only harvested at long intervals and is not thought to contribute significantly to nutrient removal. However, repeated harvesting of the 15% of plant nutrients in branch wood may have a negative impact on soil fertility and may not be sustainable.

In mature trees, the percentage of biomass and nutrients partitioned to pod production can be a substantial part of total annual biomass increment. In native woodlands or extensive silvopastoral systems where pods are only browsed, a proportion of the nutrients in the pods will be returned to the soil in the form of animal manure. Where yields are high and pods are collected, substantial nutrient removal can occur and would need to be balanced to maintain productivity. This is important when considering use of high yielding varieties for low productivity sites (e.g. Pasiecznik and Harris 1998).

Prosopis roots will access any water supply, and possible depletion of ground water reserves must be considered. Thinning and pruning have a positive effect on overall site water balance by removing understorey trees and shrubs, and removing lower branches, which have lower water use efficiency (see 4.3.2). A managed stand, uses less water than a weedy or unmanaged stand, but both may use more than open grassland. Consideration should also be given to the tree density in native woodland as an indicator of sustainable plantation densities. There is need to further analyse the effects of management on water use and water balance in *P. juliflora* and *P. pallida* dominated agroforestry systems.

While soil fertility and water availability are known to be over-riding factors in site productivity, they are known to vary during the rotation. Geesing *et al* (2000) conclude that while *Prosopis* fix nitrogen on poor soils during early establishment, in later years, when sufficient soil nitrogen has built up trees stop fixing nitrogen. Harvests of timber occur normally only once in a rotation, every 20-50 years, whereas fuelwood harvests can be every 1-5 years and pod harvests are annual. Exploitation of the other nutrient-rich tree products such as honey, gums may have an effect on nutrient demand when harvested in large quantities. Fertilisation or irrigation may be necessary particularly with annual harvests of leaves and pods or regular biomass harvests. Further work on nutrient cycling in *P. juliflora - P. pallida* agroforestry systems throughout a whole rotation is required in order to calculate maximum sustainable yields.

4.4.2 Processing

Wood

The majority of wood harvested from *P. juliflora* and *P. pallida* is used as firewood and fuelwood, separated on-site and cut to length. Machetes or small axes are the most commonly used tools. Thorns and twigs can be cleaned from branches but is not always carried out. As domestic firewood, small branches with diameters of 1-5 cm are preferred because of the ease with which they are cut with hand tools. Larger trunks and stumps of *P. juliflora* and *P. pallida* are more often used as a industrial fuelwood to feed ovens or processed into charcoal. Different sizes of wood are used in preparing stacks for charcoal production, with larger material in the centre, and thinner branches on the outside (see 3.1.2). Chipped *Prosopis* wood has been assessed for its potential value as a renewable energy source and for the manufacture of various processed wood products (see 3.1.2). Boilers have been developed that pre-dry and pre-heat wood before combustion and these have been used successfully to generate electricity with *P. juliflora* as the principle fuel. Steam boilers have also been employed to convert wood energy directly into mechanical energy for the pumping of water. Wood is first chipped to increase the surface area to weight ratio, then preheated in a specially designed gasifier (see 3.1.2).

Long and relatively straight pieces can be simply fashioned into fence posts or poles for light construction, for incorporation into house structures or for supporting shuttering while concrete is being cast. Posts and poles are more valuable than fuelwood, but the maximum value that can be obtained for *P. juliflora* and *P. pallida* wood is by conversion into boards and cants. Relatively straight logs of >20 cm diameter and >1 m long are required for adequate recovery of sawn wood from the sawing process. Wood can be sawn by hand but is more often processed by chainsaw, circular saw or band saw. Primitive sawmills and hand sawing are used for cutting *P. juliflora* logs, but sawing in this manner is time consuming and results in boards that are of variable quality. *P. juliflora* and *P. pallida* can also be chipped and successfully made into a variety of other wood products using standard equipment. Plywood and particle board of an acceptable standard and high strength have been made from *P. juliflora*, and paper and cardboard can also be made following the sulphate process (see 3.1.2).

The simplest mechanical processing of logs is with a chainsaw, either hand held or, increasingly, with some form of chainsaw jig, specially designed chainsaw table or 'micro sawmill'. In comparision to more standard circular saw and bandsaw type sawmills, the advantages to the use of chainsaws either alone, with attachments or as a chainsaw-mill are the relatively low initial capital cost and high mobility. Such very mobile systems reduces the need for transporting logs. Initial processing can be carried out in the field facilitating manual extraction or loading. Non-recoverable wood is left on site and can be used as firewood. Disadvantages are the large kerf taken by the chainsaw blade, significantly reducing timber recovery and the longer time taken to process logs.

Modified conventional sawmills and specially designed sawmills, of both the circular saw and band saw types, are used successfully to process large quantities of *Prosopis* logs around the world. Which timber processing system is most suitable for a given situation also depends on stand accessibility, total timber volume and mean trunk size and shape of *P. juliflora* and *P. pallida* trees, availability of capital, labour and equipment, and market factors. While the cost of transporting logs to a central sawmill may be more economically viable than portable sawmills where timber is plentiful, the costs of haulage from disparate stands in arid and semi-arid zones may increase profitability of portable sawmills. The added social benefits of producing sawn timber in rural areas and thus stimulating the manufacture of other timber products should also to be taken into consideration.

Before sawn timber can be utilised it must first be seasoned (see 3.1.2). Dried boards and cants can then pass into the workshop for processing into finished products using standard resaws and carpentry tools.

Pod processing

Processing involves the drying, pounding, grinding or milling of pods, either as a single process producing a whole pod extract or with some separation of pod parts and further processing of each fraction. Processing for animal feed involves milling of whole pods into a homogenous, coarse flour, although in some cases exocarp and mesocarp (pulp) are separated from the endocarp and seed. For processing into human food, separation of pod parts is generally undertaken, with the mesocarp (pulp) fraction undergoing further processing. Traditionally, dried pods are pounded in a pestle and mortar to produce a coarse flour, or ground using a variety of stone mills. For hand grinding and milling in particular, adequate drying is essential to reduce the problems caused by moist mesocarps sticking during processing. Large processing units have also been adapted or designed specifically for processing *Prosopis* pods.

Separation of pod components is an important aspect of the grinding and milling process. The two traditional food products obtained from *Prosopis* in Peru are mainly based on the soluble sugars of the pulp. The rest of the fruit, including the endocarp, insoluble fibre and seeds, is often discarded. Mesquite played an important role in the Sonoran Desert in North America, where Indian tribes cooked green pods with meat. They also made flour and dough with the dried or toasted pulp from ripe pods. A kind of durable cake was prepared by drying dough balls. The pulp was separated from unbroken endocarps by pounding the pods in mortars. If further pounded, the seeds were released from the endocarp hulls, then ground and mixed with water to obtain a fermented beverage. In Northern Argentina, flour made from the sugary pulp of other *Prosopis* species is known as 'patay' and is still consumed today (see 3.2.2).

A syrup 'algarrobina' is made from whole or crushed pods which are soaked in water for 2 hours before pressing and filtering the resulting liquid, and finally concentrating the liquid by evaporation. The process is carried out on a household level in rural Peru using very simple kitchen equipment, and the 'algarrobina' produced is sold in reusable glass bottles. Modern processes are much quicker and require no heating as they use a finely ground flour from the pulp. P. pallida pulp flour has been converted into an instantly soluble powder, and could be used as a cocoa powder substitute, obtained from the fine *Prosopis* pulp flour by re-milling and sieving it through a fine screen. Coffee substitute has been made from *P. juliflora* by roasting the coarse pulp flour at 120°C until it becomes dark brown, during which time it agglomerates into larger granules requiring further grinding. The final product is used in the same way as filter coffee granules. Good quality galactomannan gums for use in the food and pharmaceutical industry can be made from *P. pallida* seed but the process is however complicated and is marginal at present in terms of economic viability (see 3.2.2).

Other non-timber products

The processing of other non-timber products from *P. juliflora* and *P. pallida* includes the production of honey and wax, leaf compost and feed, exudate gums, fibres, dyes, tannins, fish poisons and medicines. None of these processing techniques are specific to *Prosopis* and, as these are only minor products, they will not be covered in detail. Bees nests are collected from wild or managed colonies in *Prosopis* stands and honey is separated from the wax by straining through a cloth. Honeycombs are, however, sometimes heated in which case attention must be given to the possible production of toxic chemicals during the heating process (see 3.4.1). Wax can be made into candles, polishes and other products by a variety of processes. The possibility of incorporating *Prosopis* foliage into standard compost making procedures has been suggested (see 3.3.2). Exudate gums require no processing prior to sale and are dissolved in water in the manufacturing of end products for sizing of cloth and calico printing. *Prosopis* exudate gums are used locally for making adhesives and in food preparation, yet food use is not permitted by international regulations (Anderson and Farquhar 1982) (see 3.4.2). No commercial use is made of fibres, dyes, tannins or medicines, but they are sometimes of importance in local industry and commerce, particularly where alternative products are limited 3.4.3, 3.4.4).

4.4.3 Marketing and commercialisation

Products from *P. juliflora* and *P. pallida* are important commodities in local economies in many parts of the world. They are primarily sold unprocessed but also, increasingly, as processed and packaged goods. By far the main commodities traded at present are firewood, fuelwood and charcoal for domestic and light industrial use. Trading in firewood and charcoal provides a substantial part of family income for rural populations in many arid and semi-arid areas where *P. juliflora* and *P. pallida* are common, such as in India (Reddy 1978), Pakistan (Khan *et al* 1986), Sudan (El Fadl 1997), Brazil (Silva 1990b), Peru (Díaz Celis 1995), Haiti (Lea 1996) and Mexico (Maldonado 1991). Also of importance is the trading of pods and pod products, generally as animal feeds but also, increasingly, for human use. This is important in Peru, Brazil, Mexico and India. There is only minor and localised trading at present in round wood and sawn timber, mainly in native ranges in the Americas but also where *Prosopis* has been introduced. There is also some local trading in other non-timber forest products, mainly honey and exudate gums from *P. juliflora* and *P. pallida*. However, substantial quantities of 'Acacia' honey from the Americas may actually be from *Prosopis* species.

Firewood and charcoal are sold at roadsides to dealers who transport the products to urban areas, sold directly to buyers who come and collect, or taken to markets by the producer for sale. Wood is chunked or chipped and sold as a special wood or charcoal for barbeques in the USA and in Australia. Posts, poles and saw logs from *P. juliflora* are sold in Haiti (Roig 1990) and Brazil (Pasiecznik and Harris 1998) and are reported to be sold in parts of India. However, value added timber products make only a minor contribution to revenue from *P. juliflora* and *P. pallida* trees at present and could be greatly increased. Processed pods for animal feeds are important, particularly where alternative feeds are expensive. Human food products from *P. juliflora* and *P. pallida* are, however, commercially marketed in South America, with brands of coffee substitute, syrup, flour and products baked using the flour sold in shops and markets, principally in Peru, but also Brazil, Colombia, Ecuador, Venezuela and Mexico. Pod products from other *Prosopis* species are an important item of commerce in Argentina and neighbouring countries, while trading firewood and charcoal is a valuable business in North America.

The marketing of tree products produced on state owned forests is often managed by the national or state forestry sector, employing local labour to undertake harvesting and processing. Firewood, charcoal, timber, processed pods, honey, wax and exudate gums are all known to be marketed from state plantations of *P. juliflora* in India (Tewari 1998) and native stands of *P. pallida* in Peru (Díaz Celis 1995). Marketing of these products is much facilitated by greater quality control and guaranteed production possible with such a relatively large resource base (Varshney 1996). This allows for investment in machinery and development of a marketing chain. Such systems are known to work very well in India and Cape Verde for example, where state owned *P. juliflora* and *P. pallida* plantations are common and the government

Table 35.* P. juliflora, P. pallida *and other* Prosopis *tree products commercially traded in their native ranges and where introduced.

	Native					Exotic		
	Argentina	**Haiti**	**Mexico**	**Peru**	**USA**	**Australia**	**Brazil**	**India**
Species*	alb, nig, cal, chi	jul	gla, lae, vel, jul	pal, jul	gla, vel	gla, vel, jul, pal	jul, pal	jul, pal
Wood products								
Firewood	xx	xx	xxx	xx	-	-	x	xxx
Fuelwood	xx	xx	xxx	xx	xx	x	x	xx
Charcoal	xx	xxx	xx	xxx	xx	x	x	xx
Fence posts	xx	xx	xx	xx	x	x	xx	-
Poles	xx	xx	x	xx	-	-	xx	xx
Sawn timber	xx	xx	x	xx	xx	x		-
Furniture	xxx	x	x	xx	x	-	-	-
Flooring	xxx	x	x	x	xx	-	-	-
Craft items	xx	-	xx	xxx	-	-	-	-
Non-wood products								
Baked pod products	xx	-	xx	xx	-	-	-	-
Pod flour	xx	-	xx	xx	-	-	-	-
Pod syrup	xx	-	xx	xxx	-	-	-	-
Coffee substitute	xx	-	x	xx	-	-	x	-
Animal feed	xxx	xx	xx	xx	xx	xxx	xxx	xx
Honey	xx	x	xxx	xx	xx	x	x	xx
Wax	xx	-	xx	x	-	-	-	x
Exudate gum	-	-	xx	x	x	-	-	xx

xxx - *principal output*
xx - *secondary output*
x - *minor product*
\- - *not an output*

**Species*
alb - *P. alba*
cal - *P. caldenia*
chi - *P. chilensis*
gla - *P. glandulosa*
lae - *P. laevigata*
jul - *P. juliflora*
pal - *P. pallida*
vel - *P. velutina*

uses such programmes consciously for employment generation in economically disadvantaged rural communities. State controlled management and exploitation is more common where *P. juliflora* and *P. pallida* have been introduced.

Increasing emphasis is being placed on the development of private enterprise for the production and commercialisation of *Prosopis* products. Private businesses exploit *Prosopis* products in the Americas, successfully commercialising and marketing charcoal, animal feed, furniture and flooring and food products such as honey, pod syrup, coffee substitute, flour and baked products. These are marketed under brand names and sold through retail outlets and chains. They are prevalent mainly in regions where *Prosopis* species are native and where there is a history of *Prosopis* use. They are often marketed as 'traditional' or 'rustic' products. Private processors of *Prosopis* wood and pods rarely produce all the raw materials they require and often produce none at all. Processors buy wood and pods from other farmers and landowners, creating an additional need for labour or off-season employment. Pods can also be collected from commonly owned trees along roads, in urban areas or on wasteland, providing further opportunities for revenue generation, particularly for landless people and the urban poor.

Prosopis tree products are successfully exploited and marketed by the state and private sectors in countries both in the native range and where *Prosopis* is introduced. Commercialisation of *Prosopis* products is advanced in Argentina, Australia, Brazil, Haiti, India, Mexico, Peru and the USA, with an increasing number of private companies specialising in the exploitation and marketing of these products. The diverse range of products which are involved are represented by selected country in (Table 35). The seven countries have been selected because of their relatively well developed commodity chains for certain tree products and diverse socio-economic conditions.

Chapter 5

Recommendations

5.1 Use of improved genetic material

Much emphasis by the research community on under-utilised, multi-purpose tree species in the last 30 years has concentrated on the application of traditional forestry genetic improvement programmes. *Prosopis* has lagged behind other genera and, although selection of improved species has occurred in the USA and Argentina since the early 1980s, there has been little work on tropical *P. juliflora* and *P. pallida*. There is a need to identify further superior germplasm, specifically in terms of pod quality, timber quality, tree form and thornlessness. The continuing taxonomic problems with this species complex needs to be resolved. There is a need to distribute superior germplasm throughout tropical regions where *Prosopis* has already been introduced. Finally, there is a need, as stated by FAO expert panels on forests as long ago as 1979, to make available genetically improved material of *Prosopis* species.

Selection for form and growth of naturalised trees has been carried out in India and Brazil, but this has not made use of the full range of natural variation in such genetically restricted introduced populations. In Peru, seed orchards of *P. pallida* clones selected for sweet pods and high yields have recently been established. Seed should soon be available from these and from selected trees in natural stands, for distribution to other researchers for inclusion in genetic improvement programmes world-wide. Peruvian material has been identified in several field trials as being the best performing tropical *Prosopis* in terms of pod sweetness and growth rate. However, there is some evidence that they have poorer timber quality that other provenances.

There is a vital need for complete, range-wide collections of seed, herbarium material, pods and wood. Similar detailed studies have been undertaken on many other important tropical multi-purpose tree species in the Americas, while *Prosopis* has been overlooked. Full analysis of the genetic variation available, the complex taxonomy, and variation in resource quality, is an essential pre-requisite to any in-depth attempts at genetic improvement. Once this is achieved, existing complementary technologies developed for *Prosopis* including multiplication through cuttings and grafting, can be used to make rapid advancements in the genetic improvement of tropical *Prosopis*.

5.2 Application of improved management interventions

Several specific management interventions have been proposed for use on *Prosopis* trees in both natural stands and plantations. Various pruning, thinning, fertilisation and cultivation treatments have been shown to have positive effects on growth and in reducing competition with neighbouring crops. However, only very few studies have been carried out, and the results may be location specific. It is imperative to undertake a series of studies world-wide on the effects of management interventions to assess the effects on absolute yields and the economic viability of production. Further studies are required on the effects of management interventions on water use of trees. The use of different management programmes in controlling weedy invasions is also important in the many regions where this is a problem. While genetic improvement will be positive in terms of improving production per new tree planted, there are already millions of *Prosopis* trees established world-wide, that remain unproductive due to the lack of application of suitable management procedures.

Thinning studies on weedy natural stands of *Prosopis* in the USA have shown the beneficial effects on growth and overall wood yield, but these have yet to be applied to tropical species. Concurrent work on cultural interventions could also be usefully applied to *P. juliflora* and *P. pallida*. Limited work on the effects of pruning has shown very beneficial effects on overall growth rates and on reducing water use and the competitive effects on neighbouring crops. Grafting superior material onto naturalised *Prosopis* is possible and is recommended as a method of converting weedy stands to productive agroforestry. While *Prosopis* plantations are known to increase soil fertility, improve soil structure, and decrease soil alkalinity and salinity, the effects of management interventions on these beneficial effects are not known. Further studies are required in a range of forestry and agroforestry situations and on a range of site types to confirm these results. Full economic analysis of each intervention is also essential.

It is essential that further research be undertaken on the development of productive, sustainable, diversified and economic land use systems for tropical, arid zones. *Prosopis* stands are often managed for either fuelwood or fodder, as forests with undergrazing, and rarely for poles, honey, timber or gums. However, there is the potential for developing land-uses that can produce a range of tree products concurrently in agroforestry systems. The thinning of natural stands or plantations to wide-spaced, single-stemmed trees would increase the growth of understorey grasses or agricultural crops, and reduce overall water use. Leaving a clear bole up to 2 m high would maximise revenue from timber production. Periodic lopping would produce fuelwood and poles, while introducing bee hives would lead to honey production and increase pod yields and trees could be treated to greatly increase the yield of exudate gum. Studies on all of these interventions are required.

5.3 Development and application of processing technologies

Lack of suitable technologies for processing *Prosopis* tree products has been identified as a limiting factor to further development of the species. For many centuries, trees have been harvested for firewood and poles, and pods collected to feed to livestock without further transformation. Wood found many uses, and pods have also been processed into various human foods by many indigenous peoples. As the tree was introduced around the world, these traditional uses and technologies did not follow. There is a need to develop technologies for processing *Prosopis* wood and pods that are adaptable to a variety of situations and to promote them. There is also a need to develop high-technology solutions to problems associated with extraction and separation of high value substances, such as galactomannan gums from seed, solvents from the wood and various chemicals and possible medicines from gums and leaves. Technological solutions are also required to be able to transform the wood into chips suitable for manufacturing paper or particle boards, and for cutting into veneers.

While the wood technical quality of *Prosopis* for fine furniture is on par with the world's best and most exotic timbers, i.e. rosewood, mahogany, cherry and walnut, the vast majority of the biomass in *Prosopis* exists in short small diameter pieces. Given the fact that these pieces for potential application in sawn lumber, flooring and furniture parts ($850 per cubic meter = $1000/ton) is nearly ten times the value of firewood, charcoal and chips, it is important to maximise sawn wood production from *Prosopis*. Machinery has been developed and adapted for processing short and crooked *Prosopis* logs into sawn boards. Sawmills of various types have been used successfully, including large and medium-sized circular saws, band saws and chainsaw mills, and each has specific advantages in different situations. Some experiences are available on the processing of *Prosopis* wood into plywood, chipboard and papers, chips for energy production, and even chemical processing into animal feeds. While economically marginal at the time and place of study, changing circumstances may make the technologies suitable for village-scale processing in arid zones. *Prosopis* pod processing has seen many advances over the last 20 years, with machinery now available to mill large quantities of pods, and technologies that can separate specific fractions for use in specific food applications.

Larger-scale technologies exist and have been proven, but there is a need to adapt these for medium-scale use, or for use on individual large farms. Ergonomic, technical and economic studies to improve the suitability of technology are required. Studies on seasoning, prevention of insect damage, and applicability of a variety of existing wood processing technologies such as finger-jointing and veneer-slicing would help develop *Prosopis* as a timber. Similarly, a low-cost process of milling and storing pods, and separation into commercially useful fractions would encourage pod production. Many technologies have already been developed but require application to the processing of *Prosopis* tree products.

5.4 Commercialisation of *Prosopis* tree products

Prosopis has been promoted widely for the last two decades as a firewood and fodder crop, with vast plantations established solely for producing these subsistence products. Wood and pods play an important role in local economies in many regions world-wide, both native range and where introduced. As arid zones are frequently importers of natural resources, it is essential to promote local products in an attempt at import substitution. Also, in an increasingly market-orientated world, there are more possibilities for the export of *Prosopis* wood and pod products. These will increase the economic activity in arid zones, promoting investment with a positive impact on livelihood enhancement. Commercialisation of tree products has not traditionally been the domain of natural resources researchers, and has remained a low priority in development for many years. Only recently has attention been given to this vital aspect of rural development.

Prosopis pod and wood products have been widely commercialised in the USA and Argentina for many years, and to a lesser extent in other American countries. *Prosopis* firewood and charcoal are also traded in all regions where the trees are found. These markets have evolved locally due to the relative ubiquity and very low cost of the raw material and to low processing costs. The promotion of local goods for local markets is gaining ground with an increased knowledge that this substantially aids local development. Niche markets are also now developing for specialist 'rustic' products. Certified environmentally or socially sound production systems have expanded in recent years in response to increased consumer demand. Organic foods, Fair Trade goods and sustainably managed forest products are the main examples, but there is scope for the promotion of goods from arid zones as 'greening the desert'.

Import substitution of wood and feed products, which can be produced from stands of *Prosopis*, should be a primary aim of rural development. Management and harvesting needs to be carried out by local populations, and processing needs to be kept as local as possible for integrated rural development to occur. Detailed local surveys and analyses are required to elucidate which imported products could be substituted, which *Prosopis* products have most potential, and what is necessary to aid development. While impacts are being made on local markets, these products can be promoted regionally, nationally, or even internationally through certification, trade shows and promotion through a variety of environmentally and socially sound networks.

5.5 Conclusions

Prosopis trees already play a vital part in the ecology and the economy of many arid and semi-arid zones where they are found. They play an integral part in several sustainable land use systems that are improving the livelihoods of rural desert populations while preventing further soil degradation and assisting land reclamation. Most of the silvicultural constraints to arid zone development have already been overcome, particularly in nursery and plantation establishment. Further planting should, however, make the most of the best genetic material available. With so many *Prosopis* trees already planted, and often spreading widely by natural regeneration, the issue now is how best to make use of them.

Desertification can only be reversed if economic value can be given to arid zones. This involves the production, processing and commercialisation of desert crops. Many have been suggested as ‘miracle’ plants over the last few decades, but most have failed to be adopted, being relatively intensive crops requiring high levels of investment and relatively better sites and soils. With low and very variable rainfall, returns will be poor unless irrigation is available. If irrigation is available, subsistence food crops become a priority. Agroforestry has been promoted, but again this has not been widely adopted by rural farmers in dry zones. Tree planting has been largely promoted for the positive effects on the environment, reasons that are not immediate priorities for land users. Only trees which produce financial returns have been widely planted by farmers.

We, the authors, feel the objective should not be just to give the poorest in the world’s semi-arid regions more firewood, but to create a large market of high value products that can lift them from the lowest strata of poverty. *Prosopis* has been the species of the politically disenfranchised, who do not have the influence to request research and development funding for genetic improvement, processing technology and marketing. *Prosopis* has the technical timber and pod qualities and environmental attributes to be a species of world-wide commercial importance. As scientists and development officers we must bring a balanced approach to research, development and marketing to ensure that such benefits reach the poor people of arid lands who truly deserve them.

References

Abebe, T. (1994) Growth-performance of some multi-purpose trees and shrubs in the semiarid areas of southern Ethiopia. *Agroforestry Systems* 26:237-248.

Abohassan, A. A., I. E. Kherallah and S. A. Kandeel. (1988) Effect of sewage effluent irrigation regimes on wood quality of *Prosopis juliflora* grown in Riyadh Region. *Arab Gulf Journal of Scientific Research* B6:45-53.

Abrams, M. M., W. M. Jarrell, H. A. Smith and P. R. Clark. (1990) Nitrogen accretion in soil and biomass production by three *Prosopis* species. *Agroforestry Systems* 10:93-97.

Achi, O. K. (1992) Microorganisms associated with natural fermentation of *Prosopis africana* seeds for the production of okpiye. *Plant Foods for Human Nutrition* 42:297-304.

Aggarwal, R. K. (1998) Effect of *Prosopis* species on properties of arid zone soils. pp. 27-29. In: *Prosopis* Species in the Arid and Semi-Arid Zones of India. (Eds.) J. C. Tewari, N. M. Pasiecznik, L. N. Harsh and P. J. C. Harris. *Prosopis* Society of India and the Henry Doubleday Research Association, Coventry, UK.

Aggarwal, R. K., J. P. Gupta, S. K. Saxena and K. D. Muthana. (1976) Studies on soil physico-chemical and ecological changes under twelve years old five desert tree species of western Rajasthan. *Indian Forester* 102:863-872.

Aggarwal, R. K. and A. N. Lahiri. (1977) Influence of vegetation on the status of organic carbon and nitrogen of the desert soils. *Science and Culture* 43:533-535.

Aguirre, J. J. and J. Wrann. (1985) The genus *Prosopis* and its management at the Tamarugal Pampa. pp. 3-33. In: The Current State of Knowledge on *Prosopis tamarugo*. (Ed.) M. A. Habit. FAO, Rome, Italy.

Aguirre, Q. A. (1989) Evaluacion de los plantaciones de algarrobo (*Prosopis pallida*) con riego por goteo en las zonas aridas de los departamentos de Piura e Ica., Lima, Peru.

Ahmad, A., K. A. Khan, V. U. Ahmad and S. Qazi. (1988) Antibacterial activity of an alkaloidal fraction of *Prosopis juliflora*. *Fitoterapia* 59:481-484.

Ahmad, A., A. K. Kursheed, Q. Sabiha, A. Viqaruddin and Aqueel-Ahmad. (1989) Antifungal activity of some hydrosoluble *Prosopis juliflora* alkaloids. *Fitoterapia* 60:86-89.

Ahmad, R., S. Ismail and D. Khan. (1996) Use of *Prosopis* in Arab/Gulf states, including possible cultivation with saline water in deserts. pp. 1.41-1.52. In: *Prosopis*: Semiarid Fuelwood and Forage Tree; Building Consensus for the Disenfranchised. (Eds.) P. Felker and J. Moss. Center for Semi-Arid Resources, Kingsville, Texas, USA.

Ahmad, R., S. Ismail, M. Moinuddin and T. Shaheen. (1994) Screening of mesquite (*Prosopis* spp.) for biomass production at barren sandy areas using highly saline water for irrigation. *Pakistan Journal of Botany* 26:265-282.

Ahmad, V. U. and A. Sultana. (1989) A terpenoid diketone from the leaves of *Prosopis juliflora*. *Phytochemistry* 28:278-279.

Akrimi, N. (1990) *Prosopis* in Tunisia. pp.147-151. In: The Current State of Knowledge on *Prosopis juliflora*. (Eds.) M. A. Habit and J. C. Saavedra. FAO, Rome, Italy.

Alarcón, C. and M. Díaz. (1993) Hydric and nutritional relations of *Prosopis juliflora* DC (Fabaceae, Mimosoideae) in semiarid parts of Falcon state, Venezuela. *Revista De Biologia Tropical* 41:433-441.

Alder, A. E. (1949) Indigestion from unbalanced kiawe (mesquite) bean diet. *Journal of the American Veterinary Medical Association* 153:263.

Allen, O. N. and E. K. Allen. (1981) The Leguminosae: A Source Book for Characteristics, Uses, and Nodulation. The University of Wisconsin Press, Madison, USA.

Almanza, S. G., E. G. Moya, T. L. Wendt and F. V. G. Cossio. (1992) Potencial de hibridacion natural en el mezquite (*Prosopis laevigata* y *P. glandulosa* var.*torreyana*, Leguminosae) de la altiplanicie de San Luis Potosi. *Acta Botanica Mexicana* 20:101-117.

Alvarez Sánchez, F. (1998) Características apibotanicas de la miel de algarrobo *Prosopis pallida* en el departamento de Piura. pp. 25. In: Primer Seminario Taller sobre elen la Región Grau, May 1992, Chulucanas. (Ed.) Algarrobo Comité de Coordinación de Acción Forestal Universidad Nacional de Piura, Piura, Peru.

Alves, J. L. H., M. S. A. Melo and G. D. Alves. (1990) Internal structure of plant, fruit, seed, and pollen morphology of *Prosopis juliflora* (Sw) DC. pp. 187-194. In: The Current State of Knowledge on *Prosopis juliflora*. (Eds.) M. A. Habit and J. C. Saavedra. FAO, Rome, Italy.

ALZA, T., W. RAMÍREZ AND J. JIMÉNEZ. (1998) Obtención de extractos azucarados de la algarroba y posterior concentración para la elaboración de algarrobina. pp. 31. In: Primer Seminario Taller sobre el Algarrobo en la Región Grau, May 1992, Chulucanas. Comité de Coordinación de Acción Forestal. Uiversidad Nacional de Piura, Piura, Peru.

ALZAMORA, H. E. (1988) Determinación de N, P, K en el puño de algarrobo atendiendo a sus uso como abono orgánico. M.Sc thesis, Universidad de Piura, Peru.

ANDERSON, D. M. W. (1986) The proteinaceous components of the gum from nitrogen-fixing trees. *Nitrogen Fixing Tree Research Reports* 4:47-48.

ANDERSON, D. M. W. (1989) Future prospects for *Prosopis* gum exudates for commercial, non-food purposes. *Nitrogen Fixing Tree Research Reports* 7:108-110.

ANDERSON, D. M. W. AND J. G. K. FARQUHAR. (1982) Gum exudates from the genus *Prosopis*. *International Tree Crops Journal* 2:15-24.

ANDERSON, D. M. W., J. F. HOWLETT AND C. G. A. MCNAB. (1985) The amino acid composition of gum exudates from *Prosopis* species. *Phytochemistry* 24:2718-2720.

ANON. (1943) Nutritive values of *Prosopis juliflora* pods and some grasses. *Indian Forester* 69:483-585.

ANTTILA, L. S., G. M. ALAKOSKI-JOHANSSON AND S. G. JOHANSSON. (1993) Browse preference of orma livestock and chemical composition of *Prosopis juliflora* and nine indigenous woody species in Bura, eastern Kenya. *East African Agriculture and Forestry Journal* 58:83-90.

AQEEL, A., A. K. KHURSHEED AND A. VIQARUDDIN. (1991) Toxicological studies of the antimicrobial alkaloid juliflorine. *Arzneimittel-Forschung/Drug Research* 41:151-154.

AQEEL, A., A. K. KHURSHEED, A. VIQARUDDIN AND Q. SABIHA. (1989) Antimicrobial activity of julifloricine isolated from *Prosopis juliflora*. *Arzneimittel Forschung/Drug Research* 39:652-655.

ARCE, P. AND O. BALBOA. (1990) Some aspects of the biology of *Prosopis* growing in Chile. pp. 313-322. In: The Current State of Knowledge on *Prosopis juliflora*. (Eds.) M. A. Habit and J. C. Saavedra. FAO, Rome, Italy.

ARCE, P. AND O. BALBOA. (1991) Seasonality in rooting of *Prosopis chilensis* cuttings and *in vitro* micropropagation. *Forest Ecology and Management* 40:163-173.

ARCHER, S. (1995) Tree-grass dynamics in a *Prosopis*-thornscrub savanna parkland -reconstructing the past and predicting the future. *Ecoscience* 2:83-99.

ARONSON, J., C. OVALLE AND J. AVENDANO. (1992) Early growth-rate and nitrogen-fixation potential in 44 legume species grown in an acid and a neutral soil from central Chile. *Forest Ecology and Management* 47:225-244.

ARROYO, M. T. K. (1981) Breeding systems and pollination biology in Leguminosae. pp. 723-769. In: Advances in Legume Systematics. (Eds.) R. M. Polhill and P. H. Raven. Royal Botanic Gardens, Kew, UK.

ARRUDA, G.P. DE, ARRUDA, E.C. DE, SANTOS, A.B.R. DOS, HOLANDA, A.C.A. (1990) Entomological observations. In: The Current State of Knowledge on *Prosopis juliflora*. (Eds.) M. A. Habit and J. C. Saavedra. FAO, Rome, Italy.

ARYA, S. (1993) Khejri - *Prosopis cineraria*: a golden tree of Indian desert. Dayanand Post-Graduate College, Hisar, Haryana, India.

ARYA, S., R. P. BISHT, R. TOMAR, O. P. TOKY AND P. J. C. HARRIS. (1995) Genetic variation in minerals, crude protein and structural carbohydrates of foliage in provenances of young plants of *Prosopis cineraria* (L.) Druce in India. *Agroforestry Systems* 29:1-7.

ARYA, S., O. P. TOKY, R. P. BISHT AND R. TOMAR. (1992) Potential of *Prosopis cineraria* (L.) Druce in arid and semi-arid India. pp. 61-70. In: *Prosopis* Species: Aspects of their Value, Research and Development. (Eds.) R. W. Dutton. CORD, University of Durham, Durham, UK.

ASENCIO DÌAZ, F. W. (1997) La producción de algarroba de los bosques secos. Centro Bartolomé de las Casas, Cusco, Peru.

AVGERINOS, G. C. AND D. I. C. WANG. (1980) Utilization of mesquite and honey locust pods as feeds for energy production. pp. 209-217. In: Tree Crops for Energy Co-Production on Farms. Solar Energy Institute, Estes Park, Colorado, USA.

AZEVEDO, C. F. de. (1982) Algarobeira na alimentacao animal e humana. pp. 283-299. In: Simposio Brasileiro Sobre Algaroba 1, Natal. EMPARN, Natal, Brazil.

AZEVEDO, G. (1955) Algaroba. Ministério da Agricultura, Serviço do Acordo do Fomento da Produçao Animal, Natal, Brazil.

AZEVEDO, G. (1961) Algaroba. SIA 843. Serviço de Informação Agrícola, Rio de Janeiro, Brazil.

AZEVEDO ROCHA, R. G. (1987) Algaroba na alimentação e farmacopeia do homem rural Norte-Riograndense. *Revista da Associação Brasileira de Algaroba (Mossoró)* 1:67-96.

BAIÃO, V. B., J. C. GOMES, R. SANT'ANNA AND R. CRUZ. (1987) Chemical characteristics of mesquite beans (*Prosopis juliflora*) and amino acid composition of concentrate and a protein isolate. *Arquivos de Biologia e Tecnologia* 30:275-286.

BANDELIER, A. AND F. BANDELIER. (1905) The Journey of Alvar Nuñez Cabeza de Vaca and his Companions from Florida to the Pacific 1528-1536. AS Barns, New York, USA.

BANDYOPADHYAY, B., A. K. NANDY, R. MALLICK AND A. CHATTERJEE. (1990) A comparative study on the effect of gamma-irradiation on growth and biomass yield in certain fuel-wood species. *Indian Forester* 116:392-402.

BARAJAS MORALES, J. (1987) Wood specific gravity in species from two tropical forests in Mexico. *Iawa Bulletin* 8:143-148.

BARBOSA, H. P. (1977) Valor nutritivo da algaroba (*Prosopis juliflora* (SW) DC) através de ensaio de digestibilidade em carneiros. M.Sc Thesis, Universidade Federal de Viçosa, Escola Superior de Agricultura, Viçosa, Brazil.

BARI, E. A. (1986) The identity of the common mesquite, *Prosopis* spp. Pamphlet, *Prosopis* Project, Forestry Research Centre, Sudan. 1:20.

BARRIOS, D. (Undated) Estudio de mercado y comercializacion de productos forestales del Peru. Ministerio de Agricultura, Peru.

BARTH, R. C. AND J. O. KLEMMEDSON. (1982) Amount and distribution of dry matter, nitrogen, and organic carbon in soil-plant systems of mesquite and palo verde. *Journal of Range Management* 35:412-418.

BARTSCH, R. A., S. J. R. CHEN AND J. S. PENDERGRASS. (1982) Isolation of non-carbohydrate, organic chemicals from mesquite. pp. T1-T10. In: Mesquite Utilization. (Ed.) H. W. Parker. Texas Tech University, Lubbock, Texas, USA.

BASU, P. K. AND M. C. KABI. (1987) Effect of application of biofertilizers on the growth and nodulation of seven forest legumes. *Indian Forester* 113:249-257.

BATCHELOR, C. A. (1990) *In vitro* regeneration of tropical leguminous trees and shrubs with particular reference to the genus *Prosopis*. M.Phil/PhD transfer report, Department of Biological Sciences, Coventry University, Coventry, UK.

BATCHELOR, C. A., T. C. JONES, D. Y. YAO AND P. J. C. HARRIS. (1990) The effects of cobalt nitrate, charcoal, salicylic acid and culture vessel composition on the growth of *Prosopis chilensis* shoot tips in culture. pp. 8. In: Abstracts of the 7th International Congress on Plant Tissue and Cell Culture, Amsterdam, The Netherlands.

BATCHELOR, C. A., D. YAO, M. J. KOEHLER AND P. J. C. HARRIS. (1989) *In vitro* propagation of *Prosopis* species (*Prosopis chilensis*, *Prosopis cineraria* and *Prosopis juliflora*). *Annales des Sciences Forestières* 46:S110-S112.

BAZZAZ, F. A. (1973) Seed germination in relation to salt concentration in three populations of *Prosopis farcta*. *Oecologia* 13:73-80.

BECKER, R. AND O.-K. K. GROSJEAN. (1980) A compositional study of pods of two varieties of mesquite (*Prosopis glandulosa*, *P. velutina*). *Journal of Agricultural and Food Chemistry* 28:22-25.

BELL, W. AND E. F. CASTETTER. (1951) Yuman Indian Agriculture. Primitive Subsistence on the Lower Colorado and Gila Rivers. University of New Mexico Press, Albuquerque, USA.

BENSON, L. (1941) The mesquites and screwbeans of the United States. *American Journal of Botany* 28:748-754.

BENTHAM, G. (1842) Notes on Mimoseae. *Hooker Journal of Botany* 4:346-352.

BENTHAM, G. (1875) Revision of the suborder Mimoseae. *The Transactions of the Linnean Society of London* 30:335-664.

BENTHAM, G. AND J. D. HOOKER. (1867) Genera Plantarum. Vol. 1. Reeve & Co., London, UK.

BERISTAIN, C. I. AND E. J. VERNON-CARTER. (1994) Utilization of mesquite (*Prosopis juliflora*) gum as emulsion stabilizing agent for spray-dried encapsulated orange peel oil. *Drying Technology* 12:1727-1733.

BERNARD, C. (1996) Etude d'un parc a *Prosopis africana* au Nord Cameroun (Cas du village de Holom, en pays Musey). Premier Resultats, IRAD-Projet Garoua II/CIRAD-Forêt/ORSTOM/ICRAF. CIRAD-Forêt, Montpellier, France.

BHANDARI, D. S. AND H. N. GOVIL. (1978) Evaluation of fodder tree leaves for sheep and goat in semi-arid area of Rajasthan. *Journal of Nuclear Agriculture and Biology* 7:110-113.

BHATIA, N. P., A. ADHOLEYA AND A. SHARMA. (1998) Biomass production and changes in soil productivity during longterm cultivation of *Prosopis juliflora* (Swartz) DC inoculated with VA mycorrhiza and *Rhizobium* spp. in a semi-arid wasteland. *Biology and Fertility of Soils* 26:208-214.

BHIMAYA, C. P., M. B. JAIN, R. N. KAUL AND B. N. GAUGULI. (1967) A study of age and habitat differences in the fuel yield of *Prosopis juliflora*. *Indian Forester* 93:355-359.

BHOJVAID, P. P., V. R. TIMMER AND G. SINGH. (1996) Reclaiming sodic soils for wheat production by *Prosopis juliflora* (Swartz) DC afforestation in India. *Agroforestry Systems* 34:139-150.

BIONDI, D. (1990) *Prosopis juliflora* DC in urban forestry. pp. 169-173. In: The Current State of Knowledge on *Prosopis juliflora*. (Eds.) M. A. Habit and J. C. Saavedra. FAO, Rome, Italy.

BOHRA, M. D., S. K. SHARMA AND S. LODHA. (1998) Use of *Prosopis juliflora* pods in enhancing the growth of fungal pathogens in culture medium. pp. 111-112. In: *Prosopis* Species in the Arid and Semi-Arid Zones of India. (Eds.) J. C. Tewari, N. M. Pasiecznik, L. N. Harsh and P. J. C. Harris. *Prosopis* Society of India and the Henry Doubleday Research Association, Coventry, UK.

BOSE, R. K. AND S. K. BANDOYOPADHYAY. (1986) Economics of energy plantations in alkali soils of Indian semi-arid regions. *Biomass* 11:51-60.

BRADBURY, M. AND R. AHMAD. (1990) The effect of silicon on the growth of *Prosopis juliflora* growing in saline soil. *Plant and Soil* 125:71-74.

BRAGG, L. H., J. D. BACON, C. MCMILLAN AND T. J. MABRY. (1978) Flavonoid patterns in the *Prosopis juliflora* complex. *Biochemical Systematics and Ecology* 6:113-116.

BRAUN WILKE, R. H. (1988) Revaloracion de *Prosopis ferox*. P. 5 *in* First International Workshop on Genetic Resources and Germplasm Conservation in *Prosopis*, Cosquin, Córdoba, Argentina.

BRAVO, L., N. GRADOS AND F. SAURA-CALIXTO. (1994) Composition and potential uses of mesquite pods (*Prosopis pallida* L) - comparison with carob pods (*Ceratonia siliqua* L). *Journal of the Science of Food and Agriculture* 65:303-306.

BRAVO, L., N. GRADOS AND F. SAURA-CALIXTO. (1998) Characterization of syrups and dietary fiber obtained from mesquite pods (*Prosopis pallida* L). *Journal of Agricultural and Food Chemistry* 46:1727-1733.

BRIONES, L. (1985) Retrospective anthropological vision of *Prosopis*. pp. 49-51. In: The Current State of Knowledge on *Prosopis tamarugo*. (Ed.) M. Habit. FAO, Rome, Italy.

BRISTOW, S. (1996) The use of *Prosopis juliflora* for irrigated shelterbelts in arid conditions in northern Sudan. pp. 2.45-2.63. In: *Prosopis*: Semiarid Fuelwood and Forage Tree; Building Consensus for the Disenfranchised. (Eds.) P. Felker and J. Moss. Center for Semi-Arid Forest Resources, Kingsville, Texas, USA.

BROUN, A. F. AND R. E. MASSEY. (1929) Flora of the Sudan. MacMillan and Co., London, UK.

BROWN, J. R. AND S. ARCHER. (1989) Woody plant invasion of grasslands - establishment of honey mesquite (*Prosopis glandulosa* var *glandulosa*) on sites differing in herbaceous biomass and grazing history. *Oecologia* 80:19-26.

BROWN, J. R. AND S. ARCHER. (1990) Water relations of a perennial grass and seedling vs. adult woody plants in a subtropical savanna, Texas. *Oikos* 57:366-374.

BRYANT, F. C. AND M. M. KOTHMANN. (1979) Variability in predicting edible browse from crown volume. *Journal of Range Management* 32:144-146.

BRYANT, F. C., T. MILLS, J. S. PITTS AND M. CARRIGAN. (1982) Ozone-treated mesquite as the roughage base in range cattle supplemental feed. pp. G1-G6. In: Mesquite Utilization. (Ed.) H. W. Parker. Texas Tech University, Lubbock, Texas, USA.

BUKHARI, Y. M. (1997) Cytoevolution of taxa in *Acacia* and *Prosopis* (Mimosaceae). *Australian Journal of Botany* 45:879-891.

BUKHARI, Y. M. (1998) Cytological and molecular evolution of *Acacia* and *Prosopis* (*Mimosaceae*). Academic Dissertation, Department of Plant Biology, Faculty of Agriculture and Forestry, University of Helsinki, Helsinki, Finland.

BURGA, T. I. (1988) Estudio del secado solar y almacenamiento de algarroba (*Prosopis pallida*). M.Sc. thesis, Universidad Nacional Agraria La Molina, Lima, Peru.

BURGHARDT, A. D. AND R. A. PALACIOS. (1997) Electrophoretic characterization of the American sections of *Prosopis* L. (Leguminosae: Mimosoideae). Bulletin of the International Group for the Study of Mimosoideae 20: 71-83.

BURKART, A. (1940) Materiales para una monografía del género *Prosopis* (Leguminosae). *Darwiniana* 4:57-128.

BURKART, A. (1952) Las Leguminosas Argentinas. ACME, Buenos Aires, Argentina.

BURKART, A. (1976) A monograph of the genus *Prosopis* (Leguminosae subfam. Mimosoideae). (Part 1 and 2). Catalogue of the recognized species of *Prosopis*. *Journal of the Arnold Arboretum*. 57:219-249 and 450-525.

BURKART, A. AND B. B. SIMPSON. (1977) The genus *Prosopis* and annoted key to the species of the world. pp. 201-215. In: Mesquite: Its Biology in Two Desert Ecosystems. (Ed.)B. B. Simpson. Dowden, Hutchinson and Ross, Stroudsburg, Pennsylvania, USA.

BURLEY, J., C. E. HUGHES AND B. T. STYLES. (1986) Genetic systems of tree species for arid and semiarid lands. *Forest Ecology and Management* 16:317-344.

BURMAN, U., N. K. SHARMA, L. N. HARSH AND J. C. TEWARI. (1995) Estimation of leaf area using leaf dry weight in *Prosopis juliflora* (SW) DC. through regression analysis. *Current Agriculture* 19:63-65.

BUTTERFIELD, R. (1996) *Prosopis* in Sahelian forestry projects: a case study from Niger. pp. 2.19-2.32. In: *Prosopis*: Semiarid Fuelwood and Forage Tree; Building Consensus for the Disenfranchised. (Eds.) P. Felker and J. Moss. Center for Semi-Arid Forest Resources, Kingsville, Texas, USA.

CACCAVARI DE FILICE, M. A. (1972) Granos de polen de Leguminosas de la Argentina II. Subfam. Mimosoideae; Tribu Adenanthereae. *Revista Museo Argentino Ciencias Naturales B. Rivadavia* 4:281-320.

CACERES, A., H. MENENDEZ, E. MENDEZ, E. COHOBON, B. E. SAMAYOA, E. JAUREGUI, E. PERALTA AND G. CARRILLO. (1995) Antigonorrhoeal activity of plants used in Guatemala for the treatment of sexually-transmitted diseases. *Journal of Ethnopharmacology* 48:85-88.

CADORET, K, N. M. PASIECZNIK AND P. J. C. HARRIS. (2000) The Genus *Prosopis* - A Reference Database (Version 1.0).CD ROM. HDRA, Coventry, UK.

CALDERÓN, C. W. (1986) La lagartija, un vertebrado plaga en la instalación de plantaciones de algarrobo (*Prosopis pallida*) en el campo de reforestación de la universidad de Piura. Universidad de Piura, Peru.

CAMPOS, C. M. AND R. A. OJEDA. (1997) Dispersal and germination of *Prosopis flexuosa* (Fabaceae) seeds by desert mammals in Argentina. *Journal of Arid Environments* 35:707-714.

CARMAN, N. J. (1974) Systematic and ecological investigations in the genus *Prosopis* emphasising the natural products chemistry. *Chemical Abstracts* 34:4240.

CARMAN, N. J., S. F. DOSSAJI AND T. J. MABRY. (1974) A populational survey of amino acids in *Prosopis* species from North and South America. *Biochemical Systematics and Ecology* 2:73-74.

CARRIÓN, E. (1988) Uso de la algarroba como sucedáneo del café. B.Sc. Thesis, Universidad de Piura, Peru.

CARVALHO, R. F. (1963) A Algarobeira. *Anuario dos Criadoves de São Paulo* 10:195-199.

CASTRO, M. A. (1989) Estructura y ultraestructura del leño secundario de especies argentinas del género *Prosopis* L. (Leguminosae). PhD thesis, Universidad de Buenos Aires, Argentina.

CATALÁN, L. A. AND M. BALZARINI. (1992) Improved laboratory germination conditions for several arboreal *Prosopis* species - *Prosopis chilensis*, *P. flexuosa*, *P. nigra*, *P. alba*, *P. caldenia* and *P. affinis*. *Seed Science and Technology* 20:293-298.

CATALÁN, L. A. AND R. E. MACCHIAVELLI. (1991) Improving germination in *Prosopis flexuosa* DC and *Prosopis alba* Griseb with hot water treatments and scarification. *Seed Science and Technology* 19:253-262.

CATES, R. G. AND D. F. RHOADES. (1977) *Prosopis* leaves as a source for insects. pp. 61-83. In: Mesquite, Its Biology in Two Desert Scrub Ecosystems. (Ed.)B. B. Simpson. Dowden, Hutchinson and Ross, Stroudsburg, Pennsylvania, USA.

CHATURVEDI, A. N. (1983) General volume tables for *Prosopis juliflora*, DC. Uttar Pradesh Forest Bulletin 46:4. Forest Department, Uttar Pradesh, India.

CHATURVEDI, A. N. (1984) Assessment of biomass production. *Indian Forester* 110:726-738.

CHATURVEDI, A. N. (1985) Firewood farming on degraded lands. Uttar Pradesh Forest Bulletin No. 50. Forest Department, Uttar Pradesh, India.

CHATURVEDI, A. N. AND H. M. BEHL. (1996) Biomass production trials on sodic site. *Indian Forester* 122:439-455.

CHATURVEDI, A. N., S. C. SHARMA AND R. SRIVASTAVA. (1988) Water consumption and biomass production of some forest tree species. *International Tree Crops Journal* 5:71-76.

CHAUDHRY, B. AND M. R. VIJAYARAGHAVAN. (1992) Structure and function of the anther gland in *Prosopis juliflora* (Leguminosae, Mimosoideae) - a histochemical analysis. *Phyton-Annales Rei Botanicae* 32:1-7.

CHAVAN, S. A. (1986) *Prosopis juliflora* for wasteland development in Saurashtra. pp. SAC1-SAC9. In: The Role of *Prosopis* in Wasteland Development. (Ed.) V. J. Patel. Javrajbhai Agroforestry Center, Surendrabag, Gujarat, India.

CHELLAMUTHU, V., T. N. BALASUSBRAMANIAN, A. RAJARAJAN AND S. N. PALANIAPPAN. (1997) Allelopathic influence of *Prosopis juliflora* (Swartz) DC. on field crops. *Allelopathy Journal* 4:291-302.

CHINNIMANI, S. (1998) Ecology of succession of *Prosopis juliflora* in the ravines of India. pp. 21-22. In: *Prosopis* Species in the Arid and Semi-Arid Zones of India. (Eds.) J. C. Tewari, N. M. Pasiecznik, L. N. Harsh and P. J. C. Harris. *Prosopis* Society of India and the Henry Doubleday Research Association, Coventry, UK.

CLAVIJO, J. (1991) Uso de la pulpa de algarroba para la obtención de etanol. MSc thesis, Universidad de Piura, Peru.

CLINE, G., D. RHODES AND P. FELKER. (1986) Micronutrient, phosphorus and pH influences on growth and leaf tissue nutrient levels of *Prosopis alba* and *Prosopis glandulosa*. *Forest Ecology and Management* 16:81-93.

CONNIN, S. L., R. A. VIRGINIA AND C. P. CHAMBERLAIN. (1997) Carbon isotopes reveal soil organic matter dynamics following arid land shrub expansion. *Oecologia* 110:374-386.

CONY, M. A. (1996) Genetic potential of *Prosopis* in Argentina for its uses in other countries. pp. 6.3-6.2. In: *Prosopis*: Semiarid Fuelwood and Forage Tree; Building Consensus for the Disenfranchised. (Eds.) P. Felker and J. Moss. Center for Semi-Arid Forest Resources, Kingsville, Texas, USA.

CORNEJO-OVIEDO, E., S. GRONSKI AND P. FELKER. (1992) Mature mesquite (*Prosopis glandulosa* var. *glandulosa*) stand description and preliminary effects of understory removal and fertilization on growth. *Journal of Arid Environments* 22:339-351.

CORNEJO-OVIEDO, E. H., J. M. MEYER AND P. FELKER. (1991) Thinning dense sapling stands of mesquite (*Prosopis glandulosa* var glandulosa) to optimize timber production and pasture improvement. *Forest Ecology and Management* 46:189-200.

CORONADO, J. (1988) Màquina extractora de semillas de algarroba. *in* Primer Semiario Nacional del Algarrobo, Piura, Peru. CONCYTEC, Piura, Peru.

COX, K. W. AND R. W. TOCK. (1982) The use of ozone and water in the hydrolysis of mesquite. pp. E1-E23. In: Mesquite Utilization. (Ed.)H. W. Parker. Texas Tech University, Lubbock, Texas, USA.

CRUZ, G. (1986) Obtención de harina de algarroba y posibilidades de usarla en productos para la alimentación humana. MSc thesis, Universidad de Piura, Peru.

CRUZ, G. (1990) Chemical changes in sugars and amino acids during the roasting of *Prosopis* pulp. Research Stage Report, ETH Zurich, Sitzerland (unpublished).

CRUZ, G. (1998) Algarrobo, Guarango, *Prosopis*. pp. 39-42. In: Primer Seminario Taller sobre el Algarrobo en la Región Grau, May 1992, Chulucanas. (Ed.) Comité de Coordinación Acción Forestal. Uiversidad Nacional de Piura, Piura, Peru.

CRUZ, G. (1999) Production and characterization and uses of *Prosopis* seed galactomannan. PhD thesis, ETH No. 13153, Switzerland.

CRUZ, G., B. DEL RE AND R. AMADÒ. (1987) Contribución al estudio de la composición química de los frutos maduros del algarrobo. *Abstracts of III Jornadas Peruanas de Fitoquímica. Soc. Química del Peru* 3:122

CRUZ, G. E. (1990) Evaluation of flour from *Prosopis juliflora* and *Prosopis pallida* pods in bakery and extrusion-cooking products. pp. 425-439. In: The Current State of Knowledge on *Prosopis juliflora*. (Eds.) M. A. Habit and J. C. Saavedra. FAO, Rome, Italy.

CSURHES, S. M. (Ed.). (1996) Mesquite (Prosopis spp.) in Queensland: Pest Status Review Series - Land Protection Branch. Department of Natural Resources, Queensland, Australia.

CTFT (CENTRE TECHNIQUE FORESTIER TROPICAL). (1988) *Faidherbia albida* (Del) A Chev (Synomyme: *Acacia albida* Del) Monographie. CIRAD, Nogent-sur-Marne, France.

CUEVAS, E., I. ULLOA, R. ROSENDE AND J. DONOSA. (1985) Physical and mechanical properties of tamarugo and algarrobo wood from the Tamarugal Pampa. pp. 339-348. In: The Current State of Knowledge on *Prosopis juliflora*. (Eds.) M. A. Habit and J. C. Saavedra. FAO, Rome, Italy.

DAHL, B. E. (1982) Mesquite as a rangeland plant. pp. A1-A20. In: Mesquite Utilization. (Ed.) H. W. Parker. Texas Tech University, Lubbock, Texas, USA.

DANTHU, P., A. ICKOWICZ, D. FRIOT, D. MANGA AND A. SARR. (1996) Effect of the passage through the digestive tracts of domestic ruminants on the germination of woody leguminous tree seeds in the semi-arid tropics. *Revue d'Elevage et de Medecine Veterinaire des Pays Tropicaux* 49:235-242.

D'ANTONI, H. L. AND O. T. SOLBRIG. (1977) Algarrobos in South American cultures: past and present. pp. 189-200. In: Mesquite: Its Biology in Two Desert Ecosystems. (Ed.) B. B. Simpson. Dowden, Hutchinson and Ross, Stroudsburg, Pennsylvania, USA.

DA SILVA, J. I. (1996) *Prosopis juliflora* as an alternative source of food in the world's semiarid areas. pp. 3.19-3.24 In: *Prosopis*: Semiarid Fuelwood and Forage Tree; Building Consensus for the Disenfranchised. (Eds.) P. Felker and J. Moss. Center for Semi-Arid Forest Resources, Kingsville, Texas, USA.

DE ARRUDA, G. P., E. C. DE ARRUDA, A. B. R. DOS SANTOS AND A. C. A. HOLANDA. (1990) Entomological observations. pp. 327-333. In: The Current State of Knowledge on *Prosopis juliflora*. (Eds.) M. A. Habit and J. C. Saavedra. FAO, Rome, Italy.

DE BARROS, N. A. M. T. de, F. V. NOBRE, C. F. de AZEVEDO, C. A. N. BARBOSA AND J. do N. BRANDAO. (1982) Algarobeira, Importante Forrageira para o Nordeste. Ed. 2. EMPARN, Natal, Brazil, Technical Bulletin No 5.

De Oliveira, V. R. and I. E. Pires. (1990) Pollination efficiency of *P. juliflora* (Sw) DC in Petrolina, Pernambuco. pp. 233-239. In: The Current State of Knowledge on *Prosopis juliflora*. (Eds.) M. A. Habit and J. C. Saavedra. FAO, Rome, Italy.

De Souza, S. M. and P. Felker. (1986) The influence of stock plant fertilization on tissue concentrations of N, P and carbohydrates and the rooting of *Prosopis alba* cuttings. *Forest Ecology and Management* 16:181-190.

Del Valle, F. R., E. Marco, R. Becker and R. M. Saunders. (1986) Preparation of a mesquite (*Prosopis* spp.) pod enhanced protein reduced fiber fraction. *Journal of Food Science* 51:1215-1217.

Del Valle, F. R., E. Marco, R. Becker and R. M. Saunders. (1987) Development and evaluation of a procedure to produce mesquite (*Prosopis* spp.) pod protein-concentrate. *Journal of Food Processing and Preservation* 11:237-246.

Delwaulle, J. C. (1978) Plantations Forestiéres en Afrique Tropicale Sèche. Centre Technique Forestier Tropical, Nogent-sur-Marne, France.

Delwaulle, J. C. (1979) Forest plantations in dry tropical Africa. Techniques and species to use. *Bois et Forêts des Tropiques* 188:3-30.

Dhawan, S. R. (1995) Allelopathic potential of *Prosopis* for containing the spread of *Parthenium hysterophorus* Linn. *Advances in Plant Sciences* 8:289-292.

Dhawan, S. R. and S. K. Gupta. (1996) Allelopathic potential of various leachate combinations towards SG and ESG of *Parthenium hysterophorus* Linn. *World Weeds* 3:135-144.

Dhawan, S. R., S. K. Gupta and Poonam Dhawan. (1996) Potential of leguminous plants for containing the congress grass. I - Effect of aqueous foliar leachates. *Advances in Plant Sciences* 9:151-154.

Diagne, O. (1992) Current developments on *Prosopis* species in Senegal including work on nitrogen fixation. pp. 47-60. In: *Prosopis* Species: Aspects of their Value, Research and Development. (Ed.) R. W. Dutton. CORD, University of Durham, Durham, UK.

Diagne, O. (1996) Utilization and nitrogen fixation of *Prosopis juliflora* in Senegal. pp. 1.29-1.40. In: *Prosopis*: Semiarid Fuelwood and Forage Tree; Building Consensus for the Disenfranchised. (Eds.) P. Felker and J. Moss. Center for Semi-Arid Forest Resources, Kingsville, Texas, USA.

Diagne, O. and D. D. Baker. (1994) Quantification of symbiotic N fixation by *Prosopis juliflora* (Swartz) DC using 15N-isotope dilution methodology. *Soil Biology and Biochemistry* 26:1709-1710.

Díaz Celis, A. (1995) Los Algarrobos. CONCYTEC, Lima, Peru.

Dick, J. McP., K. East and R. R. B. Leakey. (1991) Influence of propagation environment and cutting length on the rooting of *Prosopis juliflora* (Swartz) DC. *Nitrogen Fixing Tree Research Reports* 9:114-116.

Dixon, R. K., V. K. Garg and M. V. Rao. (1993) Inoculation of *Leucaena* and *Prosopis* seedlings with *Glomus* and *Rhizobium* species in saline soil: rhizosphere relations and seedling growth. *Arid Soil Research and Rehabilitation* 7:133-144.

Dixon, R. K., K. G. Mukerji, B. P. Chamola and A. Kaushik. (1997) Vesicular arbuscular mycorrhizal symbiosis in relation to forestation in arid land. *Annals of Forestry* 5:1-9.

Djavanshir, K. (1993) A new species of *Prosopis* (Mimosaceae) from Iran: *Prosopis persica* Djavanshir sp. *nova*. *Iranian Journal of Natural Resources* 46:47-49.

Doat, J. (1978) Tannins in tropical woods. *Bois et Forêts des Tropiques* 182:37-54.

Domìnguez, G. (1982) Introducción al estudio del algarrobo (*Prosopis* sp.) en Piura con especial referencia a su fauna entomológica. MSc thesis, Universidad Nacional Agraria La Molina, Peru.

Dommergues, Y., E. Duhoux and H. G. Diem (Eds.). (1999) Les Arbres Fixateurs d'Azote: Caractéristiques Fondamentales et Rôle dans L'aménagement des Écosystèmes Méditerranéens et Tropicaux. CIRAD, Montpellier, France.

Drumond, M. A. (1990) Foliar analysis of species of the genus *Prosopis* in the Brazilian semi-arid region. pp. 307-311. In: The Current State of Knowledge on *Prosopis juliflora*. (Eds.) M. A. Habit and J. C. Saavedra. FAO, Rome, Italy.

Dubey, P. (1998) A Plan for Tree Improvement with *Prosopis juliflora* in Uttar Pradesh, India. Queensland Forestry Research Institute, Gympie, Queensland, Australia.

Duque, J. G. (1980) O Nordeste as Lavouras Xerófilas. Ed. 2. Escola Superior de Agricultura, Fundação Guimaraes Duque, Mossoró.

Dutton, R. W. (Ed.) (1992) *Prosopis* Species: Aspects of their Value, Research and Development. CORD, University of Durham, Durham, UK.

Dwyer, D. D. and H. C. De Garmo. (1970) Greenhouse productivity and water use efficiency of selected desert shrubs and grasses under four soil moisture levels. *New Mexico State University Agricultural Experimental Station Bulletin* 570:1-15.

Earl, P. (1999) The taxonomy and evolution of the American mesquite (*Prosopis algarroba* new cline) and screwbean clines (*Prosopis strombocarpa* new cline) of the Mimosaceae of the Fabales, noting earlier African and Asian mesquites. Facultad de Ciencias Biológicas, Universidad Autónoma de Nuevo León, San Nicolás de los Garza, Nuevo León, Mexico (unpublished).

Earl, P. R. (1998) Evolution by hybrid replacement in *Prosopis* (Mimosoideae). pp. 494-501. In: First International Conference on Geospatial Information in Agriculture and Forestry. Vol. 1., Environmental Research Inst. Michigan, Ann Arbor, USA.

Earl, P. R. and A. Lux. (1991) *Prosopis bonplanda* n. sp. (Leguminosae): A new species from Coahuila and Nuevo León, Mexico. *Publ. Biol. Facultad de Ciencias Biológicas, Universidad Autónoma de Nuevo León, Mexico* 5:37-40.

East, R. M. and P. Felker. (1993) Forage production and quality of four perennial grasses grown under and outside canopies of mature *Prosopis glandulosa* Torr. var *glandulosa* (mesquite). *Agroforestry Systems* 22:91-110.

East, R., K. Rogers and P. Felker. (1992) Grading Mesquite Lumber. Center for Semi-Arid Forest Resources, Texas A&I University, Kingsville, Texas, USA.

Egler, F. E. (1947) Arid southeast Oahu vegetation, Hawaii. *Ecological Monographs* 17:383-435.

Ehteshamul-Haque, S., M. Abid, V. Sultana, J. Ara, A. Sattar and A. Ghaffar. (1996a) Use of *Prosopis* spp. in the control of root knot disease of okra. *Pakistan Journal of Nematology* 14:101-106.

Ehteshamul-Haque, S., V. Sultana, J. Ara, S. Parveen and A. Ghaffar. (1996b) Use of *Prosopis* spp. in the control of root infecting fungi on okra. *Pakistan Journal of Botany* 28:109-113.

Eisikowitch, D. and A. Dafni. (1988) The use and abuse of introducing honey plants. *Bee World* 69:12-14.

El Amin, H. M. (1990) *Prosopis* L. pp. 188-189. In: Trees and Shrubs of the Sudan. Ithaca Press, Exeter, UK.

El Fadl, M. A. (1997) Management of *Prosopis juliflora* for use in agroforestry systems in the Sudan. Tropical Forestry Reports 16. University of Helsinki, Helsinki, Finland.

El Fadl, M. A., S. Gronski, H. Asah, A. Tipton, T. E. Fulbright and P. Felker. (1989) Regression equations to predict fresh weight and three grades of lumber from large mesquite (*Prosopis glandulosa* var. *glandulosa*) in Texas. *Forest Ecology and Management* 26:275-284.

El Houri, A. A. (1986) Some aspects of dry land afforestation in the Sudan with special reference to *Acacia tortilis* (Forsk.) Hayne, *A. senegal* Willd. and *Prosopis chilensis* (Molina) Stuntz. *Forest Ecology and Management* 16:209-221.

Elias, T. S. (1981) Mimosoideae. pp. 143-151. In: Advances in Legume Systematics. (Eds.) R. M. Polhill and P. H. Raven. Advances in Legume Systematics. Royal Botanic Gardens, Kew, UK.

El Merzabani, M. M., A. A. Aaser, M. A. Attia, A. K. Al Duwemi and A. M. Ghazal. (1979) Unknown. *Planta Medica* 36:150.

El-Sharkawi, H. M., K. A. Farghali and S. A. Sayed. (1997) Trifactorial interactive effects of nutrients, water potential and temperature on carbohydrate allocation to the embryonic axis of desert plant seeds. *Journal of Arid Environments* 35:655-664.

Esbenshade, H. W. (1980) Kiawe: a tree crop in Hawaii. *International Tree Crops Journal* 1:125-130.

Espejel, C. M. (1980) *Prosopis laevigata* (Humb and Bonpl. ex Willd) Johnston (Leguminosae): Distribucion en el estado de Puebla, usos y produccion de goma. MSc thesis, Universidad Nacional Autonoma de Mexico, Mexico.

Estrada, L. (1974) Estudio técnico económico para la instalación de una planta de algarrobina en Piura. M.Sc. thesis, Universidad Nacional Agraria La Molina, Lima, Peru.

Ezhilan, J. G., V. Chandrasekar and V. Kurucheve. (1994) Effect of six selected plant products and oil cakes on the sclerotial production and germination of *Rhizoctonia solani*. *Indian Phytopathology* 47:183-185.

Fagg, C. W. and J. L. Stewart. (1994) The value of *Acacia* and *Prosopis* in arid and semiarid environments. *Journal of Arid Environments* 27:3-25.

FAO (Food and Agriculture Organisation). (1997) Especies Arboreas y Arbustivas para las Zonas Aridas y Semiaridas de America Latina. FAO, Santiago, Chile.

Feldman, I. (1972) Considerations concerning some problems of intrusive woody plants in the Argentine Republic. *Malezas y su Control* 1:4-24,26-27.

Felger, R. S. (1977) Mesquite in Indian cultures of southwestern North America. pp. 150-176. In: Mesquite: Its Biology in Two Desert Ecosystems. (Ed.) B. B. Simpson. Dowden, Hutchinson and Ross, Stroudsburg, Pennsylvania, USA.

FELKER, P. (1979) Mesquite: an all-purpose leguminous arid land tree. pp. 89-132. In: New Agricultural Crops, American Association for the Advancement of Science Symposium Proceedings. Vol. 38. (Ed.) G. A. Ritchie. Westview Press, Boulder, Colorado, USA.

FELKER, P. (1984) Economic, environmental, and social advantages of intensively managed short rotation mesquite (*Prosopis* spp.) biomass energy farms. *Biomass* 5:65-77.

FELKER, P. (1991) *Prosopis* in Latin America: Genetic conservation and economic development for the 21st century. In: *Prosopis* germplasm workshop, 3-6 December 1991, Mendoza, Argentina, organised by the International Development Research Centre, Ottawa, Canada.

FELKER, P. (1999) Oportunidades de inversiones en el algarrobo (*Prosopis alba*) en Santiago del Estero (Argentina). Secretaría de Producción y Medio Ambiente, La Plata, Santiago del Estero, Argentina.

FELKER, P., P. ANDERSON, D. PERINO AND D. MILLER. (1994) Grading Mesquite Lumber. Texas A&M University, Kingsville, Texas, USA.

FELKER, P. AND R. S. BANDURSKI. (1977) Protein and amino acid composition of tree legume seeds. *Journal of the Science of Food and Agriculture* 28:791-797.

FELKER, P., G. H. CANNELL AND P. R. CLARK. (1981a) Variation in growth among 13 *Prosopis* (mesquite) species. *Experimental Agriculture* 17:209-218.

FELKER, P., G. H. CANNELL, P. R. CLARK, J. F. OSBORN AND P. NASH. (1983b)Biomass production of *Prosopis* species (mesquite), leucaena, and other leguminous trees grown under heat drought stress. *Forest Science* 29:592-606.

FELKER, P., G. H. CANNELL, J. F. OSBORN, P. R. CLARK AND P. NASH. (1983a) Effects of irrigation on biomass production of 32 *Prosopis* (mesquite) accessions. *Experimental Agriculture* 19:187-198.

FELKER, P. AND P. R. CLARK. (1981) Rooting of mesquite (*Prosopis*) cuttings. *Journal of Range Management* 34:466-468.

FELKER, P. AND P. R. CLARK. (1982) Position of mesquite (*Prosopis* spp.) nodulation and nitrogen fixation (acetylene reduction) in 3-m long phraetophytically simulated soil columns. *Plant and Soil* 64:297-305.

FELKER, P., P. R. CLARK, A. E. LAAG AND P. F. PRATT. (1981b) Salinity tolerance of the tree legumes: mesquite (*Prosopis glandulosa* var. *torreyana*, *P. velutina* and *P. articulata*), algarrobo (*P. chilensis*), kiawe (*P. pallida*) and tamarugo (*P. tamarugo*) grown in sand culture on nitrogen-free media. *Plant and Soil* 61:311-317.

FELKER, P., P. R. CLARK, P. NASH, J. F. OSBORN AND G. H. CANNELL. (1982b) Screening *Prosopis* (mesquite) for cold tolerance. *Forest Science* 28:556-562.

FELKER, P., P. R. CLARK, J. F. OSBORN AND G. H. CANNELL. (1982a) Biomass estimation in a young stand of mesquite (*Prosopis* spp.), ironwood (*Olneya tesota*), palo verde (*Cercidium floridum*, *Parkinsonia aculeata*), and Leucaena (*Leucaena leucocephala*). *Journal of Range Management* 35:87-89.

FELKER, P., P. R. CLARK, J. F. OSBORN AND G. H. CANNELL. (1984) *Prosopis* pod production - comparison of North American, South American, Hawaiian, and African germplasm in young plantations. *Economic Botany* 38:36-51.

FELKER, P., P. R. CLARK, J. F. OSBORN AND G. H. CANNELL. (1986b) Utilization of mesquite (*Prosopis* spp.) pods for ethanol production. In: Tree Crops for Energy Co-Production on Farms, November 12-14 1980. YMCA of the Rockies, Estes Park, Colorado, USA.

FELKER, P., R. A. MCLAUCHLAN, A. CONKEY AND S. BROWN. (1999) Case study: development of a swath harvester for small diameter (<10 cm) woody vegetation. *Biomass and Bioenergy* 17:1-17.

FELKER, P., J. M. MEYER AND S. J. GRONSKI. (1990) Application of self-thinning in mesquite (*Prosopis glandulosa* var *glandulosa*) to range management and lumber production. *Forest Ecology and Management* 31:225-232.

FELKER, P. AND J. MOSS (Eds.). (1996) *Prosopis*: Semiarid Fuelwood and Forage Tree: Building Consensus for the Disenfranchised. Center for Semi-Arid Forest Resources, Kingsville, Texas, USA.

FELKER, P., D. SMITH AND C. WIESMANN. (1986a) Influence of mechanical and chemical weed control on growth and survival of tree plantings in semiarid regions. *Forest Ecology and Management* 16:259-267.

FELKER, P., C. WIESMAN AND D. SMITH. (1988) Comparison of seedling containers on growth and survival of *Prosopis alba* and *Leucaena leucocephala* in semi-arid conditions. *Forest Ecology and Management* 24:177-182.

FERREYRA, R. (1979) El algarrobal y manglar de la costa norte del Peru. *Boletin de Lima* 1:12-18.

FERREYRA, R. (1983) Estudio Sistematico de los Algarrobos de la Costa Norte del Peru. Mecanografiado. Instituto Nacional Forestal y Fauna, Lima, Peru.

FERREYRA, R. (1987) Estudio Systemático de los Algarrobos de la CostaNorte del Perú. Direccion de Investigacion Forestal y de Fauna, Min. de Agricultura, Lima, Peru.

Ffolliott, P. F. and J. L. Thames. (1983) Collection, Handling, Storage and Pre-treatment of *Prosopis* Seeds in Latin America. FAO, Rome, Italy.

Figueiredo, A. A. (1975) Lebensmittelchemisch relevanter inhaltsstoff der schoten def algarobeira (*Prosopis juliflora* DC). PhD. Thesis. University of Würzburg, Germany.

Fiorentino, D. C. and V. H. Bellomo. (1995) Insectos Plagas de Plantas Forestales Nativas. III Congreso Argentino de Entolmologia: Simposio Sobre Plagas Forestales Argentinas. University of Santiago del Estero, Santiago del Estero, Argentina

Fisher, C. E. (1977) Mesquite and modern man in southwestern North America. pp. 177-188 In: Mesquite: Its Biology in Two Desert Ecosystems. (*Ed.*) B. B. Simpson. Dowden, Hutchinson and Ross, Stroudsburg, Pennsylvania, USA.

Fisher, C. E., C. H. Meadors, R. Behrens, E. D. Robison, P. T. Marion and H. L. Morton. (1959) Control of mesquite on grazing lands. Texas Agricutural Experiment Station Bulletin Vol. 935. Texas Agricultural Experiment Station, College Station, Texas, USA.

Flynt, T. O. and H. L. Morton. (1969) A device for threshing mesquite seed. *Weed Science Society Proceedings* 17:302-303.

Fosberg, F. R. (1966) Miscellaneous notes on Hawaiian plants-4. *Bishop Museum Occasional Papers* 23:129-138.

Fowler, S. V. (1998) Report on the invasion, impact and control of 'Mexican thorn', *Prosopis juliflora*, on Ascension Island. International Institute of Biological Control, Ascot, UK.

Franco, C. R. and L. Maldonado. (1996) Overview of past, current and potential uses of mesquite in Mexico. pp. 6.41-6.52. In: *Prosopis*: Semiarid Fuelwood and Forage Tree; Building Consensus for the Disenfranchised. (Eds.) P. Felker and J. Moss. Center for Semi-Arid Forest Resources, Kingsville, Texas, USA.

Freckman, D. W. and R. A. Virginia. (1989) Plant-feeding nematodes in deep-rooting desert ecosystems. *Ecology* 70:1665-1678.

Freitas, B. M. (1994) Pollen identification of pollen and nectar loads collected by Africanized honey bees in the state of Ceara, Brazil. pp. 73-79. In: Proceedings of the Fifth International Conference on Apiculture in Tropical Climates, Trinidad and Tobago, 7-12 September 1992. International Bee Research Association, Cardiff, UK.

Gabar, A. E. I. A. (1990) *Prosopis chilensis* in Sudan: a nonconventional animal feed resource. pp. 371-377. In: The Current State of Knowledge on *Prosopis juliflora.* (Eds.) M. A. Habit and J. C. Saavedra. FAO, Rome, Italy.

Galera, F. M., L. Ramírez, L. Argüello, N. Rubin and N. Julio. (1990) Germplasm bank project for the genus *Prosopis* in Argentina: Stage I. pp. 217-227. In: The Current State of Knowledge on *Prosopis juliflora.* (Eds.) M. A. Habit and J. C. Saavedra. FAO, Rome, Italy.

Galera, F. M., M. Trevisson and S. A. Bruno. (1992) *Prosopis* in Argentina: initial results on cultivation in greenhouses and orchards, and pod quality for food or feed of five native *Prosopis* species of Córdoba Province. pp. 145-156. In: *Prosopis* Species: Aspects of their Value, Research and Development. (Ed.) R. W. Dutton. CORD, University of Durham, Durham, UK.

Garcia-Carreño, F. L. and O. J. L. Ochoa. (1991) The effect of saline stress on peroxidase activity in the mezquite (*Prosopis articulata*) leaf. *Journal of Arid Environments* 20:313-319.

Garg, V. K. (1993) Diagnostic leaf analysis for some fuelwood trees. *Indian Forester* 119:17-24.

Gates, P. J. and K. Brown. (1988) *Acacia tortilis* and *Prosopis cineraria*: leguminous trees for arid areas. *Outlook On Agriculture* 17:61-64.

Geesing, D., P. Felker and R. L. Bingham. (2000) Influence of mesquite (*Prosopis glandulosa*) on soil nitrogen and carbon development: implications for agroforestry and global carbon sequestration. *Journal of Arid Environments* 46: 157-180.

Genise, J., R. A. Palacios, P. S. Hoc, R. Carrizo, L. Moffat, M. P. Mom, M. A. Agullo, P. Picca and S. Torregrosa. (1990) Observations on the floral biology of *Prosopis*. 2. Floral phases and visitors in the Chaqueno Serrano district. *Darwiniana* 30:71-85.

Gile, L. H., R. P. Gibbens and J. M. Lenz. (1997) The near-ubiquitous pedogenic world of mesquite roots in an arid basin floor. *Journal of Arid Environments* 35:39-58.

Glendening, G. E. and H. A. Paulsen. (1955) Reproduction and establishment of velvet mesquite (*Prosopis juliflora* var. *velutina)* as related to invasion of semidesert grasslands. *Technical Bulletin of the US Department of Agricriculture* 1127:50.

Goel, U. and G. S. Nathawat. (1990) Relative effects of *Prosopis juliflora* (Swartz) and *Prosopis cineraria* L. Druce on seed germination and seedling growth. *Acta Botanica Indica* 18:76-79.

GOEL, U., D. B. SAXENA AND B. KUMAR. (1989) Comparative study of allelopathy as exhibited by *Prosopis juliflora* Swartz and *Prosopis cineraria* (L) Druce. *Journal of Chemical Ecology* 15:591-600.

GOEL, V. AND H. M. BEHL. (1992) Wood quality for fuel wood rotation cycles. In: IUFRO Conference, 23-28 August 1992, Nancy, France.

GOEL, V. L. (1987) Performance of some firewood species in nursery of alkali wastelands. *Indian Forester* 113:792-797.

GOEL, V. L. AND H. M. BEHL. (1994) Cloning of selected genotypes of promising tree species for sodic sites. *Journal of the Indian Botanical Society* 73:255-258.

GOEL, V. L. AND H. M. BEHL. (1995) Propagation of *Prosopis juliflora* from rooted stem cuttings. *International Tree Crops Journal* 8:193-201.

GOEL, V. L. AND H. M. BEHL. (1996) Phenological traits of some woody species grown on stress soil. *Journal of the Indian Botanical Society* 75:11-16.

GOHL, B. (Ed.). (1981) Tropical Feeds. FAO Animal Production and Health Series 12. FAO, Rome, Italy.

GOLDBLATT, P. (1981) Cytology and the phylogeny of Leguminosae. pp. 427-463. In: Advances in Legume Systematics. (*Eds.*) R. M. Polhill and P. H. Raven. Royal Botanic Gardens, Kew, UK.

GOLDSTEIN, I. S. AND A. VILLARREAL. (1972) Chemical composition and accessibility to cellulase of mesquite wood. *Wood Science* 5:15-20.

GOLUBOV, J., L. E. EGUIARTE, M. C. MANDUJANO, J. LOPEZ PORTILLO AND C. MONTANA. (1999) Why be a honeyless honey mesquite? Reproduction and mating system of nectarful and nectarless individuals. *American Journal of Botany* 86:955-963.

GOMES, A. V. AND G. I. B. DE MUÑIZ. (1990) Wood structure and ultrastructure of *Prosopis caldenia*, *P. chilensis* and *P. juliflora* and influence of ecological factors. pp. 195-216. In: The Current State of Knowledge on *Prosopis juliflora*. (*Eds.*) M. A. Habit and J. C. Saavedra. FAO, Rome, Italy.

GOMES, P. (1961) A Algarobeira. Serie SIA 865. Servico de Informacao Agricola, Rio de Janeiro, Brazil.

GOOR, A. Y. AND B. W. BARNEY. (1976) Forest Tree Planting in Arid Zones. Ronald Press, New York, USA.

GOWDA, D. R. AND M. N. RAMASWAMY. (1960) The utilisation of *Prosopis juliflora*. *Indian Forester* 86:432-434.

GRADOS, N. AND G. CRUZ. (1994) La Algarroba: Perspectivas de Utilizacion Industrial. Universidad de Piura, Piura, Peru.

GRADOS, N. AND G. CRUZ. (1996) New approaches to industrialization of algarrobo (*Prosopis pallida*) pods in Peru. pp. 3.25-3.42. In: *Prosopis*: Semiarid Fuelwood and Forage Tree; Building Consensus for the Disenfranchised. (*Eds.*) P. Felker and J. Moss. Center for Semi-Arid Forest Resources, Kingsville, Texas, USA.

GRAHAM, J. D. (1960) Morphological variation in mesquite (*Prosopis*, Leguminosae) in the lowlands of northeastern Mexico. *Southwestern Naturalist* 5:187-193.

GRIFFITH, A. L. (1945) Storage of seed of *Prosopis* species. Indian Forester 71:251-252.

GRIFFITH, A. L. (1961) *Acacia* and *Prosopis* in the Dry Forest of the Tropics. FAO, Rome, Italy.

GUERRA FILHO, D. (1963) Algarobeira vai Mudar Paisagem do Nordeste. *Anuário Bras.Econ.Florestal* 15:109-112.

GUHA, S. R. D., R. K. GUPTA, ET AL. (1970) Production of writing and printing papers from *Prosopis juliflora*. *Indian Forester* 96:429-432.

GUPTA, J. P., G. G. S. N. RAO, G. N. GUPTA AND B. V. RAMANA RAO. (1983) Soil drying and wind erosion as affected by different types of shelterbelts planted in the desert region of western Rajasthan, India. *Journal of Arid Environments* 6:53-59.

GUPTA, M. L. AND C. S. MATHUR. (1974) Studies on the seasonal variation in the chemical composition of khejri (*Prosopis spicigera* Linn.). *Indian Forester* 100:269-273.

GUPTA, R. K. AND G. S. BALARA. (1972) Comparative studies on the germination, growth and seedling biomass of two promising exotics in Rajasthan desert (*Prosopis juliflora* (Swartz) DC and *Acacia tortilis* (Forsk.) Hayne ssp. *tortilis*). *Indian Forester* 98:280-285.

HABIT, M. A. AND J. C. SAAVEDRA (Eds.). (1990) The Current State of Knowledge on *Prosopis juliflora*. FAO, Rome, Italy.

HALWAGY, M. H. (1994) Airborne pollen of Kuwait-City, Kuwait, 1975-1987. *Grana* 33:333-339.

HAMMOND, S. (1991) *In vitro* propagation of leguminous trees of the genus *Prosopis*. Professional Training Report. Coventry University, Coventry, UK.

HARDING, G. B. (1991) Sheep can reduce seed recruitment of invasive *Prosopis* species. *Applied Plant Science* 5:25-27.

HARDY, P. C., M. L. MORRISON AND R. X. BARRY. (1999) Abundance and habitat associations of elf owls and western screech owls in the Sonoran Desert. *Southwestern Naturalist* 44:311-323.

HARIHARAN, Y. AND K. V. KRISHNAMURTHY. (1998) A cytochemical study of cambium and its xylary derivatives on the normal and tension wood sides of the stems of *Prosopis juliflora* (SW). DC. *Beitrage zur Biologie der Pflanzen* 69:459-472.

HARRIS, P. J. C. (1992) Vegetative propagation of *Prosopis*. pp. 175-191. In: *Prosopis* Species: Aspects of their Value, Research and Development. (*Ed.*) R. W. Dutton. CORD, University of Durham, Durham, UK.

HARRIS, P. J. C., N. M. PASIECZNIK, M. BRADBURY AND M. T. VERA-CRUZ. (1996a) Comparative physiology, field performance and propagation of *Prosopis*. Overseas Development Administration, London, UK, ODA Project R4733, Final Report.

HARRIS, P. J. C., N. M. PASIECZNIK, M. T. VERA-CRUZ AND M. BRADBURY. (1996b) *Prosopis* genetic improvement trials in Cape Verde. pp. 4.3-4.20. In: *Prosopis*: Semiarid Fuelwood and Forage Tree; Building Concensus for the Disenfranchised. (Eds.) P. Felker and J. Moss. Center for Semi-Arid Forest Resources, Kingsville, Texas, USA.

HARSH, L. N., J. C. TEWARI, N. K. SHARMA AND M. D. BOHRA. (1998) Variability in early growth and biomass accumulation in a progeny trial of *Prosopis alba*. pp. 85-90 In: *Prosopis* Species in the Arid and Semi-Arid Zones of India. (Eds.) J. C. Tewari, N. M. Pasiecznik, L. N. Harsh and P. J. C. Harris. *Prosopis* Society of India and the Henry Doubleday Research Association, Coventry, UK.

HARSH, L. N., J. C. TEWARI, N. K. SHARMA AND P. FELKER. (1996) Performance of *Prosopis* species in arid regions of India. pp. 4.21-4.34. In: *Prosopis*: Semiarid Fuelwood and Forage tree; Building Concensus for the Disenfranchised. (Eds.) P. Felker and J. Moss. Center for Semi-Arid Forest Resources, Kingsville, Texas, USA.

HEITSCHMIDT, R. K., R. J. ANSLEY, S. L. DOWHOWER, P. W. JACOBY AND D. L. PRICE. (1988) Some observations from the excavation of honey mesquite root systems. *Journal of Range Management* 41:227-231.

HELIN, W. H. (1989) Species elimination trial, Luuq, Gedo Region, Somalia. *Commonwealth Forestry Review* 68:273-279.

HILU, K. W., S. BOYD AND P. FELKER. (1982) Morphological diversity and taxonomy of California mesquites (*Prosopis*, Leguminosae). *Madroño* 29:237-254.

HINGORANI, N. L. (1986) Power from biomass. pp. 1-8. In: The Role of *Prosopis* in Wasteland Development. (*Ed.*) V. J. Patel. Javrajbhai Patel Agroforestry Center, Surendrabag, Gujarat, India.

HOC, P. S., M. A. AGULLO AND R. A. PALACIOS. (1994) Stylar trimorphism in 4 functionally andromonoecious *Prosopis* species (Mimosaceae). *Plant Systematics and Evolution* 190:143-156.

HODKINSON, I. D. (1991) New-world legume-feeding psyllids of the genus *Aphalaroida* Crawford (Insecta, Homoptera, Psylloidea). *Journal of Natural History* 25:1281-1296.

HOFFMANN, J. H., F. A. C. IMPSON AND V. C. MORAN. (1993) Competitive interactions between two bruchid species (*Algarobius* spp.) introduced into South Africa for biological control of mesquite weeds (*Prosopis* spp.). *Biological Control* 3:215-220.

HOLLAND, D. C. (1987) *Prosopis* (Mimosaceae) in the San Joaquin Valley, California: vanishing relict or recent invader? *Madroño* 34:324-333.

HUGAR, L. B., A. S. PRABHAKAR, S. B. MAHAJANSHETTI AND P. P. REDDY. (1989) Economics of *Prosopis juliflora* activity in northern Karnataka - a case study. *Myforest* 25:95-100.

HUGHES, C. E. (1991) Exploration, collection and evaluation of woody legume genetic resources: the OFI programme and strategy for *Prosopis*. Proceedings from the IDRC *Prosopis* Germplasm Workshop, Mendoza, Argentina, December 1991.

HUGHES, C. E. AND B. T. STYLES. (1984) Exploration and seed collection of multiple-purpose dry zone trees in Central America. *International Tree Crops Journal* 3:1-31.

HUNTER, I. R. AND J. L. STEWART. (1993) Foliar nutrient and nutritive content of Central American multi-purpose tree species growing at Comayagua, Honduras. *Commonwealth Forestry Review* 72:193-197.

HUNZIKER, J. H., L. POGGIO, C. A. NARANJO AND R. A. PALACIOS. (1975) Cytogenetics of some species and natural hybrids in *Prosopis* (Leguminosae). *Canadian Journal of Genetics and Cytology* 17:253-262.

HUNZIKER, J. H., B. O. SAIDMAN, C. A. NARANJO, R. A. PALACIOS, L. POGGIO AND A. D. BURGHARDT. (1986) Hybridization and genetic variation of Argentine species of *Prosopis*. *Forest Ecology and Management* 16:301-315.

HUSSAIN, A., A. M. RANJHA, M. S. SHARAR AND A. GHAFFAR. (1990) Release of nitrogen during decomposition of legume tree leaves. *Nitrogen Fixing Tree Research Reports* 8:51-53.

HUSSAIN, G., M. SADIQ, Y. A. NABULSI AND O. J. HELWEG. (1994) Effect of saline water on establishment of windbreak trees. *Agricultural Water Management* 25:35-43.

HYDE, E. A., N. PASIECZNIK AND P. J. C. HARRIS. (1990) Evaluation of multi-purpose trees in southern Spain. *Nitrogen Fixing Tree Research Reports* 8:73-74.

ICFRE (INDIAN COUNCIL OF FORESTRY RESEARCH AND EDUCATION). (1993) Khejri (*Prosopis cineraria*). ICFRE, Dehra Dun, India.

IMO, M. AND V. R. TIMMER. (1992) Growth, nutrient allocation and water relations of mesquite (*Prosopis chilensis*) seedlings at differing fertilization schedules. *Forest Ecology and Management* 55:279-294.

IMO, M. AND V. R. TIMMER. (1997) Vector diagnosis of nutrient dynamics in mesquite seedlings. *Forest Science* 43:268-273.

INGLEBY, K., O. DIAGNE, J. D. DEANS, D. K. LINDLEY, M. NEYRA AND M. DUCOUSSO. (1997) Distribution of roots, arbuscular mycorrhizal colonisation and spores around fast-growing tree species in Senegal. *Forest Ecology and Management* 90:19-27.

INRENA (MINISTERIO DE AGRICULTURA). (1998) Mapa de bosques secos del Departamento de Piura. Map INR-82-DGEP, INRENA, Lima, Peru.

IPA (INTERNATIONAL PROSOPIS ASSOCIATION). (1988) *IPA News* 4:4. IPA, Recife, Brazil.

IPA (INTERNATIONAL PROSOPIS ASSOCIATION). (1989) *IPA News* 8:6. IPA, Recife, Brazil.

JACOBY, P. AND ANSLEY, R. J. (1991) Mesquite: classification, distribution, ecology and control. In: Noxious Range Weeds (*Eds.*) L. F. James, J. O. Evans, M. H. Ralphs and R. D. Child. Westview Press, Boulder, Colorado, USA.

JADHAV, R. N., M. M. KIMOTHI AND A. K. KANDYA. (1993) Grassland mapping monitoring of Banni, Kachchh (Gujarat) using remotely-sensed data. *International Journal of Remote Sensing* 14:3093-3103.

JAHAN, M., I. AHMAD AND S. N. H. NAQVI. (1990) Toxic and teratogenic effects of juliflorine and Margosan-O on the *Musca domestica* L. larvae. *Proceedings of Pakistan Congress of Zoology* 10:293-299.

JAIN, R. K. AND V. K. GARG. (1996) Effect of a decade old tree stands on some properties of soils while revegetating sodic wastelands. *Indian Forester* 122:467-475.

JAMBULINGAM, R. AND E. C. M. FERNANDES. (1986) Multi-purpose trees and shrubs on farmlands in Tamil Nadu State (India). *Agroforestry Systems* 4:17-32.

JANZEN, D. H. (1981) The defenses of legumes against herbivores. pp. 951-977. In: Advances in Legume Systematics. (Eds.) R. M. Polhill and P. H. Raven. Royal Botanic Gardens, Kew, UK.

JARA, F. AND J. OTIVO. (1989) Potencial forestal de la Región Grau. CIPCA, Piura, Peru.

JARRELL, W. M. AND R. A. VIRGINIA. (1990) Response of mesquite to nitrate and salinity in a simulated phreatic environment: water use, dry matter and mineral nutrient accumulation. *Plant and Soil* 125:185-196.

JARRELL, W. M., R. A. VIRGINIA, D. H. KOHL, G. SHEARER, B. A. BRYAN, P. W. RUNDEL, E. T. NILSEN AND M. R. SHARIFI. (1982) Symbiotic nitrogen fixation by mesquite and its management implications. pp. R1-R12. In: Mesquite Utilization. (Ed.) H. W. Parker. Texas Tech University, Lubbock, Texas, USA.

JENKINS, M. B., R. A. VIRGINIA AND W. M. JARRELL. (1987) Rhizobial ecology of the woody legume mesquite (*Prosopis glandulosa*) in the Sonoran desert. *Applied and Environmental Microbiology* 53:36-40.

JENKINS, M. B., R. A. VIRGINIA AND W. M. JARRELL. (1988) Depth distribution and seasonal populations of mesquite-nodulating rhizobia in warm desert ecosystems. *Soil Science Society of America Journal* 52:1644-1650.

JENKINS, M. B., R. A. VIRGINIA AND W. M. JARRELL. (1989) Ecology of fast-growing and slow-growing mesquite-nodulating rhizobia in Chihuahuan and Sonoran desert ecosystems. *Soil Science Society of America Journal* 53:543-549.

JEWERS, K., M. J. NAGLER, K. A. ZIRVI AND F. AMIR. (1976) Lipids, sterols, and a piperidine alkaloid from *Prosopis spicigera* leaves. *Phytochemistry* 15:238-240.

JHA, A. K. (1992) Evaluation of coal mine spoil as a medium for plant growth in a dry tropical environment, India. *Indian Forester* 118:909-916.

JHA, M. AND L. D. CHOUDHARY. (1990) Trial on stump planting of some tree species. *Indian Forester* 116:283-285.

JIMÉNEZ, B. AND A. N. VERGARA. (1977) Estudio sobre la composición química y posibilidades de industrializacion de la algarroba. MSc thesis, Universidad de Piura, Peru.

JINDAL, S. K. (1998) Combined selection for tree height improvement in *Prosopis cineraria*. pp. 69-72. In: *Prosopis* Species in the Arid and Semi-Arid Zones of India. (Eds.) J. C. Tewari, N. M. Pasiecznik, L. N. Harsh and P. J. C. Harris. *Prosopis* Society of India and the Henry Doubleday Research Association, Coventry, UK.

JOHNSON, C. D. (1983) Handbook on Seed Insects of *Prosopis* Species. FAO, Rome, Italy.

JOHNSON, H. B. AND H. S. J. MAYEUX. (1990) *Prosopis glandulosa* and the nitrogen balance of rangelands: extent and occurrence of nodulation. *Oecologia* 84:176-185.

JOHNSTON, M. C. (1962) The North American mesquites, *Prosopis* sect. Algarobia (Leguminosae). *Brittonia* 14:72-90.

JONES, M., F. L. SINCLAIR AND V. L. GRIME. (1998) Effect of tree species and crown pruning on root length and soil water content in semi-arid agroforestry. *Plant and Soil* 201:197-207.

JONSSON, K., L. STAHL AND P. HOGBERG. (1996) Tree fallows - a comparison between 5 tropical tree species. *Biology and Fertility of Soils* 23:50-56.

JORDAN, M. (1987) In vitro culture of *Prosopis* species. pp. 370-384. In: Cell and Tissue Culture in Forestry Vol. 3. Case Histories: Gymnosperms, Angiosperms and Palms. (Eds.) J. M. Bonga and D. J. Durzan. Nijhoff/Junk Publishers, The Netherlands.

JORDAN, M., I. CORTES AND A. GOREUX. (1987) Potentialities of cell and callus-tissue culture to regenerate two mesquite species (*Prosopis tamarugo* and *Prosopis chilensis*). *Gartenbauwissenschaft* 52:166-169.

JURASEK, P. AND G. O. PHILLIPS. (1993) The classification of natural gums. Part IV. Identification and discrimination of *Acacia*, *Combretum* and *Prosopis* gum exudates. *Food Hydrocolloids* 7:337-352.

KAARAKKA, V. AND S. JOHANSSON. (1992) Yield and water use efficiency of 32 two-year-old *Prosopis* provenances under irrigation in Bura, eastern Kenya. *Nitrogen Fixing Tree Research Reports* 10:182-185.

KAARAKKA, V. AND J. O. MAUA. (1993) Rainwater harvesting as a method for bushland rehabilitation with selected indigenous and exotic tree species. *East African Agriculture and Forestry Journal* 58:59-69.

KALLA, J. C. (1977) Statistical evaluation of fuel yield and morphological variates for some promising energy plantation tree species in western Rajasthan. *Annals of Arid Zone* 16:117-126.

KALPANA, T. P. AND C. G. K. RAMANUJAM. (1990) Melittopalynology of *Prosopis juliflora* honeys from Ranga Reddy district (A.P.) and its significance. *Indian Bee Journal* 52:44-46.

KANDASAMY, A., S. WILLIAM AND S. GOVINDASAMY. (1989) Hemolytic effect of *Prosopis juliflora* alkaloids. *Current Science* 58:142-144.

KANDASWAMY, M. AND A. VENKATA-RAO. (1956) A note on the extraction of seeds from the pods of *Prosopis juliflora*. *Madras Agricultural Journal* 43:520-521.

KANNAN, N. R. AND S. DORAISWAMY. (1993) Management of cowpea aphid borne mosaic virus (CAMV) using plant products. *Madras Agricultural Journal* 80:393-395.

KANZARIA, M. K. AND A. K. VARSHNEY. (1998) *Prosopis juliflora* - its uses. pp. 113-115. In: *Prosopis* Species in the Arid and Semi-Arid Zones of India. (Eds.) J. C. Tewari, N. M. Pasiecznik, L. N. Harsh and P. J. C. Harris. *Prosopis* Society of India and the Henry Doubleday Research Association, Coventry, UK.

KAUL, O. N. (1956) Propagating mesquite (*Prosopis juliflora*) by root and shoot cuttings. *Indian Forester* 82:569-572.

KAUSHIK, A., R. K. DIXON AND K. G. MUKERJI. 1992. Vesicular arbuscular mycorrhizal relationships of *Prosopis juliflora* and *Zizyphus jujuba*. *Phytomorphology* 42:133-137.

KAZMI, S. M. H. AND R. SINGH. (1992) Wood anatomy of exotics grown in India. 3. *Prosopis juliflora* (Sw.) DC. (Leguminosae). *Journal of the Timber Development Association of India* 38:39-42.

KHAN, A. A. (1961) Efficacy of “Fernoxone” to prevent resprouting of cut-back Mesquite. *Pakistan Journal of Forestry* 11:375-377.

KHAN, D., R. AHMAD AND S. ISMAIL. (1986) Case History of *Prosopis juliflora* Plantation at Makran Coast Through Saline Water Irrigation. Department of Botany, University of Karachi, Karachi, Pakistan, Proceeding of US-Pakistan Biosaline Research Workshop, Karachi, Pakistan.

KHAN, D., R. AHMAD AND S. ISMAIL. (1987) Germination, growth and ion regulation in *Prosopis juliflora* (Swartz) DC under saline conditions. *Pakistan Journal of Botany* 19:131-138.

KHANNA, M., A. K. DWIVEDI, S. SINGH AND P. L. SONI. (1997) Mesquite gum (*Prosopis juliflora*): Potential binder in tablet dosage forms. *Journal of Scientific and Industrial Research* 56:366-368.

KILLIAN, S. E. (1990) A study on the germinative behavior of the seeds of some *Prosopis* species. pp. 277-295. In: The Current State of Knowledge on *Prosopis juliflora*. (Eds.) M. A. Habit and J. C. Saavedra. FAO, Rome, Italy.

KINGSOLVER, J. M., C. D. JOHNSON, S. R. SWIER AND A. L. TERAN. (1977) *Prosopis* fruits as a resource for invertebrates. pp. 108-122. In: Mesquite, Its Biology in Two Desert Ecosystems. (Ed.) B. B. Simpson. Dowden, Hutchinson and Ross, Stroudsburg, Pennsylvania, USA.

KLASS, S., R. L. BINGHAM, L. FINKNER-TEMPLEMEN AND P. FELKER. (1985) Optimizing the environment for rooting cuttings of highly productive clones of *Prosopis alba* (mesquite algarrobo). *Journal of Horticultural Science* 60:275-284.

KLASS, S., J. WRIGHT AND P. FELKER. (1987) Influence of auxins, thiamine and fungal drenches on the rooting of *Prosopis alba* clone B(2) V(50) cuttings. *Journal of Horticultural Science* 62:97-100.

KUMAR, A., P. SHIVKUMAR, A. M. RAI AND A. C. BANERJEE. (1998) Genetic improvement of *Prosopis juliflora*. pp. 79-81. In: *Prosopis* Species in the Arid and Semi-Arid Zones of India. (Eds.) J. C. Tewari, N. M. Pasiecznik, L. N. Harsh and P. J. C. Harris. *Prosopis* Society of India and the Henry Doubleday Research Association, Coventry, UK.

KURUCHEVE, V., J. G. EZHILAN AND J. JAYARAJ. (1997) Screening of higher plants for fungitoxicity against *Rhizoctonia solani* in vitro. *Indian Phytopathology* 50:235-241.

KWAASI, A. A. A., R. S. PARHAR, F. A. A. ALMOHANNA, H. A. HARFI, K. S. COLLISON AND S. T. ALSEDAIRY. (1998) Aeroallergens and viable microbes in sandstorm dust - potential triggers of allergic and nonallergic respiratory ailments. *Allergy* 53:255-265.

LAHIRI, A. N., AND Y. D. GAUR. (1969) Germination studies on arid zone plants. V. The nature and roles of germination inhibitors present in the leaves of *Prosopis juliflora*. *Proceedings of the National Institute of Science, India* 35B:60-71.

LAMARQUE, A. L., D. M. MAESTRI, N. R. GROSSO, J. A. ZYGADLO AND C. A. GUZMAN. (1994) Proximate composition and seed lipid components of some *Prosopis* (Leguminosae) from Argentina. *Journal of the Science of Food and Agriculture* 66:323-326.

LARSON, R. E. AND M. E. SODJOUDEE. (1982) Mesquite utilization: from the stump to the finished product. pp. O1-O12. In: Mesquite Utilization. (Ed.)H. W. Parker. Texas Tech University, Lubbock, Texas, USA.

LA TORRE, P. (1990) Polvo soluble instantàneo a base de algarroba. MSc thesis, Universidad de Piura, Peru.

LAVIN, M. AND M. LUCKOW. (1993) Origins and relationships of tropical North America in the context of the boreotropics hypothesis. *American Journal of Botany* 80:1-14.

LEA, J. D. (1996) A review of literature on charcoal in Haiti. pp. 2.33-2.43. In: *Prosopis*: Semiarid Fuelwood and Forage Tree; Building Consensus for the Disenfranchised. (Eds.) P. Felker and J. Moss. Center for Semi-Arid Forest Resources, Kingsville, Texas, USA.

LEAKEY, R. R. B. AND K. A. LONGMAN. (1988) Low-tech cloning of tropical trees. *Appropriate Technology* 15:6.

LEAKEY, R. R. B., J. F. MESEN, Z. TCHOUNDJEU, K. A. LONGMAN, J. M. DICK, A. NEWTON, A. MATIN, J. GRACE, R. C. MUNRO AND P. N. MUTHOKA. (1990) Low-technology techniques for the vegetative propagation of tropical trees. *Commonwealth Forestry Review* 69:247-257.

LEE, S. G. AND P. FELKER. (1992) Influence of water/heat stress on flowering and fruiting of mesquite (*Prosopis glandulosa* var. *glandulosa*). *Journal of Arid Environments* 23:309-319.

LEE, S. G., E. J. RUSSELL, R. L. BINGHAM AND P. FELKER. (1992) Discovery of thornless, non-browsed, erect tropical *Prosopis* in 3-year-old Haitian progeny trials. *Forest Ecology and Management* 48:1-13.

LEONARD, J. (1986) A new variety of *Prosopis koelziana* Burkart (a Mimosaceae from Arabian Peninsula). *Bulletin du Jardin Botanique National de Belgique* 56:483-485.

LESNEY, M. S. AND P. FELKER. (1995) Two field and greenhouse diseases of *Prosopis* (mesquite). *Journal of Arid Environments* 30:417-422.

LEWIS, G. P. AND T. S. ELIAS. (1981) Mimosaea. pp. 155-168. In: Advances in Legume Systematics. (Eds.) R. M. Polhill and P. H. Raven. Royal Botanic Gardens, Kew, UK.

LIMA, M. S., C. E. C. DEMACEDO, D. C. S. NUNES AND D. A. ALBUQUERQUE. (1990) Comparative IgGl and IgE specific responses induced by proteins of *Prosopis juliflora* DC and *Dioclea grandiflora* Mart. *Arquivos De Biologia e Tecnologia* 33:581-591.

LIMA, P. C. F. (1986) Tree productivity in the semiarid zone of Brazil. *Forest Ecology and Management* 16:5-13.

LIMA, P. C. F. (1987) Produção de vagens de algaroba. *Revista da Associação Brasileira de Algaroba (Mossoró)* 1:151-170.

LIMA, P. C. F. (1990a) Performance of species of the genus *Prosopis* at 24 months of age in Petrolina. pp. 63-67. In: The Current State of Knowledge on *Prosopis juliflora*. (Eds.) M. A. Habit and J. C. Saavedra. FAO, Rome, Italy.

LIMA, P. C. F. (1990b) *Prosopis* vegetative propagation through cuttings. pp. 223-227. In: The Current State of Knowledge on *Prosopis juliflora*. (Eds.) M. A. Habit and J. C. Saavedra. FAO, Rome, Italy.

LIMA, P. C. F. (1994) Comportamento silvicultural de especies de *Prosopis*, em Petrolina-PE, Região Semi-Arida Brasileira. PhD thesis, Universidade Federal do Parana, Brazil.

LIMA, P. C. F. AND A. P. M. GALVÃO. (1984) A Pesquisa com algarobeira desenvolvida pela EMBRAPA/IBDF no Nordeste Semiarido. EMBRAPA, IBDF, Brasília, Brazil.

LIMA, P. C. F. AND F. N. P. HAJI. (1993) Occurrence of caterpillar defoliation in mesquite (*Prosopis juliflora*) in the semi-arid tropics of Brazil. *Boletim de Pesquisa Florestal* 26/27:57-59.

LIMA, P. C. F., E. B. de OLIVEIRA AND S. do A. MACHADO. (1996) Equations for biomass estimation of *Prosopis* species in the Brazilian semiarid region. *Boletim de Pesquisa Florestal* 32/33:67-79.

LIMA, P. C. F. AND M. de A. SILVA. (1991) Ocorrência sub-espontânea de uma algaroba no nordeste do Brasil. *Boletim de Pesquisa Florestal* 22/23:91-95.

LITTLE, E. L. AND R. G. SKOLMEN (Eds.). (1989) Common Forest Trees of Hawaii (Native and Introduced). Agricultural Handbook No. 679. USDA Forest Service, Washington DC, USA.

LITTLE, E. L. AND F. H. WADSWORTH. (1964) Common Trees of Puerto Rico and the Virgin Islands. Agricultural Handbook. USDA Forest Service, Washington DC, USA.

LÓPEZ, J. AND B. AVILÉS. (1990) Germination improvement treatments for seeds of four Chilean *Prosopis* species. pp. 495-502. In: The Current State of Knowledge on *Prosopis juliflora*. (Eds.) M. A. Habit and J. C. Saavedra. FAO, Rome, Italy.

LÓPEZ, S. C. AND V. MANRIQUE. (1988) Obtencion de alcohol etilico a partir del fruto de algarrobo (*Prosopis pallida*). *Zonas Aridas* 5:77-88.

LÓPEZ-PORTILLO, J., L. E. EGUIARTE AND C. MONTANA. (1993) Nectarless honey mesquites. *Functional Ecology* 7:452-461.

LOTSY, J. P. (1931) On the species of the taxonomist as it relates to evolution. *Genetica* 13:1-16.

LUCKOW, M. AND J. GRIMES. (1997) A survey of anther glands in the mimosoid legume tribes Parkieae and Mimoseae. *American Journal of Botany* 84:285-297.

LUNA, R. K. (1996) *Prosopis juliflora* (Swartz) DC. In: Plantation Trees. International Book Distributors, Delhi, India.

MACBRIDE, J. F. (1943) Flora of Peru - family Leguminosae. *Botanical Series, Field Museum of Natural History* 13:108-110.

MADAN, R. N. AND B. TANDON. (1991) Utilisation of some of plantation, agro-forestry and social forestry species for the production of dissolving pulps. *Indian Forester* 117:29-36.

MADANY, M. H. (1991) Living fences: Somali farmers adopt an agroforestry technology. *Agroforestry Today* 3:4-7.

MAGA, J. A. (1986) Polycyclic aromatic hydrocarbon (pah) composition of mesquite (*Prosopis juliflora*) smoke and grilled beef. *Journal of Agricultural and Food Chemistry* 34:249-251.

MAGHEMBE, J. A., E. M. KARIUKI AND R. D. HALLER. (1983) Biomass and nutrient accumulation in young *Prosopis juliflora* at Mombasa, Kenya. *Agroforestry Systems* 1:313-321.

MAKKAR, H. P. S., B. SINGH AND S. S. NEGI. (1990) Tannin levels and their degree of polymerisation and specific activity in some agro-industrial by-products. *Biological Wastes* 31:137-144.

MALDONADO, L. J. (1990) *Prosopis* in Mexico. pp. 153-161. In: The Current State of Knowledge on *Prosopis juliflora*. (Eds.) M. A. Habit and J. C. Saavedra. FAO, Rome, Italy.

MALDONADO, L. J. (1991) El género *Prosopis*, elemento para el manejo integrado de los recursos renovables de las zonas áridas de México, Horizonte año 2000. Quinta Reunión Regional América Latina y el Caribe. Red de Forestación Conservación y Mejoramiento de Especies del Género *Prosopis*. Centro International de Investigación para el Desarrollo, Mendoza, Argentina.

MALIK, P., A. B. SINGH, C. R. BABU AND S. V. GANGAL. (1991) Atmospheric concentration of pollen grains at human height. *Grana* 30:129-135.

MALIWAL, G. L., C. M. NADIAYADARA, S. H. PUNJANI AND C. L. PATEL. (1991) Changes in soil properties as influenced by *Prosopis juliflora* and crop covers in salt affected soils. *Annals of Arid Zone* 30:57-60.

MALONE, S. R., H. S. MAYEUX, H. B. JOHNSON AND H. W. POLLEY. (1993) Stomatal density and aperture length in 4 plant species grown across a subambient CO_2 gradient. *American Journal of Botany* 80:1413-1418.

MANICKAM, K. AND P. NARAYANASAMY. (1994) Screening of non-host plants for inhibitory activity against mungbean (*Vigna radiata* (L.) Wilczek) leaf curl disease. *Legume Research* 17:90-92.

MANSFIELD, L. E. AND G. B. GOLDSTEIN. (1981) Anaphylactic reaction after ingestion of local bee pollen. *Annals of Allergy* 47:154-156.

MARANGONI, A. AND I. ALLI. (1988) Composition and properties of seeds and pods of the tree legume *Prosopis juliflora* (DC). *Journal of the Science of Food and Agriculture* 44:99-110.

MARES, M. A., F. A. ENDERS, J. M. KINGSOLVER, J. L. NEFF AND B. B. SIMPSON. (1977) *Prosopis* as a niche component. pp. 123-149. In: Mesquite: Its Biology in Two Desert Ecosystems. (Ed.) B. B. Simpson. Dowden, Hutchinson and Ross, Stroudsburg, Pennsylvania, USA.

MARMILLON, E. (1986) Management of algarrobo (*Prosopis alba*, *P. chilensis*, *P. flexuosa* and *P. nigra*) in the semiarid regions of Argentina. *Forest Ecology and Management* 16:33-40.

MARTIN, S. C. (1948) Mesquite seeds remain viable after 44 years. *Ecology* 29:393.

MARTÍNEZ, S. (1984) Foliar architecture of species of the genus *Prosopis*. *Darwiniana* 25:279-297.

MAUA, J. O. AND A. OTSAMO. (1993) Utilization of *Prosopis juliflora* for charcoal production in Bura irrigation and setlement project in eastern Kenya. *East African Agriculture and Forestry Journal* 58:115-117.

MEHROTRA, M. D. AND V. SHARMA. (1992) Some new host records of root knot nematodes. *Indian Forester* 118:856-857.

MEINZER, O. E. (1927) Plants as indicators of ground water. *United States Geological Survey Water Supply Paper* 577:95.

MEYER, D. (1984) Processing, utilization and economics of mesquite pods as a raw material for the food industry. PhD thesis Nr. 7688, ETH, Zurich, Switzerland.

MEYER, D., R. BECKER AND H. NEUKOM. (1982) Milling and separation of *Prosopis* pod components and their application in food products. pp. L1-L12. In: Mesquite Utilization. (Ed.) H. W. Parker. Texas Tech University, Lubbock, Texas, USA.

MEYER, J. M. AND P. FELKER. (1990) Pruning mesquite (*Prosopis glandulosa* var. *glandulosa*) saplings for lumber production and ornamental use. *Forest Ecology and Management* 36:301-306.

MIETTINEN, P. (1989) Nitrogenase activity in *Prosopis juliflora* seedlings inoculated with *Rhizobium* isolates from eastern Kenya. *Nitrogen Fixing Tree Research Reports* 7:110-111.

MISAK, R. F. AND M. Y. DRAZ. (1997) Sand drift control of selected coastal and desert dunes in Egypt: case studies. *Journal of Arid Environments* 35:17-28.

MOHAN, N. P. (1940) The Mesquite. Punjab Forestry Record (Silva Publ.) 9, India.

MONTE-NEGREIROS, A., M. CARVALHO, J. X. FILHO, A. BLANCO-LABRA, P. R. SHREWRY AND M. RICHARDSON. (1991) The complete sequence of the major kunitz trypsin inhibitor from the seeds of *Prosopis juliflora*. *Phytochemistry* 30:2829-2833.

MOONEY, H. A., B. B. SIMPSON AND O. T. SOLBRIG. (1977) Phenology, morphology, physiology. pp. 26-43. In: Mesquite, Its Biology in Two Desert Ecosystems. (Ed.)B. B. Simpson. Dowden, Hutchinson and Ross, Inc., Stroudsburg, Pennsylvania, USA.

MOREIRA, T. de B., N. VIANA, C. A. FERREIRA, B. NUNES AND J. do B. NASCIMENTO. (1982a) Algarobeira, importante forrageira para of nordeste. Ed. 2. Boletim Técnico No. 5. Empresa de Pesquisa Agropecuaria do Rio Grande do Norte, Brazil.

MUSTAFA, A. R. F. M. (1990) *Prosopis chilensis*, a prospective tree for Sudan's dry zone. pp. 163-167. In: The Current State of Knowledge on *Prosopis juliflora*. (Eds.) M. A. Habit and J. C. Saavedra. FAO, Rome, Italy.

MUTHA, N. AND U. BURMAN. (1998) Effect of seed weight and sowing depth on germination and seedling quality of *Prosopis juliflora*. pp. 43-45. In: *Prosopis* Species in the Arid and Semi-Arid Zones of India. (Eds.) J. C. Tewari, N. M. Pasiecznik, L. N. Harsh and P. J. C. Harris. *Prosopis* Society of India and the Henry Doubleday Research Association, Coventry, UK.

MUTHANA, K. D. (1974) A note on frost susceptibility in arid zone trees. *Annals of Arid Zone* 13:370-373.

MUTHANA, K. D. (1985) *Prosopis* species development in India. pp. 181-191. In: The Current State of Knowledge on *Prosopis tamarugo*. (Ed.) M. A. Habit. FAO, Rome, Italy.

MUTHANA, K. D. (1988) Technology for propagation and by-products utilization of *Prosopis chilensis*. *Indian Farming* 38:11-13,21.

MUTHANA, K. D. AND G. D. ARORA. (1983) *Prosopis juliflora* (Swartz) D.C. A fast growing tree to bloom the desert. Central Arid Zone Research Institute, Jodhpur, India, CAZRI Monograph No. 22.

MUTHANA, K. D. AND B. L. JAIN. (1984) Use of saline water for raising tree seedlings. *Indian Farming* 34:37-38,40.

MUSTAFA,A.R.F.M. (1990) *Prosopis chilensis*, a prospective tree for Sudan's dry zone. P. 163-167 *in* M. A. Habit and J. C. Saavedra (*Editors*) The Current State of Knowledge on *Prosopis juliflora*. FAO, Rome, Italy.

MUZAFFAR, N. AND R. AHMAD. (1991) Some honeybee flora for *Apis* spp. in Pakistan. *Pakistan Journal of Zoology* 23:201-218.

NAMBIAR, K. K. (1946) A novel method of improving the germination of *Prosopis juliflora* seeds. *Indian Forester* 72:193-195.

NANDWANI, D. AND K. G. RAMAWAT. (1991) Callus-culture and plantlets formation from nodal explants of *Prosopis juliflora* (Swartz) DC. *Indian Journal of Experimental Biology* 29:523-527.

NAQVI, S. N. H., N. YASMIN, R. A. MAHMOOD, S. NIZAM, V. U. AHMAD AND S. QAZI. (1994) Determination of toxicity and effect of juliflorine and Dimilin on fourth instar larvae of *Aedes aegypti* (Diptera: Culicidae). *Zeitschrift fur Angewandte Zoologie* 80:155-164.

NARANJO, C. A., L. POGGIO AND S. E. ZEIGER. (1984) Phenol chromatography, morphology and cytogenetics in 3 species and natural hybrids of *Prosopis* (leguminosae-mimosoideae). *Plant Systematics and Evolution* 144:257-276.

NAS (NATIONAL ACADEMY OF SCIENCES). (1980) Firewood Crops; Shrub and Tree Species for Energy Production. Vol. 1. National Academy Press, Washington DC, USA.

NEGI, M. S., N. R. BANWAL AND R. N. SRIVASTAVA. (1998) Local volume table of *Prosopis juliflora* for timber and small wood/firewood. *Indian Forester* 124:43-47.

NEUWINGER, H. D. (1996) African Ethnobotany: Poisons and Drugs. Chapman & Hall, London, UK.

NILSEN, E. T., M. R. SHARIFI AND P. W. RUNDEL. (1991) Quantitative phenology of warm desert legumes: seasonal growth of six *Prosopis* species at the same site. *Journal of Arid Environments* 20:299-311.

NILSEN, E. T., M. R. SHARIFI, R. A. VIRGINIA AND P. W. RUNDEL. (1987) Phenology of warm desert phreatophytes - seasonal growth and herbivory in *Prosopis glandulosa* var *torreyana* (honey mesquite). *Journal of Arid Environments 13:217-229*.

NOOR, M., U. SALAM AND M. A. KHAN. (1995) Allelopathic effects of *Prosopis juliflora* Swartz. *Journal of Arid Environments* 31:83-90.

NÚÑEZ-SACARÍAS, E. (1994) Insectos del Algarrobo (*Prosopis* spp.) en el Perú: costa norte (Piura) y costa central (Ica). *Revista Peruana de Entomología* 36:69-83.

OCHOA, J. (1996) A review of the social and economic opportunities for *Prosopis* (algarrobo) in Argentina. pp. 5.19-5.34. In: *Prosopis*: Semiarid Fuelwood and Forage Tree, Building Consensus for the Disenfranchised. (Eds.) P. Felker and J. Moss. Texas A&M University, Kingsville, Texas, USA.

ODUOL, P. A., P. FELKER, C. R. MCKINLEY AND C. E. MEIER. (1986) Variation amoung selected *Prosopis* families for pod sugar and pod protein contents. *Forest Ecology and Management* 16:423-431.

OJALA, J., S. G. JOHANSSON, V. KAARAKKA AND A. OTSAMO. (1993) Effects of singling coppice in irrigated *Prosopis juliflora* at Bura, Kenya. *East African Agriculture and Forestry Journal* 58:107-110.

OLIVARES, J., M. A. HERRERA AND E. J. BEDMAR. (1988) Woody legumes in arid and semi-arid zones: the rhizobium-*Prosopis chilensis* symbiosis. pp. 65-72. In: Nitrogen Fixation by Legumes in Mediterranean Agriculture. Developments in Plant and Soil Sciences, No. 32. (Eds.) D. P. Beck and Materon, L. A. Martinus Nijhoff Publishers, Dordrecht, The Netherlands.

ORTEGA-NIEBLAS, M., L. VAZQUEZ-MORENO AND M. R. ROBLES-BURGUEÑO. (1996) Protein-quality and antinutritional factors of wild legume seeds from the Sonoran desert. *Journal of Agricultural and Food Chemistry* 44:3130-3132.

OTSAMO, A. AND J. O. MAUA. (1993) Observations on pod production of planted *Prosopis juliflora*. *East African Agriculture and Forestry Journal* 58:111-114.

OVIEDO AND G. F. de VALDES. (1535) Historia Natural y General de la Indias. Vol. 9 Part 3. Sevilla, Spain.

OWEN-SMITH, N. (1993) Woody plants, browsers and tannins in southern African savannas. *South African Journal of Science* 89:505-506.

PAK, N., H. ARAYA, R. VILLALON AND M. A. TAGLE. (1977) Analytical study of tamarugo (*Prosopis tamarugo*) an autochthonous Chilean feed. *Journal of the Science of Food and Agriculture* 28:59-62.

PALACIOS, R. A. AND L. D. BRAVO. (1981) Hibridación natural en *Prosopis* (Leguminosae) en la Región Chaqueña Argentina. Evidencias morfológicas y cromatográficas. *Darwiniana* 23:3-35.

PANCHAL, Y. C. AND PRABHAKAR-SHETTY. (1977) Chemical control of *Prosopis juliflora* (Sw) DC. Paper No. 153. Program and Abstracts of Papers, Weed Science Conference, Delhi, India.

PANCHOLY, A., S. K. JINDAL, M. SINGH, N. L. KACKAR AND K. R. SOLANKI. (1989) Interspecific variation in leaf phenolics of six *Prosopis* species. *Annals of Arid Zone* 28:299-303.

PANDEY, C. N., B. L. GANDHI AND H. C. KANNOJI. (1990) Kiln drying schedule for *Prosopis juliflora*. *Journal of the Indian Academy of Wood Science* 21:29-34.

PANDIT, B. R. (1996) An ordination of plant communities In: A reserved forest near Bhavnagar. *Indian Journal of Forestry* 19:278-282.

PANDYA, S. M. AND V. K. SIDHA. (1985) Structure and composition of forest vegetation of Kutch (Gujarat state). *Indian Forester* 111:583-595.

PANETTA, F. D. AND S. A. CARSTAIRS. (1989) Isozymic discrimination of tropical Australian populations of mesquite (*Prosopis* spp.): implications for biological control. *Weed Research* 29:157-165.

PARKASH, R. AND D. HOCKING. (1986) Trees for Fuel and Fodder. The Society for Promotion of Wastelands Development, New Delhi, India.

PARKER, H. W. (Ed.). (1982a) Mesquite Utilization. Texas Tech University, Lubbock, Texas, USA.

PARKER, H. W. (1982b) Mesquite as biomass residue. pp. C1-C11. In: Mesquite Utilisation. (Ed.) H. W. Parker. Texas Tech University, Lubbock, Texas, USA.

PARKER, H. W. (1982c) Mesquite to fuel steam boilers for enhanced oil recovery. pp. V1-V9. In: Mesquite Utilisation. (Ed.) H. W. Parker. Texas Tech University, Lubbock, Texas, USA.

PASIECZNIK, N. (1999) *Prosopis* - pest or providence, weed or wonder tree? *ETFRN News* 28/29:12-14.

PASIECZNIK, N. AND P. FELKER. (1992) Mechanical cleaning of *Prosopis* seed. *Nitrogen Fixing Tree Research Reports* 10:186-188.

PASIECZNIK, N. M. (1989) Trials and tribulations: arid land tree species trials, Almeria province, Spain. Agroforestry BSc thesis, University of Wales, UK.

PASIECZNIK, N. M. (1998) *Prosopis* provenance research in Cape Verde. pp. 73-77. In: *Prosopis* Species in the Arid and Semi-Arid Zones of India. (Eds.)J. C. Tewari, N. M. Pasiecznik, L. N. Harsh and P. J. C. Harris. *Prosopis* Society of India and the Henry Doubleday Research Association, Coventry, UK.

PASIECZNIK, N. M., F. M. A. HARRIS AND P. J. C. HARRIS. (1993) Growth of *Prosopis* and *Acacia* species and their effects on soil fertility. *Nitrogen Fixing Tree Research Reports* 11:1-3.

PASIECZNIK, N. M. AND P. J. C. HARRIS. (1998) Selection and Genetic Improvement of *Prosopis* in the North-East Region of Brazil. Report to the FAO. The Henry Doubleday Research Association, Coventry, UK.

PASIECZNIK, N. M., P. J. C. HARRIS, J. de P. TAVARES AND M. CASSAMA. (1998) Pretreatment of *Prosopis* seeds to break dormancy. *International Tree Crops Journal* 9:187-193.

PASIECZNIK, N. M., L. N. HARSH AND J. C. TEWARI. (1999) *Prosopis*: State of Knowledge - Workshop Report, 8-11 February 1999, at CAZRI, Jodhpur, India and HDRA, Coventry, UK.

PASSOS, M. A. A. AND R. L. C. FERREIRA. (1991) Influence of the seedbed covering on emergence and initial growth of algaroba *Prosopis juliflora*. *Revista Brasileira de Sementes* 13:151-153.

PASTERNAK, D., J. A. ARONSON, J. BEN-DOV, S. MENDLINGER, A. NERD AND D. SITTON. (1986) Development of new arid zone crops for the Negev Desert of Israel. *Journal of Arid Environments* 11:37-59.

PASTOR, M. R., VILELA, J., CABELLO, C. (1997) *Prosopis pallida*. In: Especies Arboreas y Arbustivas para las Zonas Aridas y Semiaridas de America Latina. FAO, Santiago, Chile.

PATCH, N. L. AND P. FELKER. (1997) Silvicultural treatments for sapling mesquite (*Prosopis glandulosa* var. *glandulosa*) to optimize timber production and minimize seedling encroachment. *Forest Ecology and Management* 96:231-240.

PATCH, N. L., D. GEESING AND P. FELKER. (1998) Suppression of resprouting in pruned mesquite (*Prosopis glandulosa* var *glandulosa* saplings with chemical or physical barrier treatments. *Forest Ecology and Management* 112:23-29.

PATEL, R. R. AND V. SAFAYA. (1986) Value added chemicals from biomass. pp. RRP1-RRP4. In: The Role of *Prosopis* in Wasteland Development. (Ed.)V. J. Patel. Javrajbhai Patel Agroforestry Center, Surendrabag, Gujarat, India.

PATEL, V. J. (Ed.). (1986) The Role of *Prosopis* in Wasteland Development. Jivrajbhai Patel Agroforestry Center, Surendrabag, Gujarat, India.

PEACOCK, J. T. AND C. MCMILLAN. (1965) Ecotypic variation in *Prosopis* (mesquite). *Ecology* 46:35-51.

PEATTIE, D. C. (1953) A Natural History of Western Trees. Riverside Press, Cambridge, Massachussetts, USA.

PEINETTI, R., M. PEREYRA, A. KIN AND A. SOSA. (1993) Effects of cattle ingestion on viability and germination rate of calden (*Prosopis caldenia*) seeds. *Journal of Range Management* 46:483-486.

PEREZ, S. C. J. G. de A. AND J. A. P. V. de M. MORAES. (1990) Effects of temperature, temperature-gibberellin interaction and thermal stress on germination of *Prosopis juliflora* (Sw) DC. *Revista Brasileira de Fisiologia Vegetal* 2:41-53.

PERRY, G. (1998) *Prosopis*. *Flora of Australia* 12:7-13.

PHILLIPS, W. S. (1963) Depth of roots in soil. *Ecology* 44:424.

PIMENTEL, M. de L. (1982) Extração de sementes de algarobeira (*P.juliflora* (SW) DC) atraves de processo quimico. pp. 330-335. In: I Simposio Brasileiro sobre Algarobeira. Vol. 1, Natal, Brazil.

PIRES, I. E., G. C. ANDRADE AND M. S. AROÚJO. (1990) Genetic variation for growth characteristics in *P. juliflora* progenies. pp. 251-257. In: The Current State of Knowledge on *Prosopis juliflora*. (Eds.) M. A. Habit and J. C. Saavedra. FAO, Rome, Italy.

PIRES, I. E. AND P. Y. KAGEYAMA. (1990) Characterization of the genetic base of a *P. juliflora* population at Soledade, Paraíba. pp. 241-250. In: The Current State of Knowledge on *Prosopis juliflora*. (Eds.) M. A. Habit and J. C. Saavedra. FAO, Rome, Italy.

POLK, K. L. AND D. N. UECKERT. (1973) Biology and ecology of a mesquite twig girdler, *Oncideres rhodosticta*, in West Texas. *Annals of the Entomological Society of America* 66:411-417.

PONCE-MACOTELA, M., I. NAVARRO-ALEGRIA, M. N. MARTINEZ-GORDILLO AND R. ALVAREZ-CHACON. (1994) In-vitro antigiardiasic activity of plant-extracts. *Revista De Investigacion Clinica* 46:343-347.

POYNTON, R. J. (1990) The genus *Prosopis* in southern Africa. *South African Forestry Journal* 152:62-66.

Prajapati, M. C. and K. T. N. Nambiar. (1977) *Prosopis juliflora* shelterbelts help increase crop production. *Indian Farming* 27:15-18.

Prajapati, M. C. and S. Singh. (1994) A beneficial aspect of nilgai (*Boselaphus tragocamelus*) in scientifically utilised ravines - an observation. *Indian Forester* 120:890-897.

Prajapati, M. C., B. Verma, S. P. Mittal, K. T. N. Nambiar and B. S. Thippannavar. (1971) Effect of lateral development of *Prosopis juliflora* D C. roots on agricultural crops. *Annals of Arid Zone* 10:186-193.

Raizada, M. B. and R. N. Chatterji. (1954) A diagnostic key to the various forms of introduced mesquite (*Prosopis juliflora* DC). *Indian Forester* 80:675-680.

Rajaram, N. and K. Janardhanan. (1991) Studies on the underexploited tree pulses, *Acacia catechu* Willd., *Parkinsonia aculeata* L and *Prosopis chilensis* (Molina) Stunz - chemical composition and antinutritional factors. *Food Chemistry* 42:265-273.

Rajput, S. S. and M. C. Tewari. (1986) Some studies on the utilisation of bio-mass of *Prosopis* spp. pp. SSR1-SSR9. In: The Role of *Prosopis* in Wasteland Development. (Ed.) V. J. Patel. Javrajbhai Agroforestry Center, Surendrabag, Gujarat, India.

Raju, G. (1986) Bio-mass conversion technology. pp. 1-6 In: The Role of *Prosopis* in Wasteland Development. (*Ed.*) V. J. Patel. Javrajbhai Patel Agroforestry Center, Surendrabag, Gujarat, India.

Ramawat, K. G. and D. Nandwani. (1991) Arid-land afforestation by tissue culture. *Bionature* 11:103-109.

Ramirez, L., A. de la Vega, N. Razkin, V. Luna and P. J. C. Harris. (1999) Analysis of the relationships between species of the genus *Prosopis* revealed by the use of molecular markers. *Agronomie* 19:31-43.

Rana, A. D. and A. P. Jain. (1984) Minimising rodent damage to afforestation sites. *Indian Farming* 34:69-70.

Rao, A. V., K. Bala and A. N. Lahiri. (1989) Influence of trees on micro-organisms of aridisol and its fertility. *Indian Forester* 115:680-683.

Rao, K. S. and R. Vasanthi. (1986) Economics and promotion of biomass gasifier for water pumping. pp. KSR1-KSR13. In: The Role of *Prosopis* in Wasteland Development. (Ed.) V. J. Patel. Javrajbhai Patel Agroforestry Center, Surendrabag, Gujarat, India.

Rao, S. R. (1951) Tree-planting on the Hagari bank to check sand drift. *Dehra Dun* 1946:124-127.

Raven, P. H. and D. I. Axelrod. (1974) Angiosperm biogeography and past continental movements. *Annals of the Missouri Botanical Garden* 61:539-657.

Raven, P. H. and R. M. Polhill. (1981) Biography of the Leguminosae. pp. 27-34. In: Advances in Legume Systematics. (Eds.) R. M. Polhill and P. H. Raven. Royal Botanic Gardens, Kew, UK.

Reddy, C. V. K. (1978) *Prosopis juliflora*, the precocious child of the plant world. *Indian Forester* 104:14-18.

Rehman, S., A. Hussain and S. Ameen. (1988) Results of early selection of *Acacia* and *Prosopis* species/seed sources. *Pakistan Journal of Forestry* 38:109-117.

Rhodes, D. and P. Felker. (1988) Mass screening of *Prosopis* (mesquite) seedlings for growth at seawater salinity concentrations. *Forest Ecology and Management* 24:169-176.

Rhymer, J. M. and D. Simberloff. (1996) Extinction by hybridization and introgression. *Annual Review of Ecology and Systematics* 27:83-109.

Ribaski, J. (1990) Agroforestry system combining *P. juliflora* and buffel grass in the Brazilian semi-arid region: preliminary results. pp. 471-477. In: The Current State of Knowledge on *Prosopis juliflora*. (Eds.) M. A. Habit and J. C. Saavedra. FAO, Rome, Italy.

Richardson, C. R. (1982) Ozone and sulfur dioxide treated mesquite as a feed for ruminants. pp. I1-I7. In: Mesquite Utilization. (Ed.) H. W. Parker. Texas Tech University, Lubbock, Texas, USA.

Riegelhaupt, E., I. B. da Silva, F. B. Campello and F. Pareyn. (1990) Volume, weight and product tables for *Prosopis juliflora* (Sw) DC at Rio Grande do Norte. pp. 69-91. In: The Current State of Knowledge on *Prosopis juliflora*. (Eds.) M. A. Habit and J. C. Saavedra. FAO, Rome, Italy.

Rocha, R. G. A. (1990) *P. juliflora* as a source of food and medicine for rural inhabitants in Rio Grande do Norte. pp. 397-403. In: The Current State of Knowledge on *Prosopis juliflora*. (Eds.) M. A. Habit and J. C. Saavedra. FAO, Rome, Italy.

Roche, L. (1986) Forestry and famine: arguments against growth without development. *Commonwealth Forestry Review* 65:2.

Rodgrigues, V. A. and J. A. Silva. (1990) Progeny trials with *P. juliflora* at seedling stage. pp. 457-463 In: The Current State of Knowledge on *Prosopis juliflora*. (Eds.) M. A. Habit and J. C. Saavedra. FAO, Rome, Italy.

ROGERS, K. E. (1986) The wood properties of mesquite (*Prosopis glandulosa* var. *glandulosa*): its basic properties and variability. Vol. 140. Texas Forest Service, College Station, Texas, USA.

ROIG, F. A. (1985) Arboles y bosques de la region arida centro oeste de la Argentina (prov. de Mendoza y San Juan) y sus posibilidades silvicolas. *in* Actos del Segundo Encuentro Regional CIID, America Latina y el Caribe, Santiago de Chile.

ROIG, V. (1990) Exploitation of *Prosopis juliflora* at Thomazeau. pp. 139-142. In: The Current State of Knowledge on *Prosopis juliflora*. (Eds.) M. A. Habit and J. C. Saavedra. FAO, Rome, Italy.

RONDÓN, J. A. (1992) Habito fenologico de 53 especies arboreas del jardin bótanico de San Juan de Lagunillas, Edition Merida *Revista Forestal de Venezuela* 16:23-33.

RUIZ, C. B. (Undated). Revision y Analisis de la Bibliografia Nacional sobre el Genero *Prosopis*. Vol. 1. CONCYTEC, Lima, Peru.

RUIZ, W. (1997) Enriquecimiento proteico de la pulpa de algarroba mediante multiplicación de levaduras. MSc thesis, Universidad de Piura, Peru.

RUNDEL, P. W., E. T. NILSEN, M. R. SHARIFI, R. A. VIRGINIA, W. M. JARRELL, D. H. KOHL AND G. B. SHEARER. (1982) Seasonal dynamics of nitrogen cycling for a *Prosopis* woodland in the Sonoran desert. *Plant and Soil* 67:343-353.

SACHETI, U. (1996) Effect of extremely high temperature on the germination of seeds of some leguminous species of arid and semi-arid areas of Oman. *Indian Journal of Ecology* 23:29-33.

SÁENZ, G., J. A. SERRA AND I. ESCRICHE. (1987) Composición química de la algarroba peruana (*Prosopis* sp.). pp. 419-427. In: Proceedings of the Second International Carob Symposium. (Eds.) P. Fito and A. Mulet. Generalitat Valenciana, Valencia, Spain.

SAIDMAN, B. O. (1986) Isoenzymatic studies of alcohol dehydrogenase and glutamate oxalacetate transaminase in four South American species of *Prosopis* and their natural hybrids. *Silvae Genetica* 35:3-10.

SAIDMAN, B. O. (1990) Isozyme studies on hybrids swarms of *Prosopis caldenia* and sympatric species. *Silvae Genetica* 39:5-8.

SAIDMAN, B. O. AND J. C. VILARDI. (1987) Analysis of the genetic similarities among seven species of *Prosopis* (Leguminosae: Mimosoideae). *Theoretical and Applied Genetics* 75:109-116.

SAIDMAN, B. O. AND J. C. VILARDI. (1993) Genetic variability and germplasm conservation in the genus *Prosopis*. pp. 187-198. In: Nursery Technology for Agroforestry: Applications in Arid and Semiarid Regions. (Eds.) S. Puri and P. K. Khosla. Oxford & IBH Publication, New Delhi, India.

SAIDMAN, B. O., J. C. VILARDI, M. I. POCOVI AND N. ACRECHE. (1996) Genetic divergence among species of the section Strombocarpa genus *Prosopis* (Leguminosae). *Journal of Genetics* 75:139-149.

SALAZAR, I. (1993) Cuantificación de taninos en cada una de las fracciones del fruto del algarrobo. MSc thesis, Universidad de Piura, Peru.

SANDISON, M. S. AND P. J. C. HARRIS. (1991) *Prosopis cineraria*: a multi-purpose tree for arid areas; NFT Highlights. Vol. 91-04. Nitrogen Fixing Tree Association (NFTA), Waimanalo, Hawaii.

SANDYS-WINSCH, D. C. AND P. J. C. HARRIS. (1991) A simple method for the vegetative propagation of *Prosopis juliflora*. *Nitrogen Fixing Tree Research Reports* 9:117-118.

SANKHLA, A. K. AND N. SANKHLA. (1979) Observations on leaf proteins of Indian desert plants. *Transactions of Indian Society of Desert Technology and University Centre of Desert Studies* 4:35-37.

SANKHLA, N., D. BAXI AND U. N. CHATTERJI. (1965) Eco-physiological studies on arid zone plants. 1. Phytotoxic effects of aqueous extract of Mesquite, *Prosopis juliflora* DC. *Current Science* 34:612-614.

SANYAL, S. N. AND R. C. SAXENA. (1980) Physical and mechanical properties of some Maharashtra timbers. *Journal of the National Buildings Organisation* 15:1-5.

SAREEN, T. S. AND S. K. YADAV. (1987) Self-incompatibility in *Prosopis juliflora* DC (Leguminosae). *Incompatibility Newsletter* 19:66-68.

SARGENT, (1902) The silva of North America. Unknown 13:15-16.

SAUNDERS, R. M., R. BECKER, D. MEYER, F. R. DEL VALLE, E. MARCO AND M. E. TORRES. (1986) Identification of commercial milling techniques to produce high sugar, high-fiber, high protein, and high galactomannan gum fractions from *Prosopis* pods. *Forest Ecology and Management* 16:169-180.

SAURA, F., J. CLAVIJO AND R. ABIA. (1991) Características químicas del endocarpio del fruto del algarrobo piurano. *Boletín de la Sociedad Química del Perú* 57:245-250.

SAXENA, S. K. AND W. A. KHAN. (1974) A quick method for obtaining clean seeds of *Prosopis juliflora*. *Annals of Arid Zone* 13:269-272.

Saxena, S. K. and J. Venkateshwarlu. (1991) Mesquite: an ideal tree for desert reclamation and fuelwood production. *Indian Farming* 41:15-21.

Scanlan, J. C. and S. Archer. (1991) Simulated dynamics of succession in a North American subtropical *Prosopis* savanna. *Journal of Vegetation Science* 2:625-634.

Schiffino, J. (1945) Riqueza Forestal Dominicana. Ed. 3. Vol. 1. Editora Montalvo, Trujillo, Dominican Republic.

Schinini, A. (1981) Contribución a la flora de Paraguay. *Bonplandia* 5:101-108.

Schuster, J. L. (1969) Literature on the Mesquite (*Prosopis L)* of North America. An Annoted Bibliography. Special Report No. 26. Texas Tech University, Lubbock, Texas, USA.

Scifres, C. J. and J. H. Brock. (1970) Growth and development of honey mesquite seedlings in the field and greenhouse as related to time of planting, planting depth, soil temperature and top removal. Texas Agricultural Experiment Station PR-2816:65-71.

Sekhar, A. C. and N. S. Rawat. (1960) A note on mechanical properties of *Prosopis juliflora. Indian Forester* 86:485-487.

Sen, D. N. and D. D. Chawan. (1970) Ecology of desert plants and observations on their seedlings. III - the influence of aqueous extracts of *Prosopis juliflora* DC. on *Euphorbia caducifolia* Haines. *Vegetatio* 21:277-298.

Sen, D. N. and M. Mehta. (1998) Seasonal variations of metabolic status of *Prosopis juliflora*. pp. 35-37. In: *Prosopis* Species in the Arid and Semi-Arid Zones of India. (Eds.) J. C. Tewari, N. M. Pasiecznik, L. N. Harsh and P. J. C. Harris. *Prosopis* Society of India and the Henry Doubleday Research Association, Coventry, UK.

Senthilkumar, P., Prince, S.P.M., Thangavel, P., Krishnasamy, R. and Subburam, V. (in press). *Prosopis juliflora* - a green solution to decontaminate heavy metal contaminated soils. *Bangladesh Journal of Forestry*

Shankarnarayan, K. A. and S. Kumar. (1986) Aerial seeding of sand dunes I. Trends in seed germination and seedling distribution. *Journal of Tropical Forestry* 2:4-20.

Sharma, B. D. and I. C. Gupta. (1989) Effect of trees cover on soil fertility in western Rajasthan. *Indian Forester* 115:348-354.

Sharma, B. M. (1968) Chemical analysis of some desert tree. pp. 248-251. In: Proceedings of the Symposium on Recent Advances in Tropical Ecology. Varanasi, India.

Sharma, B. M. (1984) Scrub forest studies - foliar and soil nutrient status of *Prosopis juliflora* DC. *Indian Forester* 110:367-374.

Sharma, D. G. (1985) Ravine reclamation through aerial seeding: an appraisal. *Journal of Tropical Forestry* 1:18-28.

Shukla, N. K., A. K. Khanduri, K. Lal and M. Lal. (1990) Physical and mechanical properties of some exotic species. *Indian Forester* 116:140-147.

Shukla, P. C., P. M. Talpada and M. B. Pande. (1984) *Prosopis juliflora* pods, a new cattle feed source. Animal Nutrition Department, Gujarat Agricultural University, Anand, Gujrat, India.

Shukla, P. C., P. M. Talpada, M. B. Pande, M. C. Desai and H. B. Desai. (1986) *Prosopis juliflora* pods and their utilization as cattle feed. In: The Role of *Prosopis* in Wasteland Development. (Ed.) V. J. Patel. Javrajbhai Patel Agroforestry Center, Surendrabag, Gujarat, India.

Siddig, M. M. B. (1983) Phenology and regeneration of mesquite (*Prosopis chilensis*) in the Sudan. M.Sc. thesis, University of Gezira, Sudan.

Sidhu, O. P. and H. M. Behl. (1997) Response of three *Glomus* species on growth of *Prosopis juliflora* Swartz at high pH levels. *Symbiosis* 23:23-34.

Silva, L. F., G. G. M. Farias, E. L. Leite, C. B. S. Nascimento, A. N. M. Negreiros, D. F. Lima and H. Flores. (1990) *Prosopis juliflora* pod flour and syrup processing and nutritional evaluation. pp. 405-417. In: The Current State of Knowledge on *Prosopis juliflora.* (Eds.) M. A. Habit and J. C. Saavedra. FAO, Rome, Italy.

Silva, M. A. (1990a) Taxonomy and distribution of the genus *Prosopis* L. p. 177-186. In: The Current State of Knowledge on *Prosopis juliflora.* (Eds.) M. A. Habit and J. C. Saavedra. FAO, Rome, Italy.

Silva, S. (1989) A algarobeira (*Prosopis juliflora* (Sw) DC) no Nordeste do Brasil. Ministerio da Agricultura, Brazil.

Silva, S. (1990b) *Prosopis juliflora* (Sw) DC in Brazil. pp. 29-55. In: The Current State of Knowledge on *Prosopis juliflora.* (Eds.) M. A. Habit and J. C. Saavedra. FAO, Rome, Italy.

Simpson, B. B. (Ed.). (1977) Mesquite, its Biology in Two Desert Shrub Ecosystems. Dowden, Hutchinson & Ross, Stroudsberg, Pennsylvania, USA.

Simpson, B. B., A. Burkart and N. J. Carman. (1975) *Prosopis palmeri*: a relict of an ancient North American colonization. *Madroño* 23:220-227.

SIMPSON, B. B., J. L. NEFF AND A. R. MOLDENKE. (1977) *Prosopis* flowers as a resource. pp. 84-107. In: Mesquite, Its Biology in Two Desert Shrub Ecosystems. (Ed.) B. B. Simpson. Dowden, Hutchinson and Ross, Stroudsburg, Pennsylvania, USA.

SINGH, G. (1970) Palaeobotanical features of Thar desert. *Annals of Arid Zone* 8:188-195.

SINGH, G. (1995) An agroforestry practice for the development of salt lands using *Prosopis juliflora* and *Leptochloa fusca*. *Agroforestry Systems* 29:61-75.

SINGH, G. (1996) The role of *Prosopis* in reclaiming high-pH soils and in meeting firewood and forage needs of small farmers. pp. 1.3-1.27. In: *Prosopis*: Semiarid Fuelwood and Forage Tree; Building Consensus for the Disenfranchised. (Eds.) P. Felker and J. Moss. Center for Semi-Arid Forest Resources, Kingsville, Texas, USA.

SINGH, G., I. P. ABROL AND S. S. CHEEMA. (1988a) Agroforestry on alkali soil: effect of planting methods and amendments on initial growth, biomass accumulation and chemical composition of mesquite (*Prosopis juliflora* (SW) DC) with inter-space planted with and without Karnal grass (*Diplachne fusca* Linn. P. Beauv.). *Agroforestry Systems* 7:135-160.

SINGH, G., I. P. ABROL AND S. S. CHEEMA. (1988b) Forage production and nutrient cycling through Karnal grass (*Diplachne fusca*) planted with mesquite (*Prosopis juliflora*) in a highly sodic soil. Central Soil Salinity Research Institute, Karnal, Haryana, India.

SINGH, G., I. P. ABROL AND S. S. CHEEMA. (1990) Effects of irrigation on *Prosopis juliflora* and soil properties of an alkali soil. *International Tree Crops Journal* 6:81-99.

SINGH, G. AND N. T. SINGH. (1993) Mesquite for the revegetation of salt lands. Bulletin No.18. Central Soil Salinity Research Institute, Karnal, Haryana, India.

SINGH, M. P. (1998) Injurious hexapoda associated with *Prosopis*. pp. 105-108. In:*Prosopis* Species in the Arid and Semi-Arid Zones of India. (Eds.) J. C. Tewari, N. M. Pasiecznik, L. N. Harsh and P. J. C. Harris. *Prosopis* Society of India and the Henry Doubleday Research Association, Coventry, UK.

SINHA, A. K., P. A. SHIRKE, U. PATHRE AND P. V. SANE. (1997) Sucrose-phosphate synthase in tree species: light/dark regulation involves a component of protein turnover in *Prosopis juliflora* (SW DC). *Biochemistry and Molecular Biology International* 43:421-431.

SMITH, C. E. J. (1967) Plant remains: the prehistory of the Tehuacan valley. pp. 220-255. In: Environment and Subsistence. (Ed.) D. S. Byers. University of Texas Press, Austin, Texas, USA.

SOLA, N. H., H. R. JULIANI AND J. L. CABRERA. (1992) Determination of some soil components under *Prosopis ruscifolia*. *Agrochimica* 36:148-153.

SOLANO, L. (1989) Características físicas y contenidos de azùcar de diversas variedades de algarroba. B.Sc. thesis, Universidad de Piura, Peru.

SOLBRIG, O. T. AND K. S. BAWA. (1975) Isozyme variation in species of *Prosopis* (Leguminosae). *Journal of the Arnold Arboretum* 56:398-412.

SOLBRIG, O. T., K. BAWA, N. J. CARMAN, J. H. HUNZIKER, C. A. NARANJO, R. A. PALACIOS, L. POGGIO AND B. B. SIMPSON. (1977) Patterns of variation. pp. 44-60. In: Mesquite, Its Biology in Two Desert Ecosystems. (Ed.) B. B. Simpson. Dowden, Hutchinson and Ross, Stroudsburg, Pennsylvania, USA.

SOLBRIG, O. T. AND P. D. CANTINO. (1975) Reproductive adaptations in *Prosopis* (Leguminosae, Mimosoideae). *Journal of the Arnold Arboretum* 56:185-210.

SOMASHEKHAR, R. (1998) Effect of salinity on *Prosopis juliflora* during early growth phase. *Indian Forester* 124:240-247.

SOUZA, S. M. de, P. C. F. LIMA AND M. de S. ARAUJO. (1983) Seeds of *Prosopis juliflora*: methods and costs of processing. *Revista Brasileira de Sementes* 5:51-61.

SPAAK, J. D. (1990) Afforestation on Cape Verde - why, how, for whom? *Bois et Forêts des Tropiques* 225:47-54.

SRIDHARA, S., B. P. SINGH, N. ARORA, J. VERMA AND S. V. GANGAL. (1992) A study on antigenic and allergenic changes during storage in 3 different biological extracts. Asian Pacific *Journal of Allergy and Immunology* 10:33-38.

SRINIVASU, V. AND O. P. TOKY. (1996) Effect of alkalinities on seed germination and seedling growth of important arid trees. *Indian Journal of Forestry* 19:227-233.

SRIVASANKAR, N., A. G. BHAT AND S. A. PATIL. (1991) A note on leaf extracts of honey mesquite *Prosopis juliflora* as a piscicide. *Indian Forester* 117:151-152.

SRIVASTAVA, K. K. AND D. K. MISHRA. (1998) Diseases of *Prosopis juliflora* in Rajasthan. pp. 109-110. In: *Prosopis* Species in the Arid and Semi-Arid Zones of India. (Eds.) J. C. Tewari, N. M. Pasiecznik, L. N. Harsh and P. J. C. Harris. *Prosopis* Society of India and the Henry Doubleday Research Association, Coventry, UK.

STANDLEY, P. C. (1926) Trees and shrubs of Mexico. *Contributions to the US National Herbareum* 23:350-353, 1657-1658.

STANDLEY, P. C. AND J. A. STEYERMARK. (1946) Flora of Guatemala. Leguminosae. *Fieldiana Botany* 24.

STEIN, U. AND F. KLINGAUF. (1990) Insecticidal effect of plant extracts from tropical and subtropical species. Traditional methods are good as long as they are effective. *Journal of Applied Entomology* 110:160-166.

STEWART, J. L., A. J. DUNSDON, J. J. HELLIN AND C. E. HUGHES. (1992) Wood biomass estimation of central American dry zone species. Tropical Forestry Paper 26. Oxford Forestry Institute, Oxford, UK.

STEWART, J. L., A. J. DUNSDON, M. A. KISHK AND M. K. ALY. (1993) Screening of non-industrial tree species on reclaimed desert land in Middle Egypt. *Journal of Arid Environments* 25:375-385.

STEWART, J. L. AND R. SALAZAR. (1992) A review of measurement options for multi-purpose trees. *Agroforestry Systems* 19:173-183.

STONE, E. L. AND P. J. KALISZ. (1991) On the maximum extent of tree roots. *Forest Ecology and Management* 46:59-102.

STUBSGAARD, F. (1990) Pretreatment of *Acacia* and *Prosopis* seed by two mechanical methods. pp. 465-468. In: The Current State of Knowledge on *Prosopis juliflora*. (*Eds.*) M. A. Habit and J. C. Saavedra. FAO, Rome, Italy.

SUDZUKI, F. (1985) Environmental moisture utilization by *Prosopis tamarugo* Phil. pp. 33-48. In: The Current State of Knowledge on *Prosopis tamarugo*. (Ed.)M. A. Habit. FAO, Rome, Italy.

SUGUR, G. V. (1988) Coppicing ability of natural stand of *Prosopis juliflora*. *Myforest*. 24:129-132.

SULIAMAN, F. A., W. F. HOLMES, S. KWICK, F. KHOURI AND R. RATARD. (1997) Pattern of immediate type hypersensitivity reactions in the Eastern Province, Saudi Arabia. *Annals of Allergy Asthma and Immunology* 78:415-418.

SUNDARABABU, R., C. SANKARANARAYANA AND S. VADIVELU. (1990) Nematode management with plant products. *Indian Journal of Nematology* 20:177-178.

SUNDARAMOORTHY, S., N. KALRA AND D. D. CHAWAN. (1996) Allelopathy and *Prosopis juliflora* provenance Israel in semi-arid agroforestry systems. *Indian Journal of Forestry* 18:214-220.

SUNDARARAJ, D. D., G. BALASUNDRAMANIYAM AND G. SOUNDRAPANDIAN. (1966) Pretreatment of the seeds of *Prosopis juliflora* DC for improving germination. *Madras Agricultural Journal* 53:259-261.

SUNDARRAJ, T., V. KURUCHEVE AND J. JAYARAJ. (1996) Screening of higher plants and animal faeces for the fungitoxicity against *Rhizoctonia solani*. *Indian Phytopathology* 49:398-403.

SUTARIA, J. N., R. ANDHARIA AND V. J. PATEL. (1986) Thermal power station based on fire wood from *Prosopis chilensis* in four talukas of Bhavnagar District. pp. 1-8. In: The Role of *Prosopis* in Wasteland Development. (Ed.)V. J. Patel. Javrajbhai Patel Agroforestry Center, Surendrabag, Gujarat, India.

TABONE, T. J., P. FELKER, R. L. BINGHAM, I. REYES AND S. LOUGHREY. (1986) Techniques in the shoot multiplication (tissue culture) of the leguminous tree *Prosopis alba* clone B2V50. *Forest Ecology and Management* 16:191-200.

TALPADA, P. M. (1985) Study on *Prosopis juliflora* pods and utilization as cattle feed by lactating cows. PhD thesis, Gujarat Agricultural University, Anand, India.

TALPADA, P. M., H. B. DESAI, M. C. DESAI, Z. N. PATEL AND P. C. SHUKLA. (1987) Composition and nutritive value of *Prosopis juliflora* pods without seeds. *Indian Journal of Animal Sciences* 57:776-777.

TALPADA, P. M. AND P. C. SHUKLA. (1988) Study on sugar and amino acids composition of *Prosopis juliflora* pods. *Gujarat Agricultural University Research Journal* 14:32-35.

TARAFDAR, J. C. AND A. V. RAO. (1998) Possibilities of manipulating mycorrhizal associations for higher production in *Prosopis juliflora*. pp. 47-48. In: *Prosopis* Species in Arid and Semi-Arid Zones of India. (Eds.) J. C. Tewari, N. M. Pasiecznik, L. N. Harsh and P. J. C. Harris. *Prosopis* Society of India and the Henry Doubleday Research Association, Coventry, UK.

TEWARI, D. D. (1998) Economics and Management of Nontimber Forest Products: A Case Study of Gujarat, India. Oxford and IBH Publishing Co. PVT. Ltd, New Delhi, Calcutta, India.

TEWARI, J. C., M. D. BOHRA, N. K. SHARMA, U. BURMA AND L. N. HARSH. (1998) Pretreatments to enhance germination of *Prosopis juliflora* seed. pp. 39-42. In: *Prosopis* Species in Arid and Semi-Arid Zones of India. (Eds.) J. C. Tewari, N. M. Pasiecznik, L. N. Harsh and P. J. C. Harris. *Prosopis* Society of India and the Henry Doubleday Research Association, Coventry, UK.

TEWARI, J. C. AND L. N. HARSH. (1998) Forestry research in arid tract of India. pp. 307-322 In: Fifty Years of Arid Zone Research in India. (*Eds.*) A. S. Faroda and M. Singh. CAZRI, Jodhpur, India.

TEWARI, J.C., P.J.C. HARRIS, L.N. HARSH, K. CADORET AND N.M. PASIECZNIK. (2000) Managing *Prosopis juliflora* (Vilayati babul): A Technical Manual. CAZRI, Jodhpur, India and HDRA, Coventry, UK.

TEWARI, V. P. AND A. WAIS. (1996) Growth modelling for *Prosopis juliflora* (Swartz.) DC. *Annals of Biology* 12:1-6.

TIMYAN, J. (1996) Bwa Yo: Important Trees of Haiti. South East Consortium for International Development, Washington DC, USA.

TORRES, S. B., J. L. FIRMINO AND V. D. C. MELLO. (1994) Germination of sabia (*Mimosa caesalpiniaefolia* Benth.) and algaroba (*Prosopis juliflora* (SW) DC) seeds. *Ciencia Rural* 24:629-630.

TORTORELLI, L. (1956) Maderas y Bosques Argentinas. Acme Agency Press, Buenos Aires, Argentina.

TOUZEAU, J. (1973) Les arbres fouragers de la zone sahélienne de l'Afrique. Vol. 75. Ecole Nationale Vétérinaire de Toulouse, Toulouse, France.

TOWLE, M. (1961) The ethnobotany of pre-Colombian Peru. *Viking Fund Publ. Anthropol* 30:55-56.

TUME, Z. P., T. M. CARDENAS AND C. W. CALDERÓN. (1989) Efecto de la napa freatica en el crecimiento y enraizamiento de *Prosopis pallida* en Piura - Nota Tecnica. *Revista Forestal del Peru* 16:65-71.

TURC, C. O. AND B. E. CUTTER. (1984) Sorption and shrinkage studies of six Argentine woods. *Wood and Fiber Science* 16:575-582.

ULICH, W. L. (1982) Economics and technology of harvesting whole-tree mesquite. pp. B1-B13. In: Mesquite Utilization. (Ed.) H. W. Parker. Texas Tech University, Lubbock, Texas, USA.

VALDIVIA, S. V. (1972) El algarrobo. una especie forestal prometedora para los trópicos áridos, Boletin de Divulgacion No. 32. Ministry of Agriculture, Lima, Peru.

VAN KLINKEN, R. D. (1999) Developmental host-specificity of *Mozena obtusa* (Heteroptera: Coreidae), a potential biocontrol agent for *Prosopis* species (mesquite) in Australia. *Biological Control* 16:283-290.

VARSHNEY, A. (1996) Overview of the use of *Prosopis juliflora* for livestock feed, gum, honey, and charcoal, as well as in combating drought and desertification: a regional case study from Gujarat, India. pp. 6.35-6.4. In: *Prosopis*: Semiarid Fuelwood and Forage Tree; Building Consensus for the Disenfranchised. (Eds.) P. Felker and J. Moss. Center for Semi-Arid Forest Resources, Kingsville, Texas, USA.

VASAVADA, P. K. AND B. P. LAKHANI. (1973) A note for obtaining clean seeds of *Prosopis juliflora* from pods through chemico-mechanical method. *Indian Forester* 99:163-165.

VELDE, G. ten. (1983) Reforestation of Nouakchott. *Arid Lands Newsletter* 18:4-8.

VELU, G., P. S. SRINIVASAN AND A. M. ALI. (1996) Allelopathy: field observations and methodology. Proceedings of the International Conference on Allelopathy, Volume 1. pp. 299-302. In: Phytotoxic Effect of Tree Crops on Germination and Radicle Extension of Legumes. (Eds.) S. S. Narwal and P. Tauro. Scientific Publishers, Jodhpur, India.

VIEIRA, R. L., N. B. GUERRA AND E. M. FREITAS. (1995) Coffee substitute from *Prosopis juliflora* DC. *Pesquisa Agropecuaria Brasileira* 30:121-124.

VIJAYAKUMARI, K., P. SIDDHURAJU AND K. JANARDHANAN. (1997) Effect of domestic processing on the levels of certain antinutrients in *Prosopis chilensis* (Molina) Stunz seeds. *Food Chemistry* 59:367-371.

VILELA, A. E. AND R. A. PALACIOS. (1997) Adaptive features in leaves of South American species of the genus *Prosopis* (Leguminosae: Mimosoideae). *Bulletin of the International Group for the Study of Mimosoideae* 20:62-70

VILLAGRA, G. M. L. AND P. FELKER. (1997) Influence of understory removal, thinning and P fertilization on N_2 fixation in a mature mesquite (*Prosopis glandulosa* var. *glandulosa*) stand. *Journal of Arid Environments* 36:591-610.

VILLAGRA, G. M. L. AND F. M. GALERA. (1992) Soil salinity-sodicity effects on germination, survival and development in four populations of *Prosopis strombulifera* (Lam) Benth (Fabaceae: Mimosoideae). pp. 219-233. In: *Prosopis* Species: Aspects of their Value, Research and Development. (Ed.) R. W. Dutton. CORD, University of Durham, Durham, UK.

VIMAL, O. P. AND P. D. TYAGI. (1986) *Prosopis juliflora*: chemistry and utilization. pp. OVP1-OVP8. In: The Role of *Prosopis* in Wasteland Development. (Ed.) V. J. Patel . Javrajbhai Patel Agroforestry Center, Surendrabag, Gujarat, India.

VIMALA, R., K. SIVAPRAKASAM AND K. SEETHARAMAN. (1993) Effect of plant extracts on the incidence of brinjal wilt. *Madras Agricultural Journal* 80:409-412.

VIRGINIA, R. A., L. M. BAIRD, J. S. L. FAVRE, W. M. JARRELL, B. A. BRYAN AND G. SHEARER. (1984) Nitrogen fixation efficiency, natural 15N abundance and morphology of mesquite (*Prosopis glandulosa*) root nodules. *Plant and Soil* 79:273-284.

VON MAYDELL, H. J. (1986) Trees and Shrubs of the Sahel. GTZ, Eschborn, Germany.

VYARAWALLA, F. AND B. C. JAIN. (1986) Energy from waste through biomass gasification. pp 1-21 In: The Role of *Prosopis* in Wasteland Development. (*Ed.*) V. J. Patel. Javrajghai Patel Agrofoforestry Center, Surendrabag, Gujarat, India.

WALDON, H. B., M. B. JENKINS, R. A. VIRGINIA AND E. E. HARDING. (1989) Characteristics of woodland rhizobial populations from surface and deep-soil environments of the Sonoran Desert. *Applied and Environmental Microbiology* 55:3058-3064.

WALTON, C. (1990) In vitro propagation of leguminous trees of the genera *Prosopis* and *Leucaena*. Professional Training Report. Coventry University, Coventry, UK.

WALTON, T., P. J. C. HARRIS AND C. A. BATCHELOR. (1990) Comparative rooting response of shoot tips from six *Prosopis* species. *Nitrogen Fixing Tree Research Reports* 8:154-155.

WARD, C. R. AND W. HUDLESTON. (1968) Studies of Insects Associated with *Prosopis* in Latin America. Texas Technological Course. Lubbock Entomology Special Report No 68.

WARD, C. R., C. W. O'BRIEN, L. B. O'BRIEN, D. E. FOSTER AND E. W. HUDDLESTON. (1977) Annotated Checklist of New World Insects Associated with *Prosopis* (Mesquite). Technical Bulletin Vol. 1557. United States Department of Agriculture, USA.

WARRAG, M. O. A. (1994) Autotoxicity of mesquite (*Prosopis juliflora*) pericarps on seed germination and seedling growth. *Journal of Arid Environments* 27:79-84.

WEBB, R. (1988) A preliminary investigation into the fodder qualities of some trees in Sudan. International Tree Crops Journal 5:9-17.

WEBERBAUER, A. (1945) El Mundo Vegetal de los Andes Peruanos. Ed. 2. Estacion Experimental Agricola La Molina.

WELDON, D. (1986) Exceptional physical properties of Texas mesquite wood. *Forest Ecology and Management* 16:149-153.

WHITE, F. (1962) Forest and Flora of Northern Rhodesia. Oxford University Press, Oxford, UK.

WHITE, J. W., V. M. BRYANT AND J. G. JONES. (1991) Adulteration testing of southwestern desert honeys. *American Bee Journal* 131:123-131.

WIGGINS, I. AND PORTER, D. (1971) Flora of the Galapagos Islands. Stanford University, Stanford, USA.

WILSON, J., R. C. MUNRO, K. INGLEBY, J. McP. DICK, P. A. MASON, J. JEFWA, P. N. MUTHOKA, A. C. NEWTON AND R. R. B. LEAKEY. (1990) Agroforestry and Mycorrhizal Research for Semi-Arid Lands of East Africa. Institute of Terrestrial Ecology, Penicuik, Scotland, UK.

WINTER, S. (1986) Response of *Prosopis juliflora* seedlings to long days and high levels of CO_2. *Nitrogen Fixing Tree Research Reports* 4:22-23.

WOJTUSIK, T., M. T. BOYD AND P. FELKER. (1994) Effect of different media on vegetative propagation of *Prosopis juliflora* cuttings under solar-powered mist. *Forest Ecology and Management* 67:267-271.

WOJTUSIK, T. AND P. FELKER. (1993) Interspecific graft incompatibility in *Prosopis*. *Forest Ecology and Management* 59:329-340.

WOJTUSIK, T., P. FELKER, E. J. RUSSELL AND M. D. BENGE. (1993) Cloning of erect, thornless, non-browsed nitrogen-fixing trees of Haiti's principal fuelwood species (*Prosopis juliflora*). *Agroforestry Systems* 21:293-300.

WOOD, P. J., A. F. WILLENS AND G. A. WILLENS. (1975) An irrigated plantation project in Abu Dhabi. *Commonwealth Forestry Review* 54:139-146.

WUNDER, W. G. (1966) *Prosopis juliflora* (*P. africana)* in the arid zone of Sudan. Pamphlet of the Forest Research Educaction Project, Forest Department of Sudan No. 26. Forest Department and UNDP, Khartoum, Sudan.

YAO, D. Y., C. A. BATCHELOR, M. J. KOELHER AND P. J. C. HARRIS. (1989) *In vitro* regeneration of *Prospis* species (*P. chilensis*, *P. cineraria*, *P. juliflora*) from nodal explants, *Chinese Journal of Botany* 1:89-97.

YOUSUF, M. AND M. GAUR. (1998) Some noteworthy insect pests of *Prosopis juliflora* from Rajasthan, India. pp. 91-94 In: *Prosopis* Species in the Arid and Semi-Arid Zones of India. (*Eds.*) J. C. Tewari, N. M. Pasiecznik, L. N. Harsh and P. J. C. Harris. *Prosopis* Society of India and the Henry Doubleday Research Association, Coventry, UK.

ZAINAL, A. S., A. M. ABDEL-RAHIM, R. M. ABU-ALI AND S. S. RADWAN. (1988) Antimicrobial substance(s) in the leaf litter of the xerophyte *Propsopis juliflora*. *Zentralblatt Für Mikrobiologie* 143:375-381.

ZECH, W. AND P. E. WEINSTABEL. (1983) Location, state of nutrition and feed value of tree species important in forestry in Upper Volta. *Plant Research and Development* 17:42-60.

ZEVALLOS, P. P. AND O. R. HIGAONNA. (1988) Valor pecuario y apcola de 10 especies forestales de las zonas secas y semisecas de Lambayeque. *Zonas Aridas* 5:31-43.

ZHANG, X. P., R. HARPER, M. KARSISTO AND K. LINDSTROM. (1991) Diversity of *Rhizobium* bacteria isolated from the root-nodules of leguminous trees. *International Journal of Systematic Bacteriology* 41:104-113.

ZIMMERMANN, H. G. (1991) Biological control of mesquite, *Prosopis* spp. (Fabaceae), in South Africa. *Agriculture Ecosystems and Environment* 37:175-186.

ZOLFAGHARI, R. AND M. HARDEN. (1982) Nutritional value of mesquite beans (*Prosopis glandulosa*). pp. K1-K16 In: Mesquite Utilization. (*Ed.*) H. W. Parker. Texas Tech University, Lubbock, Texas, USA.

ZOLFAGHARI, R., M. HARDEN AND L. HUFFMAN. (1986) Some physical and chemical-properties of honey mesquite pod (*Prosopis glandulosa*) and applications in food-products. *Cereal Chemistry* 63:104-108.

ZOLLNER, D. (1986) Sand dune stabilization in central Somalia. *Forest Ecology and Management* 16:223-232.