HDRA
the organic organisation

The biology and non-chemical control of broad-leaved dock (*Rumex obtusifolius* L.) and curled dock (*R. crispus* L.)

W Bond, G Davies, RJ Turner
HDRA, Ryton Organic Gardens, Coventry, CV8, 3LG, UK

Broad-leaved dock
(batter dock, broad dock, broadleaf dock, butter dock, cushy-cows, docken, kettle dock, smair dock)
***Rumex obtusifolius* L.**

Curled dock
(curly dock, dockum)
***Rumex crispus* L.**

Introduction
The docks (*Rumex* spp.) are a group of native plants that occur in a wide range of habitats and soil types and at altitudes up to 2,000 ft in the UK. Their biology and non-chemical control was reviewed previously by Foster (1989). More recently their ecology and non-chemical control was reviewed by Zaller (2004). Only two species are considered of major concern in agriculture, namely broad-leaved dock (*Rumex obtusifolius* L.) and curled dock (*R. crispus* L.) (Holm *et al*., 1977). Curled dock is capable of behaving as an annual, biennial or perennial but plants only persist for several years when regularly cut down and prevented from setting seed (ADAS, 1977). Curled dock has occurred infrequently as a birdseed alien (Hanson & Mason, 1985). Broad-leaved dock is a highly variable perennial species and many forms, varieties and subspecies have been described worldwide (Trimen, 1873; Cavers & Harper, 1964). The docks are currently considered by farmers to be among the most important problem weeds in organic farming systems. However, in a 1993 survey of the most important weeds according to European weed scientists, docks were in the top 15 weeds of only one out of ten of the crop groups under consideration (Schroeder *et al*., 1993).

Three subspecies of broad-leaved dock have been distinguished in the UK and four varieties of curled dock but the variation in the two species is further complicated by hybridisation (Williams, 1971). Intermediate forms of the two species were noted in the British Flora published in 1887 (Bentham & Hooker, 1887). Hybrids between curled dock and broad-leaved dock are quite common (ADAS, 1977), and may occupy whole fields (Harper & Chancellor, 1959). They exhibit a range of intermediate characteristics (Lousley & Kent, 1981) and may be more vigorous than the parents. The hybrids are thought to produce little viable seed (Chancellor, 1956; Cavers & Harper, 1964), although the infertile panicles may still develop and turn red in autumn (Lousley & Kent, 1981). However, the presence of fertile hybrids has been reported and there is evidence that backcrossing has occurred to the extent that some plants of hybrid origin are almost indistinguishable from the parent species (Williams, 1971; Stace, 1997). Both the curled and broad-leaved docks also hybridise with the wood dock (*R. sanguineus*) and the clustered dock (*R. conglomeratus*) when growing in the same area. These hybrids are not thought to be fertile. Hybrids with other docks, such as the water dock (*R. hydrolapathum*), are known but are generally of local occurrence (Lousley & Kent, 1981). In North America, populations of curled dock exhibit considerable genetic variation and this has allowed them to adapt to local conditions (Hume & Cavers, 1982b). Plants from cooler regions are short and compact with large numbers of stomata per unit area, an adaptation to reduce heat loss and optimise CO_2 exchange.

In the UK, broad-leaved dock is a weed host for the potato tuber eelworm, *Ditylenchus destructor* (Holm *et al.*, 1977; Franklin, 1970). Docks also serve as alternate hosts for bean aphis and mangold fly, and encourage subterranean larvae such as those of the swift moths (Morse & Palmer, 1925). *Mantura rustica* is a nationally scarce species of flea beetle associated with the broad-leaved dock (Crofts & Jefferson, 1999). The larvae are leaf miners.

Occurrence

Docks are said to be the most common perennial weed in grassland on dairy farms, especially in young swards (Haggar *et al.*, 1982). A survey of 502 grassland farms in England and Wales found that 40% of farmers thought docks were a problem (Peel & Hopkins, 1980). In other surveys, dock infestations were recorded on 8% of grassland. In a postal survey of dock incidence in UK grasslands, Haggar (1980) found that the highest infestations of docks were in Devon and Sussex. Factors closely associated with the presence of docks were the application of slurry, farmyard manure and nitrogen. Uneven or excessive application of slurry can smother grass and leave bare patches ideal for dock establishment (SAC, 1986). Cutting for silage was also linked with high dock numbers possibly due to the openness of the sward after cutting. In some surveys, docks were common on soils deficient in potassium, and on soils rich in nitrogen (Haggar *et al.*, 1982). However, in other studies increased potassium levels were associated with greater densities in dock populations (Humphreys *et al.*, 1999). Recent studies in the Netherlands concluded that increasing the potassium status did not favour dock development (Van Eekeren *et al.*, 2006). Few docks were found on fields subject to flooding, cutting for hay or grazing by sheep, but studies in the Netherlands suggest that docks have some resistance to flooding. In a survey of 156 organic farmers in Germany, 80% had a problem with docks (Böhm & Finze, 2003). Around 85% of grassland farmers had problems with docks, 20% of them had docks on 30% of the grassland (Böhm & Verschwele, 2004).

Broad-leaved dock is found throughout the British Isles and there does not seem to be any climatic limitation to its distribution. It is less frequent in the north of Scotland but neither the length of growing season nor the winter cold is thought to be responsible. Mature plants can withstand severe cold and drought although seedlings may be killed. Absence from high altitude areas is thought to be due to a lack of disturbed ground at these heights (Cavers & Harper, 1964). Broad-leaved dock is found in widely different plant communities and habitats including woods, arable fields, field margins, short-term leys, permanent pasture, and waste places (Clapham *et al.*, 1987). It is a common garden weed (Copson & Roberts, 1991). An open habitat is needed for seedling establishment but mature plants can survive competition. It is often found around gateways and on trodden ground in pastures. It is the most abundant dock in grassland (ADAS, 1977). In a survey of UK cereal field margins recorded as part of Countryside 2000, broad-leaved dock was one of the most frequent species recorded (Firbank *et al.*, 2002). In a survey of weeds in conventional cereals in central southern England in 1982, broad-leaved dock was found in 4, 2 and

2% of winter wheat, winter barley and spring barley respectively (Chancellor & Froud-Williams, 1984).

Broad-leaved dock is able to grow on a range of soils except the most acid, although, Brenchley (1913) found it only on sandy soils. While abundant on most soils it to some extent avoids chalk (Morse & Palmer, 1925). In flooded soils, the primary lateral roots of broad-leaved docks do not die but the root system extends due to the formation of new laterals (Laan *et al.,* 1989). Large numbers of horizontal laterals and adventitious roots are formed. In addition, broad-leaved dock develops very thick and unbranched downward growing laterals. Greenhouse studies on climate change showed that broad-leaved dock made enhanced growth at elevated CO^2 levels as long as nitrate and water were not limiting (Arp *et al.,* 1998).

Curled dock occurs in arable and meadowland, sand dunes, shingle and in waste places (Clapham *et al.*, 1987; Tansley, 1949). It has been described as the commonest British dock and is one of the five most widely distributed plants in the world (Cavers & Harper, 1964). Curled dock is found throughout Britain but is less frequent in the north according to Harper & Chancellor (1959). Brenchley (1911) characterises it as universally distributed but more a plant of clay, chalk or gravel than light sandy soils. Curled dock is said to have a preference for level, stone-free, fine-textured, poorly-drained soils (Dale *et al.*, 1965). In Norfolk, farmers considered curled dock to be their worst weed and only constant action kept it in check (Brenchley, 1913). Brenchley (1920) described curled dock as being found as often among one crop as any other. It was found in 41% of crops surveyed including cereals, roots, seed crops and legumes. In a study of seedbanks in some arable soils in the English midlands sampled in 1972-3, curled dock seed was recorded in 3% of the fields sampled in Oxfordshire and 34% of those in Warwickshire but never in large numbers (Roberts & Chancellor, 1986). Curled dock seed was poorly represented in the soil seedbank beneath contrasting pasture types (Champness & Morris, 1948). It often dies after flowering and tends to disappear from permanent grass if new seedlings fail to establish (ADAS, 1977). Curled dock was found to increase in a series of spring-sown cereals on both harrowed and herbicide treated plots (Rademacher *et al.,* 1970). Individual plants have the ability to survive in a range of environmental conditions through plasticity and genetic heterogeneity (Hume & Cavers, 1982a), while whole populations have become adapted to different climatic and edaphic conditions through resource allocation and reproductive strategy (Hume & Cavers, 1983a). Variants of curled dock grown under the same conditions have been shown to retain some of their distinct characteristics but other differences became less clear-cut outside the natural habitats (Akeroyd and Briggs, 1983a).

Curled dock has a high tolerance of UV-B radiation (Hübner & Ziegler, 1998). Leaves exposed to smog or ozone develop a red coloration due to the formation of anthocyanin pigments (Koukol & Dugger, 1967). Dock numbers may increase in crops weakened by waterlogging (Popay *et al.*, 1994). Studies in the Netherlands have shown that curled dock is resistant to flooding even at the seedling stage (Voesenek *et al.*, 1993). Older plants can survive 8 weeks of submergence in the dark due to a dormancy strategy characterized by the slower consumption of carbohydrates stored in the taproot (Laan & Blom, 1990). Within a few hours of submergence, the orientation of the leaves becomes more vertical and the petioles lengthen by up to 80% (Voesenek & Blom, 1989). Plants subjected to flooding, were able to adapt to lower light levels by increasing leaf area and developing elongated leaves (Vervuren *et al.*, 1999). In well-drained conditions much of the root growth is concentrated in lower soil layers (Voesenek & Blom, 1987). In response to waterlogging curled dock develops new flooding-resistant roots (Voesenek *et al.*, 1989). The primary lateral roots survive under flooded conditions but the root system becomes extended by the formation of new laterals and adventitious roots (Laan *et al.*, 1989). The primary roots of curled dock were able to recover after aerobic conditions were restored due to the high porosity of the roots enabling internal oxygen diffusion to take place under anaerobic conditions (Laan *et al.*, 1990; 1991).

Biology

Broad-leaved dock flowers from June to October but flowering is delayed by early shoot removal (Clapham *et al.*, 1987). Seedlings of broad-leaved dock generally do not flower in the first year (Chancellor, 1956; Harper & Chancellor, 1959). Those plants that do flower in their seedling year produce an inflorescence from July onwards. A large mature broad-leaved dock can produce up to 60,000 ripe seeds (achenes) per year (Cavers & Harper 1964; Foster 1989). The seeds are shed continuously from late summer through to winter, and can germinate in any month of the year if conditions are favourable.

The seeds are viable from an early stage of development (ADAS, 1977). In grassland, dock seeds harvested at weekly intervals from mid May to late June exhibited low germinabilty at the time of haymaking (Pekrun *et al.,* 2002). As the plants matured germinability increased. Seeds of broad-leaved dock continued to increase in dry weight and percentage germination even after inflorescences were cut from the plant (Weaver & Cavers, 1980). A few viable seeds developed from flower stems cut just 6 days after flowering. Seeds from inflorescences cut 14 days after flowering and left in the field to mature had germination levels little different from those left on the plant to ripen. Grazing by the chrysomelid beetle, *Gastrophysa viridula,* on broad-leaved dock reduces seed numbers and seed weight. Seed size does not influence percent germination but the rate of germination decreases with increasing seed size (Cideciyan & Malloch, 1982). Initial seedling growth is slower from smaller seeds but there is no noticeable difference at later growth stages.

Curled dock generally flowers earlier than the broad-leaved dock. Inflorescences are first initiated in April or early May and flowering takes place from June to October (NAAS, 1949). The flowers are usually wind pollinated but visits by bumblebees have been observed (Akeroyd & Briggs, 1983a; Grime *et al.*, 1988). It is reported that 25 to 100% of plants are self-fertile. There is some evidence that both outbreeding and inbreeding may occur in curled dock (Akeroyd & Briggs, 1983b). Plants in open habitats generally flower and set seed in the first year, but in densely crowded populations flowering may be delayed to year 2 or even year 3. Under good growing conditions a seedling may flower just 9 weeks after emergence. Sometimes flowers are produced twice in a year, in May and again after the first seeds are shed. Unlike in Britain and the rest of Europe, plants of curled dock in most North American populations require overwintering before flowering can occur (Hume & Cavers, 1983b). Prevention of flowering by mowing may encourage perennation in curled dock. In short days (8 hrs) curled dock plants were short and took 70 days to flower, in long days (15 hrs) they were tall and flowered after 35 days (Holm *et al.*, 1977). Inflorescences that develop in the autumn on plants that have been cut down earlier in the year are therefore shorter due to daylength as well as the growth check. Some curled dock plants die after setting seed others overwinter as rosettes that develop new lateral shoots in spring from axillary buds on the root crown.

In curled dock, the upper part of a flower panicle may be in bud while the lower is forming fruit. The seeds from the top of a panicle are lighter and have thinner seed coats than seeds from lower down. When a proportion of the flowers were removed from a flowering stem at anthesis, the weights of the individual seeds produced were greater and the seed coats thicker than those from untreated plants. Seeds with thicker coats did not germinate as readily as those with thinner coats (Maun & Cavers, 1971b). Defoliation of the flower panicle at anthesis had little effect on seed numbers but reduced total seed weight per panicle and the proportion of larger seeds. Seeds from defoliated plants had thinner seed coats and absorbed water readily. These seeds germinated more rapidly and had less precise germination requirements than seeds from untreated plants (Maun & Cavers, 1971a). The percentage germination is lower for smaller seeds but seed size had no effect on seedlings growth (Cideciyan & Malloch, 1982). The results could have implications for seeds produced on plants whose leaves or flowers are consumed by insects or partially destroyed by disease. Various figures are given for seed numbers per plant from less than 100 to over 40,000 seeds per year. Stevens (1932) recorded 29,500 seeds per plant for curled dock with other studies giving 3,700 seeds per plant (Stevens, 1957). The average seed number per plant in ruderal situations is given as 10,288 (Pawlowski *et al.*, 1967).

Curled dock plants cut down in flower may not ripen seed, but plants in which the seeds have begun to form and are at the milk stage will form viable seeds. Weaver & Cavers (1980) found that seeds of curled dock continued to increase in dry weight and percentage germination even after the inflorescences were cut from the plant. A few viable seeds developed from flower stems cut just 6 days after flowering. Seeds from inflorescences cut 14 days after flowering and left in the field to mature had germination levels little different from those left on the plant to ripen. Maun (1974) found that cut panicles that were dried immediately did not produce viable seed but panicles placed among mown herbage or buried in soil produced viable seeds even when cut 2-6 days after flowering began. Seeds reached physiological maturity at 18 days from anthesis, around the period of milk ripeness and gave the highest germination from this point on.

There have been wide variations between the findings of different researchers in the germination requirements of dock seed. Cavers & Harper (1966) attempted to clarify the situation by carrying out germination tests on curled and broad-leaved dock seed from different sources. They found no consistent differences in response between the two species. The seeds mostly required light or alternating temperatures for germination. There were, however, differences in the germination response of seeds from different sites, from different plants within a site, from different panicles on the same plant and from different positions within the same panicle. There was no consistent difference in germination due to the maturity of the seed when harvested. Some seeds were heavier and had different requirements for germination than lighter seeds. The heavier seeds were often the last to be shed. After shedding, heavy seeds were likely to remain dormant in soil for a longer period than small, light seeds. When the heavier seeds germinated they gave rise to larger more vigorous seedlings.

The variability in the responses of seeds has contributed to the success of docks as weeds. Recent studies on the germination of broad-leaved dock seed have demonstrated a link between the germinability of seed at the time of dispersal and the date of flowering of the parent plant (Honek & Martinková, 2002). Even when the original shoots were cut down this maternal effect was active in the seeds produced at the later flowering. Thee germination characteristics were correlated with the date when plants would have flowered originally. Laboratory studies suggest that diurnal fluctuations in temperature with an amplitude of 2^{o}C promote germination in broad-leaved dock seeds (Thompson *et al.*, 1977).

Freshly matured curled dock seeds are non-dormant and buried seeds exposed to natural seasonal temperatures for 22 months remained non-dormant (Baskin & Baskin, 1985). Seeds exhumed at monthly intervals gave 80-100% germination in a range of alternating temperature regimes. Seeds collected from individual plants and stored under different conditions of temperature and humidity for 6 months to 5 years all germinated under alternating temperatures and light (Cavers, 1974). In darkness at constant or alternating temperatures, however, there were significant interplant differences in the number of seeds that germinated following different storage conditions. Mature seed of curled dock germinated within a month of shedding under conditions of fluctuating temperature and illumination (Gill, 1938). Fresh seeds of broad-leaved dock also appeared to require a short after-ripening period of up to a month (Benvenuti *et al*., 2001). The first seeds ripened in a season are ready to produce seedlings by July.

In a preliminary study (HDRA unpublished), the viability of seed in samples from naturally occurring dock hybrids in the field ranged from 3 to 89% with an average of 41%. The hybrids were identified by the morphological appearance of the plants and their seed integuments. The variation in seed viability may reflect the level of backcrossing that had taken place in the parent plants.

In common with other species colonizing bare ground, seeds of curled and broad-leaved dock germinate in the light or shade but not in darkness (Grime & Jarvis, 1976). Germination was inhibited under a leafy canopy compared with under diffuse natural light (Taylorson & Borthwick, 1969). Light filtered through leaves is much richer in far-red light which is known to inhibit germination (Górski *et al*., 1977). When seeds were put to germinate under a leaf canopy or diffuse white light there was no germination under the canopy and 87-93% in the diffuse light. In the USA, freshly shed curled dock seed germinated in the light at alternating temperatures but did not germinate in the dark. Milberg (1997) found that broad-leaved dock seed germinated best in full light or following a 15 second light flash. In darkness or with just a 1 second flash of light, germination was poor. The seed appeared to require light levels above a certain threshold to stimulate germination. The results suggest that cultivation in the light would produce a concentrated flush of emergence while dark cultivation would result in only sporadic seedling emergence. Maun & Cavers (1971a) found that curled dock seed germination in the dark at a constant temperature was poor but seeds germinated rapidly once transferred to the light with alternating temperatures. In broad-leaved dock, under alternating temperatures, increasing the amplitude of temperature fluctuations increased germination in both the light and dark up to an amplitude of 25^{o}C (Thompson & Whatley, 1983). Illumination with red light will induce germination at constant temperature, illumination with far red light will reduce germination in alternating temperatures (Taylorson & Hendricks, 1972). These treatments have contrasting effects on the phytochrome levels that control seed germination.

It was established that at a constant 25°C, 15 minutes illumination with red light was the minimum required to stimulate the germination of fully-imbibed broad-leaved dock seeds (Vicente *et al*., 1962). To determine the period during water uptake when light was most effective in stimulating seed germination, seeds were put at various constant temperatures between 18 and 30°C and illuminated for 15 minutes at varying times after the start of water uptake. Germination increased with the length of imbibition but the period varied with temperature. Peak germination was achieved when seeds were illuminated after 96, 48, 24 and 20 hours at 18, 21, 24 and 25°C respectively. At 27°C peak germination followed illumination after 72 hours and at 30°C germination was low, showing that higher temperatures are less good for germination. The stimulation of germination was reversible by exposure to far red light for 30 minutes, but this became less effective with time and had no effect after 36 hours. In curled dock, the germination response to irradiation with red light was altered by the imbibition temperature of the seed (Taylorson & Dinola, 1990). Maximum germination followed imbibition at 15°C, while the minimum followed imbibition at 32.5°C. Germination levels fell rapidly following imbibition above 17.5°C.

Broad-leaved dock seed with the seed coat cut or damaged germinated in the dark and was not affected by far-red light (Noronha *et al*., 1971). Scarification of curled dock seed markedly improved the response to light, moist-chilling and temperature shifts (Hemmat *et al*., 1985). Removal of the entire seedcoat induced 69% germination in the dark. When scarified seed of curled dock was imbibed and held at 25°C or above for 3-7 days, a secondary dormancy was imposed which could only be broken by chilling (Deunff & Chaussat, 1968). Pre-chilling of seed removed the requirement for alternating temperatures, and germination occurred at constant temperatures in the light (Vincent & Roberts, 1977). Pre-chilled seed would also germinate at alternating and certain constant temperatures in the absence of light if nitrate was present. Germination in the light or in darkness occurred at constant temperatures following stratification in the light at temperatures between 1.5 and 15.0°C (Totterdell & Roberts, 1979). However, too long a period of stratification at the higher temperatures re-imposed dormancy. Stratification in the light fulfilled subsequent light requirements but dark stratification did not (Baskin & Baskin, 1978). Therefore seed stratified on the soil surface before burial would probably germinate in situ while seed buried and then stratified would not germinate until the soil was disturbed. It appears that losses from the seedbank are possible in the absence of light, leading to a decline in seed numbers even in undisturbed soil.

In Petri-dish tests a single temperature fluctuation from 20 to 30°C in darkness induced 30 to 40% germination of broad-leaved dock (Van Assche & Van Nerum, 1997). A minimum shift of 5°C was needed but a 15°C change was optimal, and rapid warming gave greater germination. There was some stimulation after a period of just 15 minutes at the higher temperature but 1 hour was better. Although a single shift works, a cycle of three alternations gives the best result. Warming alone will also stimulate germination. The exposure of imbibed seeds to temperatures of 40°C for 1 hour or 35°C for 10 min stimulated the germination of broad-leaved dock seed

(Vicente *et al*., 1968; Takaki *et al*., 1981; Hand *et al*., 1982). Seeds put to germinate at 22°C in darkness or continuous white light gave 30% germination in the dark and 90% in the light (Tretyn *et al.*, 1988). Meneghini *et al*., (1968) found that broad-leaved dock seed germinated in the dark if imbibed and subjected to a higher temperature (35-44°C) than the optimum germination temperature of 25°C for 2 hr or lower temperatures (4-15°C) for 32 hr. Exposure to red light for 10 min would also stimulate germination (Takaki *et al*., 1981; Hand *et al*., 1982). The stimulating effect of high temperature and red light can be reversed by irradiation with far-red light immediately after treatment. Taylorson & Hendricks (1973) found that imbibed seeds of curled dock held in darkness at temperatures above 5°C developed secondary dormancy and became increasingly less responsive to red light the higher the temperature and the longer the exposure. The dormancy could be overcome by a prolonged period at a low temperature or a brief high temperature shift. In laboratory studies, increasing the amplitude of the fluctuation in day/night temperatures also increased germination levels (Benvenuti *et al*., 2001). Germination was increased following a period of dry storage (Grime *et al.*, 1988). In laboratory tests with dry-stored curled dock seed sown on moist paper or soil in the light there was around 60% germination at a constant 18-20°C (Cross, 1930-33). At alternating temperatures of 20 / 30°C or 8 / 20 / 30°C there was over 80% germination.

Both species germinate readily on the soil surface (Mohler, 1993). In pot tests, the percentage germination of curled and broad-leaved dock seed was reduced if the seed was buried just 10 mm deep in soil (Weaver & Cavers, 1979a). With curled dock, seedling emergence was significantly greater when seed was left on the soil surface rather than buried (Boyd & Van Acker, 2003). Nineteen days after sowing, emergence was 48, 21, 10 and 5% for seeds sown at depths of 0, 10-20, 30-40, and 60-70 mm respectively. This suggests that seeds may be better left on the soil surface after shedding to encourage germination and predation, but germination will only occur if sufficient moisture is present. Burial of curled dock seed beneath 6 mm of sand reduced germination levels or greatly prolonged the period of seedling emergence. This is cited as an example of enforced dormancy (Maun & Cavers, 1971b). Benvenuti *et al*. (2001) found 80 mm to be the limiting depth beyond which no germination occurred. Recovery of the seed demonstrated that this lack of emergence was not due to fatal germination. In a loam soil more than 90% of dock seedlings recorded had emerged from the top 15 mm of soil in the field (Unpublished results). The maximum depth of emergence was 25 mm.

In broad-leaved dock seed buried 25 mm deep in soil cultivated at monthly intervals, seedlings emergence occurred throughout the year with a peak flush in April that tailed off through to July/August (Chancellor, 1979). Roberts & Neilson (1980) also found that odd seedlings emerged throughout the year from seeds buried at 75 mm deep in soil that was cultivated three times per year. Peaks of emergence occurred in April and from July to October. Seeds mixed into soil in February from seed heads that had stood through the winter began to emerge from March (Unpublished data). The soil was stirred at monthly intervals, and emergence was greatest in April/May and July/August then tailed off in September/October. In this limited study with a clay loam soil, depth of seedling emergence ranged from 0 to 70 mm. In the peak periods of emergence, seedlings emerged from deeper in the soil than earlier or later in the year.

In curled dock germination was mainly from March to April and from July to August (Chancellor, 1970). Roberts & Neilson (1980) found that emergence of curled dock occurred mostly from March to September but with odd seedlings emerging throughout the year. In common with many weeds, flushes of curled dock seedlings emerge soon after periods of heavy summer rainfall. Under natural conditions seeds near the soil surface are subjected to periods of wetting and drying, alternating temperatures and light which primes them to germinate rapidly after substantial rainfall (Vincent & Cavers, 1978). Seeds buried deeper in the soil are not subjected to this combination of factors and remain dormant.

Dock seedlings have a low competitive ability and find it difficult to become established in closed vegetation. Seeds of curled and broad-leaved dock sown in December in different habitats showed flushes of emergence in March-April and July-August but few of the seedlings survived more than a few months (Cavers and Harper, 1967a). In pot studies, broad-leaved dock sown at the same time as perennial ryegrass (*Lolium perenne*) suffered competition from the grass (Keary & Hatcher, 2004). When the dock seed was sown 21 or 42 days in advance of the grass the dock seedlings were able to establish a leaf canopy. In other pot experiments twice as many curled dock seedlings became established in a clay than in a silty-loam soil (Harper & Chancellor, 1959). Seedling establishment was poor in waterlogged soils and in the presence of ryegrass. Seedlings often emerge in the open on cultivated ground or in pasture where the turf has become damaged. When curled dock seed was sown in field plots where the existing vegetation had been dug in to represent disturbed patches, seed sowing density had no effect on emergence (Weaver & Cavers, 1979a). More seedlings survived over-winter where a larger area of soil was disturbed perhaps because encroachment by the existing vegetation was less complete.

Dock seedlings can emerge in dense patches but the level of seedling mortality increases with seedling numbers (Chancellor, 1956). Seedlings emerge at different times through the year but time of emergence has little effect on survival (Pino *et al.*, 1997). Survivorship has more to do with seedling age and size. Mortality is greater in small, young seedlings. Unpublished preliminary studies suggest that the microbiological and nutrient status of the soil can have a significant effect on dock seedling vigour. In Canada, it was found that fewer than 10% of curled dock seedlings survived into the following year (Weaver & Cavers, 1979b). Young transplants survived for 12 months in the same habitats and some plants of curled dock flowered but many suffered leaf losses on transplanting and subsequent growth was poor. Transplants of broad-leaved dock actively competed with other herbage plants and were better adapted to long term survival than curled dock. However, less than 2% of month old seedlings of broad-leaved dock transplanted into an old reseeded grassland survived for up to 4 years (Hongo, 1989b). In newly sown grassland, dock seedling survival was enhanced by frequent cutting of the sward (Hongo, 1989a). Broad-leaved dock is better adapted to survival in grassland than curled dock but the latter has a better capacity to multiply in unstable arable habitats.

Once a broad-leaved dock plant has developed a deep taproot it has an advantage over shallow rooted crops and grasses and becomes difficult to eradicate. Established plants can withstand trampling and mowing. New shoots are sent up soon after decapitation and flowering is merely delayed until autumn (ADAS, 1977). Repeated regeneration may lead to the development of large clumps. Broad-leaved dock overwinters as a rosette with small dark leaves and a stout rootstock. In spring new leaves develop rapidly and there is a vegetative phase of elongation. A vertical underground stem is developed around 5 cm long. The roots may extend to a depth of 1 to 1.5 m on some soils. The flowering stem arises from the apex of a shoot and may grow to 120 cm tall and is well branched. Further shoots may originate from adventitious buds on the underground stem, particularly after damage. Flowers are initiated in early May and the first flowering occurs in late-May or June and the second in August-September according to Cavers & Harper (1964). However, the NAAS Advisory leaflet (1949) gives the flowering period as just August to September.

Individual plants of broad-leaved dock, especially in pastures, can be very long-lived forming compound crowns with multiple taproots. Secondary taproot production occurs in the second flowering year when the stem system begins to branch (Pino *et al*., 1995). After three years, the taproots increase in size and the underground organs begin to fragment. Older plants become heavily divided and secondary taproots turn into the main root system which then produces further secondary taproots. Eventually a dense population from a single clone will occupy a large area. Clonal growth is the main method of regeneration in dense vegetation where seedling establishment is unlikely to occur. When grassland is ploughed, seedling recruitment and re-establishment from fragments become more important in the regeneration of the dock population.

There is some confusion about the ability of broad-leaved dock to regenerate from underground organs. The vertical underground stem may reach 5 cm in length and the crown is presumably kept at ground level by root contraction (Cavers & Harper, 1964). The roots beneath this are large fleshy and fanged. Several authors claim that regeneration is possible from any part of the underground organs even if cut into short pieces (Hunt & Harkess, 1968). However, detailed studies have also shown that only fragments from above the root collar are able to produce new plants (Roberts & Hughes, 1939; Pino *et al*., 1995). In pot tests with pieces of broad-leaved dock ‘root’, no regrowth occurred from pieces taken from 9-15 cm depth. It was reported that this was because buds did not occur on dock ‘root’ tissue below 9 cm deep (Dierauer, 1993). Detached portions of the true root are said not to grow into new plants (MAFF, 1956) but Hudson (1955) obtained regeneration from a small percentage of true root segments taken in March. In general though, true root cuttings did not regrow and it may be that a small portion of stem tissue was present on the few roots that did regenerate. It is ‘commonly agreed’ that only the upper 7.5 cm of the underground organs of broad-leaved dock will regenerate and this occurs more readily early in the season (Holme *et al*., 1977). However, many farmers would disagree, and shoot regeneration has been noted on the lateral root of a decapitated taproot (personal observation). It takes around 50 days from emergence for a seedling to develop a rootstock that will regenerate if the seedling is decapitated (SAC, 1986; Monaco & Cumbo, 1972). It has also been observed that the flower stems of broad-leaved dock that have been trampled down into contact with the ground can form new plants at the leaf axils (personal observation).

Most authors agree that curled dock does not regenerate vegetatively as extensively as broad-leaved dock but again there is much confusion on this topic. A thick fleshy underground stem 3-4 cm long surmounts the vertical taproot. Root contraction keeps the crown of the plant at or beneath the soil surface. Regrowth of curled dock from the rosette stage begins very early in spring with the first warm weather. According to MAFF (1956), detached portions of the true root do not regrow. It is 'generally agreed' that only the upper 4.0 cm of the underground organs of curled dock will regenerate and this occurs more readily early in the season (Holme *et al*., 1977). Hunt and Harkess (1968) state that curled dock only regenerates from the top 2.5 cm or so of root. However, Chancellor (1956) found that curled dock regenerated from 1 cm segments taken from 12.5 cm below soil surface. Seedlings take around 40 days from emergence to develop a rootstock that will regenerate if a seedling is decapitated (Monaco & Cumbo, 1972).

Persistence and Spread

Estimates put dock seed numbers in soil at five million seeds per acre in the top 15 cm of soil (Hunt & Harkess, 1968). The seeds are said to be capable of surviving in the soil for 50-60 years (Healy, 1953). Seeds of both curled and broad-leaved dock contain high concentrations of *Ortho*-dihydrophenol (Hendry *et al*., 1994). The chemical is thought to inhibit microbial decomposition of the seeds as well as defending them against herbivory. In Duvel's buried seed experiments, 3-5% of broad-leaved dock seed survived after 39 years burial in uncultivated soil below 55 cm. Earlier in the experiment, after 20 years burial at 10, 55 and 105 cm deep, over 80% of the seeds were able to germinate (Toole & Browne, 1946; Goss, 1924). Seeds in dry storage remain viable for 8 years (Brenchley, 1918).

Curled dock seed that had been buried 25 cm deep in soil for 5 years retained over 80% viability (Kjaer, 1940). Goss (1924) recorded levels of germination of 9, 24 and 14% respectively in seed buried in soil for 20 years at 20, 55 and 105 cm deep. In Duvel's seed burial experiment 12% of curled dock seeds buried in soil at 105 cm survived after 30 years and 6% after 39 years (Toole & Browne, 1946). In Beal's seed burial experiment curled dock seed remained viable after 50 years burial in soil at 50 cm deep (Crocker, 1938). Curled dock was one of only three species with seeds that survived after 70 years burial in the experiment (Darlington & Steinbauer, 1961). Two percent of the seeds remained viable after 80 years but none survived 90 or 100 years burial (Kivilaan & Bandurski, 1981). Seed buried in mineral soil at 13, 26 or 39 cm depth and left undisturbed retained 30, 26 and 0% viability respectively after 20 years (Lewis, 1973). Seed buried in a peat soil at 26 cm for 20 years retained 13% viability. In studies with seeds buried at 2.5, 10.0 or 17.8 cm deep in soils with different water tables, seeds of curled dock did not deteriorate as quickly as those of other species (Lewis, 1961). Most seeds survived 1 month of burial but germination levels were somewhat less after a further month. Waterlogging appeared to induce dormancy and prevent sprouting in situ. Dock seeds buried in the soil, can germinate rapidly following soil disturbance if conditions are favourable (Roberts & Totterdell, 1981).

There is no obvious natural seed dispersal mechanism but the seeds are said to be light enough to be blown by the wind (Cavers & Harper, 1964). Spines on the perianth segments may also facilitate distribution on clothing and in animal fur. Nevertheless, dock seedlings often occur in patches around the parent plant. In the USA, viable dock seeds have been found in irrigation water taken from open waterways (Shull, 1962; Kelley & Bruns, 1975; Wilson, 1980). Seeds of both curled and broad-leaved dock have been shown to float for up to 2 days in water (Cavers & Harper, 1967b). The winged integuments around the seeds help to keep them floating. Seeds of the maritime form of curled dock will continue to float for several months. Most seeds of curled dock decomposed after 9 months submergence in water (Bruns, 1965). Around 77% were still viable after 6 months and a few seeds remained firm and possibly viable for 36 months.

Docks have been introduced onto clean land as impurities during the sowing of cereals or pastures (Long, 1938; MAFF, 1956). The incidence of dock seeds in samples of wheat, barley, oats and rye tested by the Official Seed Testing Station from 1961 to 1968 was 2, 2, 3-8 and 2-10% of samples respectively (Tonkin, 1968). Curled dock seed was by far the commonest contaminant, being found in around 1% of wheat and barley seed samples tested by the Official Seed Testing Station each year between 1961 and 1968. In oats the frequency was 2% and in rye between 0.4 and 5.0% of samples contained curled dock seed. In cereal seed sampled in the period 1978 to 1981, curled dock seed was found in up to 5% of wheat and up to 4% of barley samples tested (Tonkin, 1982). At the Official Seed Testing Station for Scotland the incidence of curled dock and other weed seeds in certified and pre-certified seed 1996/97 showed that seed of curled dock was present in 3.5% of pre-certified samples but was absent from certified seed (Don, 1997). Most of the contaminated samples contained just a few seeds but the highest figures for dock seeds in an 8 oz sample were 131 seeds in wheat, 157 in barley and 69 seeds in oats. In a survey of cereal seed drilled in 1970 on UK farms, curled dock seed was found in 15% of samples from home saved seed but none in merchants' seed (Tonkin & Phillipson, 1973). Broad-leaved dock seed was found in 10% of samples from home saved seed with none found in the merchants seed. The results emphasise the need for cleaning and testing of home saved seed before use. Curled dock seed was shown to survive storage under granary conditions for up to 4 years (Lewis, 1958).

Long (1938) commented that curled dock was much commoner than the broad-leaved dock in areas where clover seed was produced, and that its seeds were likely to be found in samples of English clover seed. In 1960/1 and 1963/64, it was common in samples of both English and New Zealand red clover (MacKay, 1964). In seed samples tested by the official seed testing station in 1960-61, curled dock seeds were found in up to 8% of grass seed samples of UK origin and up to 16% of Scandinavian origin (Gooch, 1963). Up to 22% of red and up to 17% of white clover seed samples contained curled dock seed. In general, the frequencies were lower than those recorded in 1951-52, perhaps due to greater herbicide use. Dock seed was an important contaminant in up to 18% of forage, root and vegetable brassica seed, 4% of leek and 3% of carrot seed samples tested. Curled dock seed was also likely to be found in seed of rye-grass, cock's-foot and Timothy (ADAS, 1977). The level of dock seed contamination of herbage seed samples in 1956 from a range of countries suggests that in the past docks with varied genetic backgrounds are likely to have been introduced into the UK (Wellington, 1959). The contamination of some grass and clover seed samples in 1956 was little better than in 1922-23 despite improvements in seed cleaning.

Dock seed is likely to be shed and spread during cereal harvesting both in the cropped area and further afield. It can be carried on farm machinery and in the straw as well as among the harvested grain. Curled dock seed that had been combine harvested germinated 4 to 24% more than hand harvested seed (Currie & Peeper, 1988). This was probably due to scarification of the seed coat during mechanical harvesting. Scarified seed responded more readily to germination enhancing stimuli such as moist chilling treatments than intact seed (Hemmat *et al*., 1985).

In a weedy alfalfa crop (*Medicago sativa* L.) much of the dock's seed was removed from the field as ripening seed heads bailed with the crop (Pino *et al*., 1993). Haggar *et al*. (1982) thought one cause of dock build up was the feeding of contaminated hay and concentrate feeds to cattle followed by the application of their infested manure to the fields. Dock seeds are able to pass through the digestive tract of cattle unharmed (Hance & Holly, 1989). Viable seeds have been found in cattle droppings and are said to remain alive for at least 3 weeks in composted dung. A study in the USA found significant numbers of apparently viable weed seeds including docks in manure samples from both heifer and dairy herds (Pleasant & Schlather, 1994). In other studies, curled dock seeds gave 58% germination after 47 hours digestion by cattle and 3% germination if then stored for 3 months in the manure (Zimdahl, 1993). The seeds survived 1 month of anaerobic fermentation at 400 mm depth in manure but not at 1800 mm (Simpson & Jefferson, 1996). Dock seeds were destroyed when fed to chickens (Holm *et al*., 1977). However, while the viability of curled dock seeds consumed by the chickens was destroyed, dropped seeds could still contaminate the poultry manure (Copper *et al*., 1960). Dock seedlings have been raised from the droppings of other birds (Salisbury, 1961). In laboratory tests, only low numbers of dock seeds were ingested by earthworms but intact and viable seeds were found in worm casts (McRill, 1974). While not a very effective method of dispersal it may provide a site for the establishment of seedlings in a grass sward.

Trials have shown that dock seeds can survive long periods of immersion in slurry. Germination levels of 10% after 16 weeks at 20 ^{o}C and 26% after 24 weeks at 8-10 ^{o}C have been reported (UKMANI, 1974). Immersion of broad-leaved dock seed for 6 weeks in untreated cattle slurry had little effect on percentage germination at any temperature. The germination decreased to a low level in aerated slurry and in slurry fermented for methane production, viability had ceased after 4 weeks (Besson *et al*., 1986). The effect was much greater in untreated pig slurry where viability was low after 6 weeks at 4 ^{o}C and was nil after 4 weeks at 14 ^{o}C. Dock seeds were killed after 1 week in aerated pig slurry.

The viability of mature dock seeds was reduced in silage particularly where 0.5% formic acid was added to the silage to aid fermentation (Masuda *et al*., 1984). Broad-leaved dock seeds ensiled in grass silages of different dry matter percentages showed a decline in vitality with time (Van Eekeren *et al*., 2006). Seed viability was lost after 6 weeks in silage with a dry matter of 23% and after 8 weeks when the dry matter content was 34%. At 60% dry matter, 30% of seeds were still viable after 8 weeks ensilage.

Studies on the effect of temperature on the viability of imbibed weed seeds suggest that seeds of broad-leaved dock require relatively high temperatures to destroy viability (Thompson *et al*., 1997). Temperatures up to 56^{o}C for 16 days did not affect subsequent germination. This is around the temperature at which sewage sludge may be maintained to avoid killing beneficial micro-organisms. Dock seeds held at 75 or

100°C for 16 days were killed. A few minutes exposure to a temperature of 83°C was sufficient to prevent dock seed germination.

Management

There are some who would argue that docks are not true weeds of grassland because they contribute to the herbage and hence do not need to be controlled. They may also contribute trace elements to a grazing animals diet. The leaves of curled dock, for example, contain an unusually high amount of zinc (Karlsson, 1952). Studies of the nutritive value of a range of grassland species indicated that broad-leaved dock was relatively high in P and K levels in the leaves, and particularly high in Mg (Wilman & Riley, 1993). There are potential advantages in enhancing the concentration of important elements in the diet of livestock through the presence of dicotyledonous weeds (Wilman & Derrick, 1994). However, curled dock has a relatively high content of oxalic acid that can affect dietary calcium bioavailability (Guil *et al.,* 1996). In addition tissue analysis shows it is low in calcium. The high oxalic acid to calcium ratio, with a mean value of 32, could exacerbate the adverse impact on calcium nutrition.

In the USA, studies of the forage quality of curled dock showed that at the early vegetative stages it had a comparable quality to cultivated forages (Bosworth *et al*., 1985; Marten *et al*., 1987). Its value as forage and the palatability to grazing lambs rapidly decreased as the plants matured. In feeding studies with sheep the voluntary intake of dried broad-leaf dock was high and it was readily broken down during maceration (Wilman *et al.,* 1997). The rate of intake of the fresh leaves was low, particularly when chopped, probably because of the taste or smell (Derrick *et al.,* 1993). When 10% broad-leaved dock leaves were included in the Lucerne/grass diet of stall fed cattle, the animals suffered no bloat (Waghorn & Jones, 1989). Cattle fed on herbage without the dock added did suffer bloat. Tannins in the dock leaves precipitate out soluble protein in the rumen liquor. Omrod (1966) considered that in grassland even a severe dock infestation was likely to occupy less than 5% of the pasture. Nevertheless, the presence of broad-leaved dock in grassland at densities of 5 to 10 docks per m^2 reduced the weight of harvested grass by 30%, although the total weight of herbage remained constant (Oswald & Haggar, 1983). It was estimated that a 20-30% ground cover of docks would result in a 20% reduction in grass growth.

In a study of changes in the botanical composition of grassland fields during the organic conversion period, docks appeared to increase in young swards to a plateau of 40% of fields in which docks were visible. However, the docks were only becoming a problem in 20% of them. About 10% of swards had an actual dock problem after 5 years (Haggar & Padel, 1996). The number of long-term pastures in which docks were a problem fell from 20% at the start of conversion to 5% by year 4. In a survey of the impact of sward management practices, dock density increased during conversion on fields cut for silage but decreased on grazed fields. A simple mathematical model to study the economics of controlling broad-leaved dock in grassland has been constructed based on data from several sources (Doyle *et al*., 1984). The model was designed for determining the merits of herbicide use but with further research input it might provide some insight into the economics of other control strategies.

Broad-leaved dock was said to be avoided by cattle, sheep, horses and rabbits but was apparently eaten readily by deer (Cavers & Harper, 1964). However, Courtney & Johnston (1978) found that in grassland grazed intensively by dairy cattle the consumption of broad-leaved dock was the same as that of the grass, and that the dock had comparable digestibility. Docks also made a substantial contribution to the total herbage under a system of cutting for conservation silage, and were acceptable to stock (Courtney, 1972). Sheep are more selective grazers than cattle but horses are the most fastidious (Haggar *et al.*, 1982). Horses should therefore graze with sheep or cattle to prevent a build up of docks. It has been suggested that sheep are used to graze off seedling docks in the autumn and mature docks in March–May when they are more palatable. Sheep will eat young dock plants if grazed tightly and will take out the crowns but care is needed to avoid damage to the pasture. Cattle will graze young docks with less risk of overgrazing and if grazed at intervals of less than 3 weeks the docks are kept in check. Unlike cattle and sheep, horses tend to confine their droppings to one area of a field and this can lead to ingress by docks (Wells, 1985). However, Gibson (1996) says that docks are absent from latrine areas but are often associated with areas of disturbance near shelters or where supplementary feed is given. In Germany, grazing pasture with small ruminants reduced dock populations within 2 years (Böhm & Finze, 2003). Grazing by goats in particular leads to a significant decrease in dock density (Finze & Böhm, 2004). Sheep reduced the docks by 42% and goats reduced them by 71%. Where the pasture was grazed by cattle the population increased. The increase was greater with strip grazing than with rotational grazing. Nuoffer (1993) found that goats were selective in grazing curled dock in field beans and potatoes. It is known that different breeds of livestock vary in their grazing or browsing preferences and abilities and this may need to be taken into account for improved dock control (Soil Association, 2002). Pigs grazing on grassland may not eat the dock roots but will uproot them (Short, 2005).

A newly sown ley is vulnerable to dock infestations from seeds in the seedbank being very slow to develop a dense sward (Hopkins & Bowling, 1998). Initially the dock seedling are sensitive to competition from the grass and increasing the sowing rate of perennial ryegrass can have a marked effect on dock development. In resown grass/clover infested with broad-leaved dock seedlings, cutting reduced seedling numbers (Van Eekeren *et al.*, 2006). Increasing the cutting frequency from every 6 weeks to every 2 weeks reduced root biomass but did not increase seedling losses over a 25-week period. Once out of the seedling stage, docks growing in grass are resistant both to grazing and cutting, and to competition from the grass (ADAS, 1977). No system of mowing is effective (MAFF, 1956). Broad-leaved dock seedlings were favoured when swards were cut frequently whereas mature docks grew better in grass cut infrequently (Hughes *et al.*, 1993). Frequent cutting encouraged regeneration of taproots and branching of the shoots, increasing the potential for future growth. In trials, the cutting height, cutting frequency and fertilisation regime were all found to affect docks to some extent (Hopkins & Johnson, 2002; Hopkins, 1999). The results may assist in containing an infestation, but none of the treatments presented a possible method for controlling docks fully. Cutting needs to be low enough to take off all the leaves and frequent enough to prevent any regrowth flowering but timing depends on pasture management. Cutting grass shorter may give the docks an advantage. Courtney (1986) reported that when a grass sward was cut frequently (5-7 cuts per year) the presence of docks had little effect on yield. When the sward was cut less frequently (3-4 cuts per year) total yields were reduced and the herbage contained a high proportion of dock foliage. Niggli *et al.* (1993) found that cutting at 6-week intervals favoured the docks more than cutting every 4 weeks. The docks were also favoured by increasing nitrogen rates, but the composition of the grass sward affected dock growth too. Pure swards of Italian ryegrass hindered the growth of young docks more than pure swards of perennial ryegrass, smooth meadow-grass or meadow foxtail. However, the regrowth potential of the docks increased when grass competition was reduced by cutting. The relative growth rate of broad-leaved dock was shown to exceed that of perennial ryegrass (Jeangros & Nösberger, 1992). The dock allocated more dry matter to the leaves and was less sensitive to a reduction in light intensity under shading. In curled dock, the starch content of the root declines after defoliation and may take 3 weeks to return to previous levels (Hatcher, 1996). Repeated defoliation within periods shorter than 3 weeks may eventually lead to plant death.

Trials have been carried out to determine the effect of using a mechanical soil aerator in spring on the development of docks in a dock-infested silage field (Hopkins, 1999). The treatment applied in April had some benefit over the non-aerated area perhaps through improved sward growth or disruption of the dock roots but after three years no significant difference was detected.

While NPK fertilizers had no effect on the germination of broad-leaved dock seed in grassland, increased levels of N reduced dock seedling establishment due to improved grass growth (Humphreys, 1995). The rapid achievement of a dense ground cover in sward establishment also reduces dock numbers. Dock longevity is favoured by a longer interval between cutting or mowing of the sward. Grass has a lower requirement for K than docks and grows better when the N level in soil is relatively higher than P & K. Cattle slurry has a high content of K compared with the levels of N & P and docks are able to take advantage of this, especially at high application rates. Applications of slurry in late summer or autumn favour dock seedling establishment. Cow slurry has been shown to supply K in excess of the requirement of the grasses in the sward, allowing it to accumulate in the soil (Christie, 1987). It is better to apply the slurry earlier in the year and at moderate rates or as split applications.

In grassland a high dock seed bank population in soil does not necessarily lead to a high infestation of docks (Pekrun *et al.*, 2005). The establishment of seedlings can be minimised by avoiding gaps in the vegetation. In pasture, it is prudent to prevent sward damage from trampling and poaching, particularly overwinter (ADAS, 1977; Hopkins & Bowling, 1998). Winter grazing and winter cutting regimes should be avoided (Philipps *et al.*, 2003). Dock plants in and around the field should be prevented from seeding. Slurry should be applied evenly to avoid creating patches where dock seedlings can emerge.

Established plants should be removed by pulling, spudding or using a docking-iron when the soil is soft (NAAS, 1949; Morse & Palmer, 1925). In an arable field, the level of control increased with the extent of removal of individual dock plants (Pekrun *et al.*, 2002). The maximum amount of root should be extracted. Removal must take place before flowering and all plant parts should be burned. Pulled docks must not be thrown on headlands or in ditches where they are likely to survive. However, it has been observed that sheep will eat pulled dock plants left on the headland (Personal communication). The time taken to extract docks with hand tools depends on the growth stage of the dock, the terrain, the density of the dock population, the density of other vegetation and the level of soil moisture. Large docks taken longer to uproot than young plants. Removal is easier on flat sites in well grazed vegetation. Docks are pulled out more readily from moist soil. Young docks at a low density may take around 8 man-hours per ha to clear using docking tools while older, established plants at a high density could take over 130 man-hours per ha to clear (Trevelyan, 2001). Docks in grass can be pulled in winter and early spring with a follow-up in May. Hand removal is effective for local infestations but where a large area is affected, ploughing and resowing may be the best option (Hopkins and Bowling, 1998). Plants should be pulled once the flower stem lengthens, usually in June (Soil Association, 2002). This is best done when the soil is moist. Apparently, regeneration is less likely to occur in wet soils. In an unpublished HDRA preliminary study of regeneration from dock roots left in situ after the removal of the upper 1, 5, 10 or 15 cm including the crown, there was no regeneration from roots cut at 10 cm or 15 cm depth. After 21 weeks there was 60% regeneration of roots that had been cut at 1 cm and 25% of roots cut at 5 cm depth. In a separate study 13% of roots cut at 7.5 cm depth had regenerated after 6 months. The curled dock generally has a straighter taproot and is easier to uproot intact. Docks are said to be easier to pull up when the seeds begin to swell. It is thought that the roots shrink as the resources are drained into the seeds. In Germany, manual weeding reduced the dock population by 75% but was time consuming. A self-driven 'dock rooting machine' reduced the dock spread by around 57%. Burning off the foliage had little effect on dock numbers. The 'Eco-Puller' is a tractor trailed, PTO driven machine developed for mechanically pulling perennial weeds out from grassland (Crofts & Jefferson, 1999). It is said that docks should be pulled after the seeds have been shed but this would limit the benefit of removal.

On set-aside land, Aquilina (1992) and Aquilina & Clarke (1994) applied cutting treatments at different times and frequencies to control broad-leaved dock. The docks were cut at early flower bud stage and/or full flower and/or viable seed stage. At one site the treatments were made with a reciprocating knife mower, at a second site a vertical flail mower was used. All the cut material was left in situ. At the first site, the dock population increased following treatment over a 3-year period. At the second site the dock population was reduced by between 50 and 72% over the same period. It was not clear whether this difference was due to the plant populations at the sites or to the implements used. Broad-leaved dock was common in unsown set-aside land in Scotland but numbers were lower where a sown cover had been established (Fisher *et al.,* 1992).

Wheat and barley yields were unaffected by seedling broad-leaved docks but yields of wheat were significantly reduce by regrowth from dock roots (Popay & Stiefel, 1994). Regenerating docks may be a problem in cereals that follow a ley (Lampkin, 1998). When old leys are put back into cultivation the docks should be topped regularly prior to cultivation to reduce plant vigour. The sward should be cultivated in June following tight grazing from April giving time for further cultivations prior to autumn cropping. Ploughing and rolling break up the soil and release the dock roots for collection and destruction or to expose them to desiccate at the soil surface. Some farmers have tried modified subsoilers with extra legs connected to a chain to try to bring the dock roots to the surface for collection and disposal. Others have used potato lifters (Short, 2005). It has been suggested that the roots can be shredded and composted with farmyard manure.

The population dynamics of broad-leaved dock were studied under alfalfa / winter cereal crop rotations (Masalles *et al*., 1997; Pino *et al*., 1998). Alfalfa (lucerne) is normally left to grow for 5-6 years during which it is harvested at a height of 4-5 cm every 30-40 days from April to October. During the cereal cropping period, the old alfalfa crop is ploughed down and a winter cereal established. After harvesting and ploughing-in the cereal a new crop of alfalfa is sown. Analysis and modelling of the results suggest that dock populations increased under the alfalfa cropping period and decreased under the cereals. There was an increase in curled dock seedling emergence following mowing 1 year after alfalfa establishment (Huarte & Benech Arnold, 2003). Nevertheless, curled dock germination was reduced in the presence of the crop particularly when crop density was high. In the soil under alfalfa the thermal amplitude was less than that of bare soil, mainly because the maximum temperature was much higher on the bare soil. However, the amplitude increased after mowing. The established docks were able to survive the cutting regimes in the alfalfa but suffered losses when the land was ploughed for the cereal. In established alfalfa crops where there was little soil cultivation to incorporate shed dock seed into the soil, Pino *et al*. (1993) found that many of the dock seeds germinated giving seedling flushes in late summer to autumn. Where seed shedding was prevented by shoot removal the seedbank in the top 4 cm of soil was reduced from 2,357 to 245 seeds per m^2 after one year. However, with dock seed production recorded at over 60,000 per m^2, seedbank numbers could easily be restored if further seeding occurred.

It is vitally important to sow only pure crop seed, free of weed seed contaminants (Long, 1938). Dock seeds collected during combine harvesting of cereals should be retained and denatured, not scattered back onto the stubble. Straw containing mature dock seedheads should not be spread as mulch. Farmyard manure should be composted to ensure that dock and other weed seeds it contains are killed.

In New Zealand, undersowing cereals with clover reduced the number of docks reaching maturity. Where undersowing is used to establish a ley in the understory of an arable crop, the ground cover remains in the stubble after crop harvest and into the winter (Measures, 2000). It ensures the ley is well established and able to suppress further weed seedling emergence. A summer fallow during which the soil was rotary hoed three times, eliminated docks while a single rotary hoeing followed by a green feed crop did not (Popay & Stiefel, 1994). There was no benefit from deep ploughing after the first rotary hoeing (Popay *et al*., 1994). A single shallow stubble cultivation immediately after cereal harvest followed by deep ploughing later in the autumn helps to contain populations of curled dock in an arable rotation (Pekrun & Claupein, 2006). Seed shedding in cereals results in numerous dock seedlings emerging in subsequent crops. The seedling to not grow well under a competitive crop and in small numbers can be hand rogued but if they become a serious problem it may be best to cut the cereal for whole crop silage to prevent further seeding. Docks that remain in the stubble after cereal harvest can grow rapidly if the stubble is left uncultivated. The stubble may be grazed or cultivated to prevent flowering.

In the past, seedling docks were hoed off in spring and autumn. Young seedlings can also be destroyed by thorough cultivations or ploughing (MAFF, 1956; Hughes *et al*., 1993). Control of established plants was by removing the docks bodily during ploughing (Long, 1938; NAAS, 1949) or during bare or bastard fallowing (MAFF,1956). Ploughing followed by fallowing and repeated cultivations during spring and early summer exhausts the older roots and controls young seedlings of broad-leaved dock (SAC, 1986). Hunt & Harkess (1968), however, considered deep ploughing to be only a temporary solution against mature docks as the docks can grow through after being ploughed well down. Any docks left on the soil surface will readily re-root. In an preliminary study (HDRA unpublished) of the period of drying needed to prevent regeneration of uprooted dock roots of different lengths with their crown still attached, no docks regenerated after a period of 4 to 8 weeks drying. An average of 21% of roots regenerated after a 1-week drying treatment. In a separate study dock roots left on the soil surface and covered with black plastic sheeting for 8 weeks did not survive. Roots buried at 30 cm deep did not re-emerge in the period of the study. Dock roots may be collected up and burned (Morse & Palmer, 1925).

Established docks may be shallowly undercut with sweeps or a turf cutter (Philipps *et al.*, 2003). There is little soil disturbance but the crowns remain in situ and are likely to regenerate without further action. Another suggestion for the control of established docks is a series (3-4) of rotary cultivations preferably in April-June. The rotovations begin at a shallow depth and become progressively deeper with time to around 6 inches. Each time the docks begin to resprout a further rotovation takes place. The succession of carefully managed rotovations is intended to exhaust the reserves of the roots. Pino *et al*. (1995) proposed that docks should be severed below the root collar by rotovation and the severed shoot portions buried to below 15 cm, preferably 30 cm, by ploughing.

Dierauer (1993) tried a range of non-chemical control methods against broad-leaved dock including: drilling down into the roots, cutting plants at ground level, at 5 cm and at 10 cm deep, flaming, mowing, applying a bio-dynamic preparation of the ash of dock seeds, exposing the plants to the eggs and adults of *Gastrophysa viridula* beetles, and tearing out the entire root. Most of the treatments were only successful in the short term. The drilled roots for example had resprouted within six weeks of treatment, and cutting off the leaves had little effect. Cutting at 5 cm deep gave a 27% reduction in docks, cutting at 10 cm gave an 80% reduction, which was as good as the effect of tearing out the whole root.

In field studies, mulching the soil with residues of hairy vetch (*Vicia villosa*) and of rye (*Secale cereale*) reduced the emergence of curled dock seedlings (Mohler & Teasdale, 1993). Weed emergence declined with increasing rate of residue, however, the natural amount of residue that remained after a cover crop was killed off was insufficient for good weed control. A low rate of residue could encourage greater weed emergence.

In greenhouse tests, corn gluten meal (CGM) applied as a surface and incorporated treatment to soil sown with curled dock seed has been shown to reduce plant development (Bingaman & Christians, 1995). Application rates of 324, 649 and 973g per m^2 reduced curled dock seedling survival by 75, 94 and 97% respectively. Shoot length was reduced by over 90%. Corn gluten hydrolysate (CGH), a water soluble material derived from CGM, was found to be more active than CGM when applied to the surface of pots of soil sown with curled dock seed (Liu & Christians, 1997).

Wheat gluten meal sprinkled over curled dock seeds on wet blotter paper reduced germination by 70% at 300g per m^2 (Gough & Carlstrom, 1999). The treatment reduced primary root and shoot length by 99 and 91% respectively.

Cavers and Harper (1964) list a range of fungi and insects that attack, feed on or occur on docks but this not an indication of their efficacy as control agents. The potential for the biological control of curled and broad-leaved dock using insects was reviewed in some detail by Grossrieder & Keary (2004) with particular reference to organic farming in Switzerland. Insect control agents both native and non-native were evaluated including the weevils *Hypera rumicis,* not recorded in Europe, and *Lixus cribricollis,* originating Morocco, the larvae of 4 *Sesiid* moth species, known to feed on docks in Europe, and the aphid *Brachycaudus rumexicolens* whose origin is uncertain, as well as the UK native insects described below. The authors considered that the augmentation of native species was the best approach for dock control at present.

The use of the stem boring larvae of the native weevils *Apion violaceum* and *A. miniatum* for controlling broad-leaved dock has been investigated (Hopkins & Whittaker, 1980; Freese, 1995). The females of both species deposit their eggs onto the midrib of leaves and the larvae bore into the stems. The larvae then eat into the stem and roots leading to plant death. *Apion miniatum* lays its eggs two weeks earlier than *A. violaceum* and the larvae inhabit the lower parts of the stem. The larvae of *A. violaceum* are more widely distributed along the stem. Both species are themselves attacked by a range of parasitoid species that feed on the larvae and reduce their effectiveness as biological control agents (Hopkins *et al.*, 1984).

Larvae of the leaf-mining fly *Pegomya nigitarsis* cause blotch mines on the leaves of broad-leaved, curled and wood docks (Whittaker, 1994). The damage reduces photosynthesis and increases water loss from the leaves. A badly infested plant may have more than half its leaves attacked by mines which can cover the entire surface area of the leaf. In the UK, larvae are found from May to November. The fully grown larvae emerge from the leaf and pupate in the upper layers of the soil.

In the UK and elsewhere, there has been research on the chrysomelid beetle (*Gastrophysa viridula*) as a biocontrol agent for both curled and broad-leaved dock (Bentley *et al*., 1980). The small leaf feeding beetle is restricted to curled and broad-leaved dock plants. It overwinters as an adult and emerges in April. Males and gravid females are found on docks in May (Whittaker *et al*., 1979). Eggs are laid on the underside of leaves in batches of around 30. The egg laying beetles show a preference for broad-leaved docks over curled docks in the ratio of 9 to 1 (Bentley & Whittaker, 1979). Mean egg numbers of 800 per plant have been recorded on broad-leaved dock plants. The black larvae that emerge from the eggs pass through 3 instars and pupate within 3-4 weeks. The pupae enter the soil surrounding the dock plants and later emerge as adults that climb back up onto the plants. Adult beetles are most numerous in May, July and September. A generation may be completed in 4-6 weeks and 3 generations are possible each year. The eggs and larvae, but not the adults, may be eaten by *Anthocoris nemorum* and are preyed upon by syrphid larvae. Syrphid eggs are laid one per clump in the middle of the beetle eggs. The white egg is clearly visible among the yellow *Gastrophysa* eggs. The emerged syrphid larva can consume 200 eggs or larvae during its development. Around 50% of eggs are lost to the larvae.

The predator pressure increases with increasing plant diversity in the vegetation cover (Smith & Whittaker, 1980a).

The application of the herbicide Asulam to docks can reduce beetle numbers depending on the growth stage of the beetle at the time of application (Speight & Whittaker, 1987). The effect of the herbicide on the morphology of the docks, particularly the foliage, is responsible for the reduction. All stages of the beetle are vulnerable to flooding, particularly the older larvae, and local populations can be wiped out (Whittaker *et al.*, 1979). Cutting and mowing of docks at critical stages can also have a major effect on beetle populations due to the limited dispersal of the adults. The beetles disperse by crawling and none are observed to fly. The average distance moved is 3 m and the maximum is 7 m. Re-invasion of cleared areas is therefore very slow.

In some habitats the beetle is sufficiently numerous to defoliate the host plants, in others it occurs at a very low density. In the field, a natural population of beetles can remove 45% of the leaf area of a dock (Bentley & Whittaker, 1979). When given a choice, the beetles show a preference for feeding on broad-leaved dock but this also depends on the dock species the beetle was raised on. Heavy grazing by the beetle can significantly reduce whole plant dry weight of both dock species, potentially resulting in a 65% reduction. When growing together, curled dock is less competitive than broad-leaved dock. Beetle grazing can reduce its competitive ability further and may affect the frequency and distribution of curled dock in mixed populations.

Beetles seem unwilling to leave a dock clump and search for feeding sites elsewhere (Smith & Whittaker, 1980a). If the larvae defoliate the host they may be required to search for a new food source and mortality at this time can be high due to predation and the risk of starvation. After flowering, leaf production by a dock clump ceases for up to 2 months so the beetle population can experience a drop in food source especially where the flowering of dock plants in a given habitat is synchronised. This can affect the number of generations produced and the proportion of gravid females. As the dock plants begin to flower and the stem leaves die back the beetles move up the plant and ultimately feed on the flowers and seeds. When the next flush of basal leaves is produced the beetles move down again to feed on them. Adults avoid laying eggs on old senescent leaves and in preference will lay them on the new basal leaves when these are produced. In hay meadows, periodic mowing or grazing prevents dock flowering and hence leaf loss becoming synchronised. This allows *G. viridula* to survive better through the season. There is evidence that as the diversity and maturity of the vegetation increases, the hostility of the habitat towards the beetles also increases preventing populations achieving their full potential of 3 generations per year (Smith & Whittaker, 1980b).

Twenty two separate species of rust fungus infect *Rumex* spp. (Inman, 1970). The rust fungus *Uromyces rumicis* is non-systemic but can cause serious foliar injury and has been shown to have some potential as a biological control agent (Inman, 1971; Schubiger *et al.*, 1986). The primary host range appears to be restricted to *Rumex* spp. Selections of curled dock have demonstrated a wide range of disease reactions following inoculations with urediospores of the fungus (Inman, 1969). The rust is widespread in Europe, it infects the dock foliage in August-September causing the affected leaves to die but not the whole plant. Symptoms begin as a red spot that expands to form the typical rust pustule. It is not known if the primary inoculum each year comes from overwintered spores or from spores on overwintered mycelia. During the growing season the rust spreads by wind blown urediniospores that require a moist surface for germination. The alternate host in the life cycle of the fungus is lesser celandine (*Ranunculus ficaria*) but this only plays a minor part in the life cycle of the pathogen. There has been particular interest in its use in the USA (Inman, 1971; Frank, 1971). Various naturally occurring flavour-related compounds were shown to stimulate germination of both curled dock seed and urediniospores of *U. rumicis* (French *et al*., 1986). Benzonitrile, found in cocoa aroma, was the most active compound tested on both seeds and spores.

Among other fungi that frequently cause disease in *Rumex* spp., *Ramularia rubella* (a necrotrophic Ascomycete) and *Venturia rumicis* (a hemibiotrophic Ascomycete) are present throughout the year. *Ramularia rubella* causes red spots around 1 cm diameter to develop on dock leaves. It endemic to Europe, the host range is restricted to *Rumex* spp. and it is considered to have potential as a mycoherbicide against weedy *Rumex* (Huber-Meinicke *et al*., 1989). Symptoms appeared within 3-5 days of the application of a suspension of conidia. Severely affected leaves with 50% of leaf area infected died within 7-10 days. Leaves less affected by the fungus survived but photosynthetic capacity was reduced. Infected plants could produce more leaves and, despite reducing food reserves in the rootstock, the fungus alone had no major effect on plant survival. *Venturia rumicis* (Syn. *Mycosphaerella rumicis*) also causes a leaf spotting disease of *Rumex* spp. and has been widely recorded in Great Britain (Kerr, 1961). The fungus thrives in cool wet conditions but is less prevalent in hot dry weather. Leaves become infected by ascospores which may germinate within 8 hours of being shed. Moisture is needed for germination and for subsequent ascospore release, which can occur 20 days after an infection has developed. The spores may be discharged up to 1.5 cm, may simply fall on a nearby leaf or may be carried further afield on wind currents. *Ovularia obliqua* also causes a leaf spotting disease of *Rumex* spp. The spots often enlarge under moist conditions to cover a large area of a leaf.

Experiments have indicated that infection by one pathogen predisposes a leaf to infection by another (Hatcher & Paul, 2000). However, it has been shown that leaf damage by the beetle *G. virudula* leads to a reduction in infection by the pathogens both on the grazed and undamaged leaves of a plant (Hatcher *et al*., 1994a). Herbivory appears to induce a systemic resistance to the pathogens. The response suppressed the development of pustules of *U. rumicis* and reduced the penetration of fungal hyphae into the leaf (Hatcher *et al*., 1995). Conversely, when the beetle and the rust fungus *U. rumicis* occur together on dock leaves, the presence of the fungus increases mortality of beetle larvae at early stages of development and reduces the fecundity and longevity of the adult beetles (Hatcher *et al*., 1994b). When the effects of the rust fungus and beetle grazing were compared singly and combined on curled dock, beetle grazing or rust alone had the greatest effect (Hatcher *et al*., 1994c). When combined, the order of attack was important in the level of damage caused. Beetle grazing followed by rust infection was no worse than the rust alone. Rust followed by beetle grazing caused the greatest reduction in biomass in curled but not in broad-leaved dock. A model was developed to help in predicting the amount of damage likely from the rust and beetle.

In studies of the beetle-rust interaction on the autumn growth and overwintering of curled and broad-leaved docks the effects were monitored from August onwards (Hatcher, 1996). The rust fungus *U. rumicis* infects the docks mainly from August to October, at the same time that the beetle is present. There is some separation as the fungus is poor at infecting young leaves while these are the leaves favoured for egg laying by the beetle. Between August and October, the beetle alone removed 79% of the leaf area. The rust was slow to develop but caused a 50% decrease by October. A combination of the two had an additive effect and leaf area was reduced by 92% on curled and 88% on broad-leaved docks. Root and shoot weight of both dock species was also reduced more by the combination. Herbivory and fungal infection will limit the competitive ability of docks in grassland.

In other experiments the addition of nitrogen fertilizer increased dock growth but did not allow it to escape the effects of the beetle and fungus (Hatcher *et al.,* 1997a). The density of rust pustules decreased with increasing nitrate as did beetle herbivory and egg laying (Hatcher *et al.*, 1997b). It is suggested that there may be an optimum nitrogen fertilization level for *G. viridula* development (Hatcher *et al.*, 1997c). Singly, nitrogen deficiency and the rust fungus reduce dock growth. When combined, they may put an additive stress on the plant (Hatcher & Ayres, 1998).

Natural colonization by insects and fungi may take several years to build up but can cause significant damage to dock populations (Hatcher, 1999). The artificial introduction of additional beetles increases the level of damage. Site conditions have a big effect on weed recovery.

Exposure to an arbuscular-mycorrhizal fungal inoculum has been shown to cause a 60% reduction in biomass in the broad-leaved dock, a non-host weed species (Jordan *et al.*, 2000). Broad-leaved dock has been shown to be susceptible to infection by the honey fungus *Armillaria mellea* (West *et al.*, 2000). The foliage of infected plants became wilted or senesced. Although there may be potential for biocontrol of docks, infected plants could spread honey fungus to nearby trees and shrubs.

Legislation

The Weeds Act, 1959, requires an occupier of land to prevent the spread of broad-leaved dock and curled dock. Set-aside land is not exempt.

The 1951 regulations made under the Seeds Act 1920, defined the seed of all *Rumex* species as injurious weed seeds. The Plant Varieties and Seed Act, 1964 section 16(3)(c), gives the Minister the power to prohibit the sale of seeds containing more than a prescribed proportion of docks and sorrels.

Acknowledgement

The review was compiled as part of the Organic Weed Management Project, OF 0315, funded by DEFRA.

References

ADAS (1977). Weed Control: Docks. *Advisory Leaflet No*. **46**. HMSO, Edinburgh, UK.

Akeroyd J R & Briggs D (1983a). Genecological studies of *Rumex crispus* L. I. Garden experiments using transplanted material. *New Phytologist* **94**, 309-323.

Akeroyd J R & Briggs D (1983b). Genecological studies of *Rumex crispus* L. II. Variation in plants grown from wild-collected seed. *New Phytologist* **94**, 325-343.

Aquilina M (1992). Effect of timing and frequency of cutting on perennial broad-leaved weeds. *BCPC Monograph No*. **50**, *Set-Aside*, 143-146.

Aquilina M & Clarke J H (1994). Effect of cutting date and frequency on perennial broad -leaved weeds on set-aside. *Aspects of Applied Biology* **40**, *Arable farming under CAP reform*, 541-546.

Arp W J, Van Mierlo J E M, Berendse F, Snijders W (1998). Interactions between elevated CO_2 concentration, nitrogen and water: effects on growth and water use of six perennial plant species. *Plant, Cell and Environment* **21**, 1-11.

Baskin J M & Baskin C C (1978). A contribution to the germination ecology of *Rumex crispus* L. *Bulletin of the Torrey Botanical Club* **105** (4), 278-281.

Baskin J M & Baskin C C (1985). Does seed dormancy play a role in the germination ecology of *Rumex crispus*? *Weed Science* **33**, 340-343.

Bentham G & Hooker J D (1887). *British Flora*, L Reeve & Co, London, UK.

Bentley S & Whittaker J B (1979). Effects of grazing by a Chrysomelid beetle *Gastrophysa viridula* on competition between *Rumex obtusifolius* and *Rumex crispus*. *Journal of Ecology* **67** (1), 79-90.

Bentley S, Whittaker J B, Malloch A J C (1980). Field experiments on the effects of grazing by a chrysomelid beetle (*Gastrophysa viridula*) on seed production and quality in *Rumex obtusifolius* and *Rumex crispus. Journal of Ecology* **68**, 671-674.

Benvenuti S, Macchia M, Miele S (2001). Light, temperature and burial depth effects on *Rumex obtusifolius* seed germination and emergence. *Weed Research* **41**, 177-186.

Besson J M, Schmitt R, Lehmann V, Soder M (1986). Differences in germination behaviour of weed seeds following treatment with slurry which had been stored, aerated or fermented for methane production. *Mitteilungen für die Schweizerische Landwirtschaft* **35**, 73-80.

Bingaman B R & Christians N E (1995). Greenhouse screening of corn gluten meal as a natural control product for broadleaf and grass weeds. *HortScience* **30** (6), 1256-1259.

Böhm H & Finze J (2003). [Strategies to control perennial weeds in organic farming systems – present state of knowledge and further research requirements: situation analysis and review of attempts to control *Rumex* spp.]. *Report, Instut für ökologischen Landbau, Bundesforschungsanstalt für Landwirtschaft.* Online at http://orgprints.org/6167

Böhm H & Verschwele A (2004). [Control of *Rumex* spp. and *Cirsium arvense* in organic farming]. *Landbauforschung Völkenrode* **273**, 39-47. Online at http://orgprints.org/4166

Bosworth S C, Hoveland C S, Buchanan G A (1985). Forage quality of selected cool-season weed species. *Weed Science* **34** (1), 150-154.

Boyd N S & Van Acker R C (2003). The effects of depth and fluctuating soil moisture on the emergence of eight annual and six perennial plant species. *Weed Science* **51**, 725-730.

Brenchley W E (1911). The weeds of arable land in relation to the soils on which they grow. *Annals of Botany* **25**, 155-165.

Brenchley W E (1913). The weeds of arable soil III. *Annals of Botany* **27**, 141-166.

Brenchley W E (1918). Buried weed seeds. *Journal of Agricultural Science* **9** (1), 1-31.

Brenchley W E (1920). *Weeds of farm land*. Longmans, Green and Co, London, UK.

Bruns V F (1965). The effects of fresh water storage on the germination of certain weed seeds. *Weeds* **13** (1), 38-40.

Cavers P B (1974). Germination polymorphism in *Rumex crispus.* The effects of different storage conditions on germination responses of seeds collected from individual plants. *Canadian Journal of Botany* **52**, 575-583.

Cavers P B & Harper J L (1964). Biological Flora of the British Isles No. 98 *Rumex obtusifolius L. and R. crispus* L. *The Journal of Ecology* **52**, 737-766.

Cavers P B & Harper J L (1966). Germination polymorphism in *Rumex crispus* and *Rumex obtusifolius*. *Journal of Ecology* **54**, 367-382.

Cavers P B & Harper J L (1967a). Studies in the dynamics of plant populations I. The fate of seed and transplants introduced into various habitats. *Journal of Ecology* **55**, 59-71.

Cavers P B & Harper J L (1967b). The comparative biology of closely related species living in the same area IX. *Rumex*: the nature of adaptation to a sea-shore habit. *Journal of Ecology* **55**, 73-82.

Champness S S & Morris K (1948). The population of buried viable seeds in relation to contrasting pasture and soil types. *Journal of Ecology* **36** (1), 149-173.

Chancellor P (1956). Studies on the ecology of some species of the genus *Rumex*. *Proceedings of the 3rd British Weed Control Conference*, Blackpool, England, 197-203.

Chancellor R J (1970). Biological background to the control of three perennial broad-leaved weeds. *Proceedings of the 10th British Weed Control Conference*, Brighton, UK.

Chancellor R J (1979). The seasonal emergence of dicotyledonous weed seedlings with changing temperature. *Proceedings of the EWRS Symposium, The Influence of Different Factors on the Development and Control of Weeds*, 65-72.

Chancellor R J & Froud-Williams R J (1984). A second survey of cereal weeds in central southern England. *Weed Research* **24**, 29-36.

Christie P (1987). Some long-term effects of slurry on grassland. *Journal of Agricultural Science (Camb.)* **108**, 529-541.

Cideciyan M A & Malloch A J C (1982). Effects of seed size on the germination, growth and competitive ability of *Rumex crispus* and *Rumex obtusifolius. Journal of Ecology* **70** (1), 227-232.

Clapham A R, Tutin T G, Moore D M (1987). *Flora of the British Isles*. 3rd edition, Cambridge University Press, Cambridge, UK.

Copper J B, Maxwell T L Jr, Owens A D (1960). A study of the passage of weed seeds through the digestive tract of the chicken. *Poultry Science* **39**, 161-163.

Copson P J & Roberts H A (1991). Garden weeds – a survey in Warwickshire. *Professional Horticulture* **5**, 71-73.

Courtney A D (1972). Docks in grassland, their influence on herbage productivity. *Proceedings 11th British Weed Control Conference*, Brighton, UK, 315-322.

Courtney A D (1986). Impact and control of docks in grassland. *Weeds, Pests and Diseases of Grassland and Herbage Legumes. British Crop Protection Council Monograph* **29**, (ed J S Brockman), 120-127.

Courtney A D & Johnston (1978). A consideration of the contribution to production of *Rumex obtusifolius* in a grazing regime. *Proceedings British Crop Protection Conference – Weeds*, Brighton, UK, 325-331.

Crocker W (1938). Life-span of seeds. *Botanical Revue* **4**, 235-274.

Crofts A, Jefferson R G (eds) (1999). *Lowland Grassland Management Handbook.* 2nd Edition, English Nature/The Wildlife Trusts.

Cross H (1930-33). Laboratory germination of weed seeds. *Proceedings of the Association of Official Seed Analysts of North America* **24**, 125-128

Currie R S & Peeper T F (1988). Combine harvesting affects weed seed germination. *Weed Technology* **2** (4), 499-504.

Dale H M, Harrison P J, Thomson G W (1965). Weeds as indicators of physical characteristics in abandoned pastures. *Canadian Journal of Botany* **43**, 1319-1327.

Darlington H T & Steinbauer G P (1961). The eighty-year period for Dr Beal's seed viability experiment. *American Journal of Botany* **48**, 321-325.

Deunff Y Le & Chaussat R (1968). Study of secondary dormancy in *Rumex crispus* L. seed. *Annales de Physiologie Végétale* **10** (4), 227-236.

Derrick R W, Moseley G, Wilman D (1993). Intake by sheep, and digestibility of chickweed, dandelion, dock, ribwort and spurrey, compared with perennial ryegrass. *Journal of Agricultural Science* **120**, 51-61.

Dierauer H U (1993). Efficiency of different non-chemical methods of controlling Broadleaf dock (*Rumex obtusifolius*). *Communications of the 4th International Conference I.F.O.A.M. Non Chemical Weed Control,* Dijon, France, 311-314.

Don R (1997). Weed seed contaminants in cereal seed. *Proceedings of the 1997 Brighton Crop Protection Conference – Weeds,* Brighton, UK.

Doyle C J, Oswald A K, Haggar R J, Kirkham F W (1984). A mathematical modelling approach to the study of the economics of controlling Rumex obtusifolius in grassland. *Weed Research* **24**, 183-193.

Finze J & Böhm H (2004). [Effect of direct measures and grazing management on the density of dock species (*Rumex* spp.) in organically managed grassland]. *Zeitschrift für Pflanzenkrankheiten und Pflanzenschutz* **XIX**, 527-535.

Firbank L G, Norton L R, Smart S M (2002). Recording cereal field margins in Countryside Survey 2000. *Report to the Department for Environment, Food and Rural Affairs* (Revised March 2002), 16 pp.

Fisher N M, Dyson P W, Winham J, Davies D H K (1992). A botanical survey of set-aside land in Scotland. *BCPC Monograph No.* **50** *Set-aside*, 67-72.

Foster L (1989). The biology and non-chemical control of dock species *Rumex obtusifolius* and *Rumex crispus. Biological Agriculture and Horticulture* **6**, 11-25.

Frank P A (1971). Report on the status of the rust fungus *Uromyces rumicis* introduced into quarantine as a control agent for curly dock *Rumex crispus* . *Proceedings of the 2nd International Symposium on Biological Control of Weeds*,121-125.

Franklin M T (1970). Interrelationships of nematodes, weeds, herbicides and crops. *Proceedings of the 10th British Weed Control Conference*, Brighton, UK, 927-933.

Freese G (1995). Structural refuges in two stem-boring weevils on *Rumex crispus. Ecological Entomology* **20** (4), 351-358.

French R C, Kujawski P T, Leather G R (1986). Effect of various flavor-related compounds on germination of curly dock seed (*Rumex crispus*) and curly dock rust (*Uromyces rumicis*). *Weed Science* **34** (3)**,** 398-402.

Gibson C W D (1996). The effects of horse grazing on species-rich grassland. *English Nature Research Report* No. **164**, English Nature, Peterborough.

Gill N T (1938). The viability of weed seeds at various stages of maturity. *Annals of Applied Biology* **25** (3), 447-456.

Gooch S M S (1963). The occurrence of weed seeds in samples tested by the official seed testing station, 1960-1. *The Journal of the National Institute of Agricultural Botany* **9** (3), 353-371.

Górski T, Górska K, Nowicki J (1977). Germination of seeds of various herbaceous species under leaf canopy. *Flora Bd*. **166**, S, 249-259.

Goss W L (1924). The vitality of buried seeds. *Journal of Agricultural Research* **29**, 349-362.

Gough R E & Carlstrom R (1999). Wheat gluten meal inhibits germination and growth of broadleaf and grassy weeds. *HortScience* **34**(2), 269-270.

Grime J P, Hodgson J G, Hunt R (1988). *Comparative Plant Ecology*, Unwin Hyman Ltd, London, UK.

Grime J P & Jarvis B C (1976). Shade avoidance and shade tolerance in flowering plants II. Effects of light on the germination of species of contrasted ecology. Reprinted from: *Light as an Ecological Factor :II, The 16th Symposium of the British Ecological Society, 1974*, Blackwell Scientific Publications, Oxford, 525-532.

Grossreider M & Keary I P (2004). The potential for the biological control of *Rumex obtussifolius* and *Rumex crispus* using insects in organic farming, with particular reference to Switzerland. *Biocontrol News and Information* **25** (3), 65N-75N.

Guil J L, Torija M E, Giménez J J, Rodríguez-Garcia I, Giménez A (1996). Oxalic acid and calcium determination in wild edible plants. *Journal of Agricultural and Food Chemistry* **44** (7), 1821-1823.

Haggar R J (1980). Survey on the incidence of docks (*Rumex* spp.) in grassland in 10 districts in the United Kingdom in 1972. *ADAS Quarterly Review* **39**, 256-70.

Haggar R J, Johnson J, Peel S, Snaydon R W, Tayler R S (1982). Weed control in grassland. *Weed Control Handbook – Principles*, 7th edition, ed. H A Roberts, Blackwell Scientific Publications, Oxford. UK, 351-368.

Haggar R J & Padel S (1996). Conversion to organic milk production. IGER *Technical Report* No. **4**, 66-73**.**

Hance R J & Holly K (1989). *Weed Control Handbook: Principles*. 8th Edition, Blackwell, Oxford.

Hand D J, Craig G, Takaki M, Kendrick R E (1982). Interaction of light and temperature on seed germination of *Rumex obtusifolius* L.. *Planta* **156**, 457-460.

Hanson C G & Mason J L (1985). Bird seed aliens in Britain. *Watsonia* **15**, 237-252.

Harper J L & Chancellor A P (1959). The comparative biology of closely related species living in the same area. IV. *Rumex*: interference between individuals in populations of one and two species. *Journal of Ecology* **47**, 679-695.

Hatcher P E (1996). The effect of insect-fungus interactions on the autumn growth and over-wintering of *Rumex crispus* and *R. obtusifolius* seedlings. *Journal of Ecology* **84**, 101-109.

Hatcher P E (1999). A long-term study of the effects of insects and fungi on *Rumex obtusifolius* – the first two years. *Proceedings 11th EWRS Symposium*, Basel, 95.

Hatcher P E & Ayres P G (1998). The effect of fungal infection and nitrogen fertilization on the carbohydrate composition of *Rumex obtusifolius* leaves. *European Journal of Plant Pathology* **104**, 553-559.

Hatcher P E & Paul N D (2000). Beetle grazing reduces natural infection of *Rumex obtusifolius* by fungal pathogens. *New Phytologist* **146**, 325-333.

Hatcher P E, Paul N D, Ayres P G, Whittaker J B (1994a). Interactions between *Rumex* spp., herbivores and a rust fungus: *Gastrophysa viridula* grazing reduces subsequent infection by *Uromyces rumicis*. *Functional Ecology* **8** (2), 265-272.

Hatcher P E, Paul N D, Ayres P G, Whittaker J B (1994b). The effect of a foliar disease (rust) on the development of *Gastrophysa viridula* (Coleoptera: Chrysomelidae). *Ecological Entomology* **19** (4), 349-360.

Hatcher P E, Paul N D, Ayres P G, Whittaker J B (1994c). The effect of an insect herbivore and a rust fungus individually, and combined in sequence, on the growth of two *Rumex* species. *New Phytologist* **128** (1), 71-78.

Hatcher P E, Ayres P G, Paul N D (1995). The effect of natural and simulated insect herbivory, and leaf age, on the process of infection of *Rumex crispus* L. and *R. obtusifolius* L. by *Uromyces rumicis* (Schum.) Wint. *New Phytologist* **130** (2), 239-249.

Hatcher P E, Paul N G, Ayres P G, Whittaker J B (1997a). Added soil nitrogen does not allow *Rumex obtusifolius* to escape the effects of insect-fungus interactions. *Journal of Applied Ecology* **34**, 88-100.

Hatcher P E, Paul N G, Ayres P G, Whittaker J B (1997b). Nitrogen fertilization affects interactions between the components of an insect-fungus-plant tripartite system. *Functional Ecology* **11** (5), 537-544.

Hatcher P E, Paul N G, Ayres P G, Whittaker J B (1997c). The effect of nitrogen fertilization and rust fungus infection, singly and combined, on the leaf chemical composition of *Rumex obtusifolius. Functional Ecology* **11** (5), 545-553.

Healy A J (1953). The control of docks. *New Zealand Journal of Science and Technology* **34** (5), 473-475.

Hemmat M, Zeng G-W, Khan A A (1985). Responses of intact and scarified curly dock (*Rumex crispus*) seed to physical and chemical stimuli. *Weed Science* **33** (5), 658-664.

Hendry G A F, Thompson K, Moss C J, Edwards E, Thorpe P C (1994). Seed persistence: a correlation between seed longevity in the soil and *ortho*-dihydroxyphenol concentration. *Functional Ecology* **8**, 658-664.

Holm L G, Plucknett D L, Pancho J V, Hergerger J P (1977). *The World's Worst Weeds, distribution and biology*. University Press of Hawaii, Honolulu, Hawaii.

Honek A & Martinková Z (2002). Effects of individual plant phenology on dormancy of *Rumex obtusifolius* seeds at dispersal. *Weed Research* **42** (2), 148-155.

Hongo A (1989a). Survival and growth of seedlings of *Rumex obtusifolius* L. and *Rumex crispus* L. in newly sown grassland. *Weed Research* **29** (1), 7-12.

Hongo A (1989b). Transplant survival of *Rumex obtusifolius* L. and *Rumex crispus* L. in three old reseeded grasslands. *Weed Research* **29** (1), 13-19.

Hopkins A (1999). Cultural methods for controlling docks in organically farmed grassland (extension 1998-1999)(OFT0115T). (accessed 9/7/07). http://orgprints.org/9927/

Hopkins A & Bowling P (1998). Pernicious weeds. *Organic Farming* (issue 60, Winter 1998), 60.

Hopkins A & Johnson R H (2002). Effect of different manuring and defoliation patterns on broad-leaved dock (*Rumex obtusifolius*) in grassland. *Annals of Applied Biology* **140** (3), 255-262.

Hopkins M J G & Whittaker J B (1980). Interactions between Apion spp. And Polygonaceae 2. *Apion violaceum* and *Rumex obtusifolius* . *Ecological Entomology* **5**, 241-247.

Hopkins M J G, Williams P, Fisher J P (1984). The parasite complex associated with stem boring *Apion* spp. feeding on *Rumex* spp. *Entomologists Monthly Magazine* **120**, 187-192.

Huarte H R & Benech Arnold R L (2003). Understanding mechanisms of reduced annual weed emergence in alfalfa. *Weed Science* **51**, 876-885.

Huber-Meinicke G, Défago G, Sedlar L (1989). *Ramularia rubella* (Bon.) Nannf. as a potential mycoherbicide against *Rumex* weeds. *Botanica Helvetica* **99** (1), 81-89.

Hübner C & Ziegler H (1998). UV-B effects on physiological parameters of three species of *Rumex* with natural distribution at different altitudes. *Journal of Plant Physiology* **152**, 336-344.

Hudson J P (1955). Propagation of plants by root cuttings II. Journal of *Horticultural Science* **30** (4), 242-251.

Hughes C N G, Froud-Williams R J, Fox R T V (1993). The effects of fragmentation and defoliation on Rumex obtusifolius and its implications for grassland management. *Proceedings of the Brighton Crop Protection Conference – Weeds*, Brighton UK, 767-772.

Hume L & Cavers P B (1982a). Geographic variation in a widespread perennial weed, *Rumex crispus.* The relative amounts of genetic and environmentally induced variation among populations. *Canadian Journal of Botany* **60**, 1928-1937.

Hume L & Cavers P B (1982b). Adaptation in widespread populations of *Rumex crispus* as determined using composite diagrams. *Canadian Journal of Botany* **60**, 2637-2651.

Hume L & Cavers P B (1983a). Resource allocation and reproductive and life history strategies in widespread populations of *Rumex crispus*. Canadian Journal of Botany **61**, 1276-1282.

Hume L & Cavers P B (1983b). Differences in the flowering requirements of widespread populations of *Rumex crispus*. Canadian Journal of Botany **61**, 2760-2762.

Humphreys J (1995). Investigations into aspects of the dynamics of *Rumex obtusifolius* L. (Broad-leaved dock) populations in grassland. PhD Thesis University College Dublin, National University of Ireland. 345 pp.

Humphreys J, Jansen T, Culleton N, MacNaeidhe F S, Storey T (1999). Soil potassium supply and *Rumex obtusifolius* and *Rumex crispus* abundance in silage and grazed grassland swards. *Weed Research* **39** (1), 1-13.

Hunt I V & Harkess R D (1968). Docks in Grassland. Scottish Agriculture, **47** (3), 160-162.

Inman R E (1969). Host resistance and biological weed control. *Proceedings 1st International Symposium on Biological Weed Control*, 41-45.

Inman R E (1970). Observations on the biology of *Rumex* rust *Uromyces rumicis* (Scum.) Wint. *Botanical Gazette* **131** (3), 234-241.

Inman R E (1971). A preliminary evaluation of *Rumex* rust as a biological control agent for curly dock. *Phytopathology* **61**, 102-107.

Jeangros B & Nösberger J (1992). Comparison of the growth response of *Rumex obtusifolius* L. and *Lolium perenne* L. to photon flux density. *Weed Research* **32**, 311-316.

Jordan N R, Zhang J, Huerd S (2000). Arbuscular-mycorrhizal fungi: potential roles in weed management. *Weed Science* **40**, 397-410.

Karlsson N (1952). Analytical work on zinc in the vegetation of Middle Sweden. *Acta Agric. Scand*. **2**, 173-182.

Keary I P & Hatcher P E (2004). Combining competition from *Lolium perenne* and an insect-fungus combination to control *Rumex obtusifolius* seedlings. *Weed Research* **44**, 33-41.

Kelley A D & Bruns V F (1975). Dissemination of weed seeds by irrigation water. *Weed Science* **23** (6), 486-493.

Kerr J E (1961). The life history and taxonomic position of *Venturia rumicis* (Desm.) Wint. *Transactions of the British Mycological Society* **44** (4), 465-486.

Kivilaan A & Bandurski R S (1981). The one hundred-year period for Dr Beal's seed viability experiment. *American Journal of Botany* **68** (9), 1290-1292.

Kjaer A (1940). Germination of buried and dry stored seeds. I. 1934-1939. *Proceedings of the International Seed Testing Association* **12**, 167-190.

Koukol J & Dugger W M Jr (1967). Anthocyanin formation in a response to ozone and smog treatment in *Rumex crispus* L. *Plant Physiology* **42**, 1023-1024.

Laan P. Berrevoets M J, Lythe S, Armstrong W, Blom C W P M (1989). Root morphology and aerenchyma formation as indicators of the flood-tolerance of *Rumex* species. *Journal of Ecology* **77**, 693-703.

Laan P & Blom C W P M (1990). Growth and survival responses of *Rumex* species to flooded and submerged conditions: The importance of shoot elongation, underwater photosynthesis and reserve carbohydrates. *Journal of Experimental Botany* **41** (228), 775-783.

Laan P, Clement J M A M, Blom C W P M (1991). Growth and development of *Rumex* roots as affected by hypoxic and anoxic conditions. *Plant and Soil* **136**, 145-151.

Laan P, Tosserams M, Blom C W P M, Veen B W (1990). Internal oxygen transport in *Rumex* species and its significance for respiration under hypoxic conditions. *Plant and Soil* **122**, 39-46.

Lampkin N (1998). *Organic Farming.* Farming Press, Miller Freeman UK Ltd, Ipswich, UK.

Lewis J (1958). Longevity of crop and weed seeds 1. First interim report. *Proceedings of the International Seed Testing Association* **23** (2), 340-354.

Lewis J (1961). The influence of water level, soil depth and type on the survival of crop and weed seeds. *Proceedings of the International Seed Testing Association* **26** (1), 68-85.

Lewis J (1973). Longevity of crop and weed seeds: survival after 20 years in soil. *Weed Research* **13**, 179-191.

Liu D L & Christians N E (1997). Inhibitory activity of corn gluten hydrolysate on monocotyledonous and dicotyledonous species. *HortScience* **32** (2), 243-245.

Long H C (1938). Weeds of Arable Land. *MAFF Bulletin No.* **108**, 2nd edition. HMSO, London, UK.

Lousley J E & Kent D H (1981). Docks and knotweeds of the British Isles. *BSBI Handbook No.* **3**. Botanical Society of the British Isles, London.

MacKay D B (1964). The incidence and significance of injurious weed seeds in crop seed. *Proceedings 7th British Weed Control Conference*, Brighton, UK, 583-591.

MAFF (1956). Docks and Sorrels. *Advisory Leaflet No*. **46**. HMSO, Edinburgh, UK.

Marten G C, Sheaffer C C, Wyse D L (1987). Forage nutritive value and palatability of perennial weeds. *Agronomy Journal* **79** (6), 980-986.

Masalles R M, Pino J, Sans F X (1997). The role of population dynamics on the non-chemical weed control. *Proceedings of the Third ENOF Workshop – Resource use on organic farming*, Ancona, 107-112.

Masuda Y, Nishimura T, Kobayashi T, Yamano D, Nakano Y, Goto I (1984). Germination ability of *Rumex obtusifolius* L. in silages. *Science Bulletin of the Faculty of Agriculture, Kyushu University*, **38**, 181-185.

Maun M A (1974). Viability of *Rumex crispus* seeds harvested at different stages of maturity. *Canadian Journal of Plant Science* **54**, 547-552.

Maun M A & Cavers P B (1971a). Seed production and dormancy in *Rumex crispus*. I. The effects of removal of cauline leaves at anthesis. *Canadian Journal of Botany* **49** (7), 1123-1130.

Maun M A & Cavers P B (1971b). Seed production and dormancy in *Rumex crispus*. II. The effects of removal of various proportions of flowers at anthesis. *Canadian Journal of Botany* **49** (10), 1841-1848.

McRill M (1974). The ingestion of weed seeds by earthworms. *Proceedings 12th British Weed Control Conference*, Brighton, UK, 519-524.

Measures M (2000). Undersowing. *Elm Farm Research Centre Bulletin No.* **48**, March 2000, 10.

Meneghini M, Vicente M, Noronha A B (1968). Effect of temperature on dark germination of *Rumex obtusifolius* L. seeds. A tentative model. *Arquivos do Instituto Biológico* **35** (1), 33-38.

Milberg P (1997). Weed seed germination after short-term light exposure: germination rate, photon fluence response and interaction with nitrate. *Weed Research* **37**, 157-164.

Mohler C L (1993). A model of the effects of tillage on emergence of weed seedlings. *Ecological Applications* **3** (1), 53-73.

Mohler C L & Teasdale J R (1993). Response of weed emergence to rate of *Vicia villosa* Roth and *Secale cereale* L. residue. *Weed Research* **33**, 487-499.

Monaco T J & Cumbo E L (1972). Growth and development of curly dock and broadleaf dock. *Weed Science* **20** (1), 64-67.

Morse R & Palmer R (1925). *British weeds their identification and control*. Ernest Benn Ltd, London, UK.

NAAS (1949). Docks and Sorrels. *Advisory Leaflet No*. **46**. HMSO, London, UK.

Niggli U, Nösberger J, Lehmann J (1993). Effects of nitrogen fertilization and cutting frequency on the competitive ability and the regrowth capacity of *Rumex obtusifolius* L. in several grass swards. *Weed Research* **33**, 131-137.

Noronha A, Vicente M, Silberschmitd (1971). The influence of the seed-coat on the germination of the photosensitive seeds of *Rumex obtusifolius* L. *Arquivos do Instituto Biológico*, S. Paulo, **38** (1), 19-25.

Nuoffer G G (1993). Biological weed control with goats. *Communications of the 4th International Conference I.F.O.A.M. Non Chemical Weed Control*, Dijon, France, 207-211.

Omrod J F (1966). Weeds and the farmer. *Proceedings 8th British Weed Control Conference*, Brighton, UK, 861-864.

Oswald A K & Haggar R T (1983). The effects of Rumex obtusifolius on the seasonal yield of two mainly perennial ryegrass swards. *Grass and Forage Science* **38**, 187-191.

Pawlowski F, Kapeluszny J, Kolasa A, Lecyk Z (1967). Fertility of some species of ruderal weeds. *Annales Universitatis Mariae Curie-Sklodowska Lublin-Polonia* **22** (15), 221-231.

Peel S & Hopkins A (1980). The incidence of weeds in grassland. Proceedings 1980 *British Crop Protection Conference – Weeds*, Brighton, UK, 877-890.

Pekrun C & Claupein W (2006). The implication of stubble tillage for weed population dynamics in organic farming. *Weed Research* **46**, 414-423.

Pekrun C, Hofrichter V, Link J, Thumm U, Claupein W (2005). [Influencing generative reproduction of *Rumex obtusifolius* by agronomic means. *8 Wissenschaftstagung Ökologischer Landbau – Ende der Nische*, Kassel, 265-268.

Pekrun C, Jund D, Hofrichter V, Wagner S, Thumm U, Claupein W (2002). [Indirect means of weed control against *Rumex* spec. on arable fields and grassland in organic farming]. *Zeitschrift Pflanzenkrankheiten Pflanzenschutz*, **18**, 533-540.

Philipps L, Welsh J, Braithwaite A, Turner B (2003). Dock control strategies. *Elm Farm Research Centre Bulletin* (March 2003), 4.

Pino J, Sans F X, Masalles R M (1993). The effect of periodical shoot removal on *Rumex obtusifolius* L. establishment in irrigated alfalfa (*Medicago sativa* L.) crops *Communications of the 4th. International Conference I.F.O.A.M. Non Chemical Weed Control*, Dijon, France, 327-332.

Pino J, Haggar R J, Sans F X, Masalles R M, Sackville Hamilton R N (1995). Clonal growth and fragment regeneration of *Rumex obtusifolius* L. *Weed Research* **35**, 141-148.

Pino J, Sans F X, Masalles R M (1997). Effects of intrinsic and environmental factors on seedling survival of *Rumex obtusifolius* in Mediterranean alfalfa crops. *Canadian Journal of Botany* **75**, 939-945.

Pino J, Sans F X, Masalles R M (1998). Population dynamics of *Rumex obtusifolius* under contrasting lucerne cropping systems. *Weed Research* **38**, 25-33.

Pleasant J MT & Schlather K J (1994). Incidence of weed seed in cow (*Bos* sp.) manure and its importance as a weed source for cropland. *Weed Technology* **8**, 304-310.

Popay I & Stiefel W (1994). Non- chemical control of couch and broad-leaved dock. *Proceedings 10th International IFOAM Conference*, Lincoln, New Zealand, 1-3.

Popay I, Stiefel W, Daly M (1994). Weeds in organic crops. *Proceedings 10th International IFOAM Conference*, Lincoln, New Zealand, 4 pp.

Rademacher B, Koch W, Hurle K (1970). Changes in the weed flora as a result of continuous cropping of cereals and the annual use of the same weed control measures since 1956. *Proceedings of the 10th British Weed Control Conference*, Brighton, UK, 1-6.

Roberts E H & Totterdell S (1981) Seed dormancy in *Rumex* species in response to environment factors. *Plant, Cell and Environment* **4**, 97-106.

Roberts H A & Chancellor R J (1986). Seed banks of some arable soils in the English midlands. *Weed Research* **26**, 251-257.

Roberts H A & Neilson J E (1980). Seed survival and periodicity of emergence in some species of *Atriplex, Chenopodium, Polygonum* and *Rumex*. *Annals of Applied Biology* **94**, 111-120.

Roberts R A & Hughes E W (1939). Biological studies in the control of docks (*Rumex* spp.). *Welsh Journal of Agriculture* **15**, 218-317.

SAC (1986). The control of docks. *Publication No*. **56**, The Scottish Agricultural Colleges.

Salisbury E J (1961). *Weeds and Aliens*. Collins, London, UK.

Schroeder D, Mueller-Schaerer H, Stinson C A S (1993). A European weed survey in 10 major crop systems to identify targets for biological control. *Weed Research* **33** (6), 449-458.

Schubiger F X, Défago G, Kern H, Sedlar L (1986). Damage to *Rumex crispus* L. and *Rumex obtusifolius* L. caused by the rust fungus *Uromyces rumicis* (Schum.) Wint. *Weed Research* **26** (5), 347-50.

Short W (2005). All out attack will beat docks in organic grass. *Farmers Weekly* **143** (13), 53.

Shull H (1962). Weeds in irrigation water. *Weeds* **10**, 248-249.

Simpson N A & Jefferson R G (1996). Use of farmyard manure on semi-natural (meadow) grassland. *English Nature Research Report No.* **150**, English Nature, Peterborough, UK.

Smith R W & Whittaker J B (1980a). Factors affecting *Gastrophysa viridula* populations (Coleoptera: Chrysomelidae) in different habitats. *Journal of Animal Ecology* **49**, 537-548.

Smith R W & Whittaker J B (1980b). The influence of habitat type on the population dynamics of *Gastrophysa viridula* Degeer (Coleoptera: Chrysomelidae). *Journal of Animal Ecology* **49**, 225-236.

Soil Association (2002). Organic weed and scrub control on nature conservation sites. *Soil Association Technical Guide*, Soil Association Producer Services, Bristol, UK.

Speight R I & Whittaker J B (1987). Interactions between the Chrysomelid beetle *Gastrophysa viridula*, the weed *Rumex obtusifolius* and the herbicide asulam. *Journal of Applied Ecology* **24**, 119-129.

Stace C (1997). *New Flora of the British Isles*, Second edition, Cambridge University Press, Cambridge, UK.

Stevens O A (1932). The number and weight of seeds produced by weeds. *American Journal of Botany* **19**, 784-794.

Stevens O A (1957). Weights of seeds and numbers per plant. *Weeds* **5**, 46-55.

Takaki M, Kendrick R E, Dietrich S M C (1981). Interaction of light and temperature on germination of *Rumex obtusifolius* L. *Planta* **152**, 209-214.

Tansley A G (1949). The British Islands and their vegetation. Volume II, 2nd Edition, Cambridge University Press.

Taylorson R B & Borthwick H A (1969). Light filtration by foliar canopies: significance for light-controlled weed seed germination. *Weed Science* **17**, 48-51.

Taylorson R B & Dinola L (1990). Phytochrome and membrane behaviour as influenced by temperature and anaesthetic treatment of *R. crispus* seeds. *Seed Science & Technology* **18**, 549-558.

Taylorson R B & Hendricks S B (1972). Phytochrome control of germination of *Rumex crispus* L. seeds induced by temperature shifts. *Plant Physiology* **50**, 645-648.

Taylorson R B & Hendricks S B (1973). Phytochrome transformation and action in seeds of *Rumex crispus* L. during secondary dormancy. *Plant Physiology* **52**, 475-479.

Thompson K, Grime J P, Mason G (1977). Seed germination in response to diurnal fluctuations of temperature. *Nature* **267** (5607), 147-149.

Thompson A J, Jones N E, Blair A M (1997). The effect of temperature on viability of imbibed weed seeds. *Annals of Applied Biology* **130**, 123-134.

Thompson K & Whatley J C (1983). Germination responses of naturally-buried weed seeds to diurnal temperature fluctuations. *Aspects of Applied Biology* **4**, *Influence of environmental factors on herbicide performance and crop and weed biology*, 71-76.

Tonkin J H B (1968). The occurrence of broad-leaved weed seeds in samples of cereals tested by the Official Seed testing Station, Cambridge. *Proceedings 9th British Weed Control Conference*, Brighton, UK, 1199-1204.

Tonkin J H B (1982). The presence of seed impurities in samples of cereal seed tested at the Official Seed Testing Station, Cambridge in the period 1978-1981. *Aspects of Applied Biology* **1**, *Broad-leaved weeds and their control in cereals*, 163-171.

Tonkin J H B & Phillipson A (1973). The presence of weed seeds in cereal seed drills in England and Wales during spring 1970. *The Journal of the National Institute of Agricultural Botany* **13**, 1-8.

Toole E H & Browne E (1946). Final results of the Duvel buried seed experiment. *Journal of Agricultural Research* **72**, 201-206.

Totterdell S & Roberts E H (1979). Effects of low temperatures on the loss of innate dormancy and the development of induced dormancy in seeds of *Rumex obtusifolius* L. and *Rumex crispus* L. *Plant, Cell and Environment* **2**, 131-137.

Tretyn A, Kopcewicz J, Slesak E (1988). Interaction of light and the cholinergic system in the regulation of seed germination. *Biologia Plantarum (Praha)* **30** (5), 338-342.

Trevelyan J (2001). Work-rate predictor charts. Lazy Dog Tools Ltd

Trimen H (1873). On *Rumex obtusifolius*. *The Journal of Botany* (2nd Series) **2**, 128-132.

UKMANI (1974). Biology and control of Rumex species in grassland. *Annual Report on Research and Technical Work of the Ministry for Northern Ireland*, 95.

Van Assche J A & Van Nerum D M (1997). The influence of the rate of temperature change on the activation of dormant seeds of *Rumex obtusifolius* L. *Functional Ecology* **11**, 729-734.

Van Eekeren N, Fehér L, Smeding F, Prins U, Jansonius P (2006). Controlling broad-leaved dock (*Rumex obtusifolius*) in grass clover mixtures. *Grassland Science in Europe,* Vol. **II**, 391-393. http://orgprints.org/8622/

Vervuren P J A, Beurskens S M J H, Blom C W P M (1999). Light acclimation, CO_2 response and long-term capacity of underwater photosynthesis in three terrestrial plant species. *Plant, Cell and Environment* **22** (8), 959-968.

Vicente M, Engelhardt M, Silberschmidt K (1962). The influence of temperature on the germination response to light of seeds of *Rumex obtusifolius* L. *Phyton* **19** (2), 163-167.

Vicente M, Noronha A B, Silberchmidt K, Meneghini M (1968). Successive reversion of the effect of temperature on germination of *Rumex obtusifolius* L. by far-red light. *Phyton* **25** (1), 11-13.

Vincent E M & Cavers P B (1978). The effects of wetting and drying on the germination of *Rumex crispus. Canadian Journal of Botany* **56** (18), 2207-2217.

Vincent E M & Roberts E H (1977). The interaction of light, nitrate and alternating temperatures in promoting the germination of dormant seeds of common weed species. *Seed Science & Technology* **5**, 659-670.

Voesenek L A C J & Blom C W P M (1987). Rooting patterns of *Rumex* species under drained conditions. *Canadian Journal of Botany* **65**, 1638-1642.

Voesenek L A C J & Blom C W P M (1989). Growth responses of *Rumex* species in relation to submergence and ethylene. *Plant Cell and Environment* **12**, 433-439.

Voesenek L A C J, Blom C W P M, Pouwels R H W (1989). Root and shoot development of *Rumex* species under waterlogged conditions. *Canadian Journal of Botany* **67**, 1865-1869.

Voesenek L A C J, Van Oorschot F J M M, Smits A J M, Blom C W P M (1993). The role of flooding resistance in the establishment of *Rumex* seedlings in river flood plains. *Functional Ecology* **7**, 105-114.

Waghorn G C & Jones W T (1989). Bloat in cattle 46. Potential of dock (*Rumex obtusifolius*) as an antibloat agent for cattle. *New Zealand Journal of Agricultural Research* **32**, 227-235.

Weaver S E & Cavers P B (1979a). Dynamics of seed populations of *Rumex crispus* and *Rumex obtusifolius* (Polygonaceae) in disturbed and undisturbed soil. *Journal of Applied Ecology* **16**, 909-917.

Weaver S E & Cavers P B (1979b). The effects of date of emergence and emergence order on seedling survival rates in *Rumex crispus* and *R. obtusifolius*. *Canadian Journal of Botany* **57** (7), 730-738.

Weaver S E & Cavers P B (1980). Reproductive effort of two perennial weed species in different habitats. *Journal of Applied Ecology* **17**, 505-513.

Wellington P S (1959). Assessment and control of the dissemination of weeds by crop seeds. In: *The Biology of Weeds*, (Ed. J L Harper). A symposium of the British Ecological Society, Oxford, UK, 94-107.

Wells D (1985). Some ecological aspects of the management of vegetation. *Proceedings of the Brighton Crop Protection Conference – Weeds,* Brighton, UK, 973-982.

West J S, Hughes C, Fox R T V (2000). *Armillaria mellea* can infect the perennial weed, *Rumex obtusifolius,* in the UK. *Plant Pathology* **49**, 808.

Whittaker J B (1994). Physiological responses of leaves of *Rumex obtusifolius* to damage by a leaf miner. *Functional Ecology* **8**, 627-630.

Whittaker J B, Ellistone J, Patrick C K (1979). The dynamics of a Chrysomelid beetle *Gastrophysa viridula*, in a hazardous natural habitat. *Journal of Animal Ecology* **48**, 973-986.

Williams J T (1971). Seed polymorphism and germination II. The role of hybridisation in the germination polymorphism of *Rumex crispus* and *R. obtusifolius*. *Weed Research* **11**, 12-21.

Wilman D & Derrick R W (1994). Concentration and availability to sheep of N, P, K, Ca, Mg and Na in chickweed, dandelion, dock, ribwort and spurrey, compared with perennial ryegrass. *Journal of Agricultural Science* **122**, 217-223.

Wilman D, Derrick R W, Moseley G (1997). Physical breakdown of chickweed, dandelion, dock, ribwort, spurrey and perennial ryegrass when eaten by sheep and when macerated. *Journal of Agricultural Science* **129**, 419-428.

Wilman D & Riley J A (1993). Potential nutritive value of a wide range of grassland species. *Journal of Agricultural Science* **120**, 43-49.

Wilson R G Jr (1980). Dissemination of weed seeds by surface irrigation water in Western Nebraska. *Weed Science* **28**, 87-92.

Zaller J G (2004). Ecology and non-chemical control of *Rumex crispus* and *R. obtusifolius* (Polygonaceae): a review. *Weed Research* **44**, 414-432.

Zimdahl R L (1993). *Fundamentals of Weed Science.* Academic Press, Inc.