The biology and non-chemical control of Cleavers (*Galium aparine* L.)

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

Cleavers
(beggar lice, catchweed bedstraw, cliders, clithe, cliver, goosebill, goose-grass, gripgrass, hariff, sticky willie)
***Galium aparine* L.**

Occurrence
Cleavers is a native winter to summer annual herb found in fields and hedgerows (Clapham *et al.*, 1987; Stace, 1997). It is a frequent garden weed (Copson & Roberts, 1991). It also occurs on maritime shingle beaches (Taylor, 1999). It is common in the UK and has been recorded up to 1,500 ft (Salisbury, 1961). In early surveys of Bedfordshire, Hertfordshire and Norfolk, cleavers was generally distributed, occasionally frequent on both heavy loams and light land but never dominant (Brenchley, 1911; 1913). It is considered an indicator of loam (Hanf, 1970). Cleavers is well adapted to making effective use of high nitrogen levels (Mahn, 1988), and prefers nutrient-rich soils (Malik & Vanden Born, 1988). The requirement for phosphate and nitrogen limits the distribution of cleavers (Taylor, 1999). It is most frequent on soils with a pH of 5.5 to 8.0. Cleavers establishes well after soil disturbance and forms dense patches (Weber, 2003). It develops a more extensive root system than many other plants allowing it to survive better under dry conditions (Holm *et al.*, 1977).

In the UK, cleavers is a predominant weed of winter cereals where it may grow over and drag down the crop helped by its spiny stems and leaves. It renders harvesting operations difficult (Long, 1938). In a survey of conventional cereal crops in central southern England in 1982, cleavers was the most frequent broad-leaved weed (Chancellor & Froud-Williams, 1984). In a survey of conventional winter oilseed rape in the same area in 1985 it was again the most frequent weed being found in 57% of fields (Froud-Williams & Chancellor, 1987). Cleavers' seed was found in 4% of arable soils in a seedbank survey in Scotland in 1972-1978 (Warwick, 1984). A study of changes in the weed flora of southern England between the 1960s and 1997 suggested that cleavers had become more common (Marshall *et al.*, 2003). In a survey of UK cereal field margins recorded as part of Countryside 2000, cleavers was the second most frequent species recorded (Firbank *et al.*, 2002). In arable fields in France cleavers is common in the emerged vegetation but less well represented in the soil seedbank (Barralis & Chadoeuf, 1987). In a comparison of the ranking of arable weed species in unsprayed crop edges in the Netherlands in 1956 and in 1993, cleavers had moved up from 21st to 13th place (Joenje & Kleijn, 1994). In a series of 4 national weed surveys made in Hungary between 1950 and 1997, cleavers moved from 137th to 10th place in the rankings (Tóth *et al.*, 1999; 1997). In 1993, a survey of the most important weeds according to European weed scientists ranked cleavers as an important weed in winter and spring cereals and winter rape (Schroeder *et al.*, 1993).

The occurrence of morphologically distinct ecotypes has been reported (Froud-Williams & Ferris-Kaan, 1991). Some of the differences are related to habitat. Plants from selected populations varied in biomass, height and other characters (Hill & Courtney, 1991). Both provenance and genetic factors were thought to be responsible. Seed from hedgerow plants was found to be less dormant than the seed from arable plants (Froud-Williams, 1985). However, the species is often found spreading from the hedge bottom into arable fields (Marshall, 1985; 1989). DNA studies detected limited differences between arable and non-arable plants that are possibly linked with the germination requirements (Mitchelson *et al.,* 1995). The effect may be to spread the period of germination from autumn through into spring and avoid the losses that can occur due to autumn cultivations. Potential variability due to polyploidy enables cleavers to respond to changing environmental conditions (Taylor, 1999). Seedlings from scrambling, upright hedgerow plants have the bushy prostrate habit characteristic of cleavers from open shingle habitats if grown without support.

The stem nematode, *Ditylenchus dipsaci*, can infest cleavers (Franklin, 1970).

Cleavers has medicinal and therapeutic uses (Barker, 2001). It has been used for food processing and animal feed (Defelice, 2002). Cleavers is a very frequent birdseed alien (Hanson & Mason, 1985). The roasted seeds are said to be one of the best substitutes for coffee, however, its medicinal use as a laxative and as an emetic would suggest that consumption should be in moderation. Anthroquinones in the sap may cause skin irritation. Cleavers accumulates potassium (Salisbury, 1962a).

Biology

Cleavers flowers from June to August (Clapham *et al.*, 1987; Stace, 1997), and May to November (Hanf, 1970). The flowers are self-pollinated. Seed is set from July to October (Grime *et al.,* 1988). The average number of seeds per plant is 300-400 but counts of over 1,000 seeds per plant have been recorded (Malik & Vanden Born, 1988). The average seed number per plant is 375 according to Pawlowski *et al.* (1970). Stevens (1957) gives the seed numbers per plant as 105 but quotes other authors giving figures of up to 360. Hanf (1970) suggests 300 to 400 seeds. Guyot *et al.*, (1962) give the seed number as 300 to 1,200 per plant and the 1,000 seed weight as 7.6 g. In a study of seed from several distinct populations the 1,000 seed weight ranged from 5.6 to 9.5 g (Hill & Courtney, 1991).

Fresh seed has been reported to germinate readily. Laboratory studies showed that the optimum temperature for germination varies with seed age (Hirdina, 1959). Young seed germinated best between 2 and 10^{o}C, while seed several years old germinated more readily at between 10 and 20^{o}C. Under natural conditions in the field germination usually ceases at 15^{o}C. Fresh seeds germinate better in the dark than in the light, the optimum germination temperature is 12-15^{o}C (Åberg, 1956). One year old seeds germinate equally-well in darkness and under low light levels. On the soil surface, germination is inhibited by light and seeds do not germinate unless covered with soil (Malik & Vanden Born, 1988). Germination was relatively high in alternating temperatures in darkness or under a green ‘safe’ light but much lower at a constant temperature (Grime *et al.,* 1981). Dormancy is broken by chilling (Grime *et al.*, 1988). Buried seed loses dormancy in the autumn and gradually acquires it again in spring to become totally dormant between May and August. Dormancy is released again during late-summer and early autumn. The level of seed germination increased from 36 to 100% following a 1-month period of moist storage at 5^{o}C (Grime *et al.*, 1981). Seeds kept outdoors in moist soil overwinter, exhumed in darkness and put to germinate in 12 hours per day light, in darkness following a 5 second light flash or in complete darkness gave 47%, 33% and 29% germination respectively (Andersson *et al.*, 1997).

In the field, seeds germinate late in the year, throughout the winter under mild conditions and into early spring (Holm *et al.*, 1977). Seedling emergence begins between mid-September and mid-October (Taylor, 1999). Germination occurs over a protracted period meaning seedlings are at a range of growth stages (Grime *et al.*, 1988). Seed from distinct populations differed in the time to 50% germination from 13.4 to 16.5 days (Hill & Courtney, 1991). Seedlings are not damaged by frost (Malik & Vanden Born, 1988; Salisbury 1962b). Tolerance increases from -7^{o}C in late autumn to -17^{o}C in early winter but then decreases again as spring approaches (Taylor, 1999).

Seeds from different populations vary in their response to light and nitrate, they also differ in dormancy level (Froud-Williams, 1985). Seed from hedgerow plants is less dormant than seed from plants in the cultivated fields and germinates over a wider temperature range. Controlled environment studies have found that seedlings from hedgerow and arable populations of cleavers differ in the requirement for vernalisation (van der Weide, 1992). Data from these studies has allowed the development rates and flowering dates of plants with different emergence dates to be predicted. Daylength and the maximum temperature were the most important factors in determining the period between emergence and flowering, soil moisture level and light intensity were less important.

Seedling emergence recorded at monthly intervals for seeds mixed into the top 20 mm of soil occurred from August to May with a peak in March-April (Chancellor, 1979). The seedlings were removed after recording and the soil stirred thoroughly. Seed sown at different depths with and without cultivation in soil in pots and boxes in the field, emerged in low numbers through the winter, spring and summer when left on the soil surface (Froud-Williams *et al.*, 1984). Emergence occurred in winter when seed was buried at 25 mm and the soil left uncultivated, and when seed was buried at 75 mm and cultivated in February or June. Surface sowing generally gave poorer germination than burial. In fields and hedgerows, emergence patterns varied both between and within populations (Cussans & Ingle, 1999). Most emergence was in the autumn but around 7% of seeds germinated in spring from March to May.

In Sweden cleavers is considered a winter annual (Håkansson, 1979). Seeds mixed with soil in the autumn, put in frames in the field, exhumed at intervals and put to germinate at alternating temperatures emerged mainly in the autumn after sowing. Very few seeds remained to germinate in the following year.

The optimum depth for emergence was 25 to 50 mm, the maximum was 100 mm according to Froud-Williams (1985). Malik & Vanden Born (1988) found optimal emergence occurred from depths of 20 to 50 mm. The maximum depth of emergence varied between 40 and 200 mm. Field seedlings in a sandy loam soil emerged from the top 150 mm of soil with the majority evenly spread down to 100 mm (Unpublished results). Cleavers was less sensitive to depth of burial and fineness of the seedbed than smaller seeded species (Cussans *et al.*, 1996). In greenhouse studies surface seeds and those below 60 mm deep had significantly lower emergence than seeds at 10-40 mm deep (Boyd & Van Acker, 2003). Exposure to light inhibited seed germination.

Following seed germination and emergence in autumn, cleavers seedlings reach a height of 10-20 cm, at which stage they overwinter (Taylor, 1999). Stem elongation begins in April and the first flowers appear at the beginning of June. Cleavers has a high nitrogen requirement and is encouraged by late nitrogen applications to cereal crops (Hirdina, 1959). Seedling growth is slow to begin with but reaches a peak as the cereals begin to head. The dry weight of a plant increases considerably in the summer often doubling between June and July (Wilson & Wright, 1987). Cleavers is able to take advantage of wet summers but there can be considerable variation in the weight of individual plants.

Persistence and Spread

Thompson *et al.* (1993) suggest that based on seed characters, cleavers seed is likely to persist for less than 5 years. Viability in soils is limited to 2-3 years (Holm *et al.*, 1977; Malik & Vanden Born, 1988; Weber, 2003). Seeds stored in compost heaps were killed when temperatures exceeded 50^{o}C (Holm *et al.*, 1977). Seeds left in flooded soil for 20 days were no longer viable. Seed longevity in dry storage is given as 4-5 years (Guyot *et al.,* 1962).

The decline of seeds broadcast onto the soil surface and then ploughed-in was followed over a 6-year period of cropping with winter or spring wheat. The experiment was made on a clay and a silty loam soil. Every effort was made to prevent further seed return to the soil. Cleavers had a mean annual decline rate of 58% and an estimated time to 95% decline of 4-5 years (Lutman et al., 2002). Seedbank decline was also studied in a succession of autumn-sown crops (winter wheat & winter OSR) in fields ploughed annually for 3-4 years with seed return prevented. The annual rate of loss was 66%, the time to 99% decline was estimated at 3.6 years. Annual seedling emergence in any one year represented 2% of the seedbank (Wilson & Lawson, 1992). Cleavers seed sown in the field and followed over a 5 year period in winter wheat or spring barley showed an annual decline of around 80% (Barralis *et al.*, 1988). Emerged seedlings represented 15% of the seedbank. Seedling emergence declined considerably after year 3.

Computer based weed patch mapping has shown that patches of cleavers remain relatively stable from year to year but expand 1 to 3 m on the leading edge in the direction of harvesting and cultivation (Wheeler *et al.,* 2001).

When present in cereals harvested with a combine, cleavers seeds are found predominantly in the grain and gleanings with few present in the chaff (Petzold, 1956). A preliminary study in Sweden demonstrated that the number of weed seeds left on the ground after combine harvesting oats was much higher than when the crop was harvested with a binder, dried in shocks and then threshed (Åberg, 1956). There were over 15 times more cleavers seeds recorded on the soil surface after oats had been combine harvested.

The seeds are dispersed by water and by animals (Weber, 2003). The fruits' surface is covered with hooked bristles that cling to animals and clothing (Long, 1938). The seeds float in water. In a survey of weed seed contamination of grass and clover seed of English origin in 1960-61, cleavers seed was found in 1% of perennial ryegrass, 2% of Italian ryegrass, 3% of tall fescue, 1.6% of red fescue, 1.1% of meadow fescue and 3% of red clover samples tested (Gooch, 1963). In vegetable and root crop seed that year it was found in 12% of turnip, 27% of swede, 23% of mustard, 31% of sugar beet, 14% of fodder beet and 26% of mangel seed samples tested. Cleavers seeds have been found in cereal and other crop seed samples (Holm *et al*., 1977). In cereal seed samples tested in 1961-68 cleavers was one of the most frequent contaminants being found in up to 13% of rye, 7% of oats, 12% of barley and 12% of wheat samples tested (Tonkin, 1968). In a survey of weed seed contamination in cereal seed in drills ready for sowing on farm in spring 1970, it was found in 21% of samples (Tonkin & Phillipson, 1973). Most of this was home saved seed. In the period 1978-1981, cleavers seed was found in 19-29% of wheat and 10-19% of barley seed samples tested (Tonkin, 1982). The highest number of cleavers seeds recorded in a 125 g cereal sample was 322. Cleavers was again one of the most commonly recorded broad-leaved species. In cereal seed samples tested in 1986-97, cleavers was still found as a contaminant in up to 7% of oat, 3% of barley and 19% of wheat samples tested (Don, 1997).

Some species of ants may transport the seeds for short distances but do not appear to use them as a food source (Taylor, 1999). The seeds survive passage through the digestive systems of cattle, horses, pigs, goats, and birds (Holm *et al*., 1977). Seed has been found in cattle droppings and seedlings have been raised from the excreta of various birds (Salisbury, 1961). Viable seeds have been found in manure. Farmyard manure produced on farm or brought in may contain cleavers seeds from contaminated straw (Holm *et al*., 1977). After 2 weeks of windrow composting at temperatures of 50-65^{o}C, cleavers seeds were no longer viable (Tompkins *et al*., 1998). Seeds lost the capacity to germinate after 34 days in stored manure (Hirdina, 1959). Imbibed seeds in trays of moist soil held at 51^{o}C for 4 days lost viability (Thompson *et al*., 1997). Seed held at 155^{o}C for 10 minutes, 204^{o}C for 7.5 minutes or 262^{o}C for 5 minutes was killed.

Management

Control is aided by sowing only pure crop seeds (Holm *et al*., 1977). In particular, it is important to ensure the fruits are not present in cereal, clover and other larger crop seeds (Morse and Palmer, 1925). Control should aim to prevent seed production (Weber, 2003). Mulching the soil surface may prevent seed germination. Surface cultivations encourage the seeds to germinate and the emerged seedlings can then be killed by harrowing or ploughing.

Around 60% of freshly shed seeds will germinate and produce seedlings in the first year if the soil is surface cultivated only (Gerowitt & Scharlemann-Busse, 1999). If the land is ploughed seedling numbers drop to 20%, however, many of the buried seeds suffer fatal germination being unable to reach the soil surface. Unlike many weed seeds, cleavers seed does not persist in the soil and ploughing does not lead to the build up of an extensive soil seedbank (Cussans *et al*., 1987). Ploughing was more effective than minimum tillage in controlling cleavers in winter wheat (M^{c}Closkey *et al*., 1991). Minimum cultivation puts the shed weed seeds at the optimum depth for germination. There is the potential for a rapid increase of the cleavers population in non-ploughing cultivation systems where shed seeds are retained in the surface soil (Wilson & Wright, 1991). However, in winter cereals a large proportion of the cleavers seeds are removed with the harvested grain. Cleavers density increased with organic fertilizer applications in winter wheat under minimum tillage except in competition with barren brome (*Anisantha sterilis*) (McCloskey *et al.,* 1998).

Cleavers is favoured by winter cropping with cereals and oilseed rape. In winter cereals, harrowing with a tine weeder at an early crop stage can give a 79% reduction in density of the weed (Steinmann & Gerowitt, 1993). A second harrowing at a later crop stage improves the level of control. The weed seedlings need to be large enough to be caught by the tines. Herbicide studies suggest that cleavers can be left in winter wheat until March/April before removal without loss of yield (Wright, 2001). However, allowing the weed to remain until harvest reduced crop yield by 64%. At early crop stages, cleavers reduces grain number and later it reduces the fill of the remaining grains (Baylis & Watkinson, 1991). Autumn emerging cleavers has a greater effect on winter wheat yield than cleavers that emerges in spring (Cussans & Ingle, 1999). As cleavers germinates primarily in the autumn-winter it has been found to decrease markedly following a series of spring cereals (Rademacher *et al.*, 1970).

Cleavers has been identified as the most competitive broad-leaved weed in winter cereals and oilseed rape (Wilson & Wright, 1987; Lutman *et al.*, 1995). Even a low population can have an appreciable effect on yield and calculating a threshold level is not realistic. In addition, cleavers can increase rapidly from a low population that is left uncontrolled (Wilson & Wright, 1991). Almost complete control is needed to avoid the population increasing in subsequent crops. Zanin *et al.* (1993) determined the economic threshold for cleavers in winter wheat to be 2 plants per m^2 but its effect was much less in the absence of nitrogen. At low nitrogen levels the crop is more competitive but at high nitrogen levels, particularly at lower crop densities, cleavers is more competitive (Baylis & Watkinson, 1991). Also, the winter mortality of cleavers can vary with year and site and, although it is not as vulnerable as some weeds, any losses can affect predictions of yield reduction (Storkey *et al.*, 1997).

Seed numbers in soil were reduced by 85% following a 1-year fallow and by over 90% if fallowing was extended for a second year (Brenchley & Warington, 1933). The land was ploughed, disked and harrowed during this period. Seed numbers increased under cropping with winter wheat for the same period. Most of the increase was in year 2, perhaps due to cultural conditions that year. A long fallow period of 4 years appeared to eliminate the weed as no further seedlings appeared afterwards (Brenchley & Warrington, 1936). Fallowing every 5 years over a 15 year period reduced seed numbers in soil after the first fallowing by 80% (Brenchley & Warington, 1945). This level of seed numbers was maintained after each subsequent fallow year although numbers may have increased during the intervening cropped years.

Competition with sown species suppressed the growth of cleavers in headlands sown with grass or wildflower/grass mixes in comparison with unsown headlands that had been allowed to regenerate naturally (West *et al*., 1997). Growth is hindered in mixtures containing fast growing plants such as mustard or vetch (Hirdina, 1959). In winter cereals, growth and seed production was reduced in the presence of competitive weeds, particularly barren brome (*Anisantha sterilis*) (Lintell-Smith *et al.*, 1991). In arable field hedgerows in May, cleavers growth was more extensive in areas cut in the autumn compared with those cut in April (West & Marshall, 2001). In the longer term, sowing a native perennial seed mix created a botanically diverse hedge base habitat that inhibited re-invasion by annual weeds. In a five-year study of weed spread, a boundary strip 2 m wide was sown with perennial ryegrass, mown twice a year, or was kept bare and rotovated twice a year (Milson *et al.*, 1994). In comparison with a winter wheat cropped strip the boundary strips delayed the spread of cleavers from the hedge into the field but did not prevent it. There was little difference in efficacy between the boundary strip treatments.

In pot studies, corn gluten meal (CGM) applied pre-emergence and pre-plant incorporated at 324 g/m^2 reduced the survival of seedlings by 66% (Bingaman & Christians, 1995). A rate of 973 g/m^2 reduced survival by 94%. Root and shoot growth of the survivors was reduced more by the incorporated treatment. In laboratory tests, leachate from composted household waste decreased the germination of cleavers seed and in pot tests, covering the seeds with up to 3 cm depth of compost reduced seedling emergence (Ligneau & Watt, 1995).

Around 40 phytophagous insect species have been recorded on cleavers (Taylor, 1999). A downy mildew is found infecting some seedlings in spring and autumn. Cleavers is eaten by geese.

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

References

Åberg E (1956). Weed control research and development in Sweden. *Proceedings of the 3rd British Weed Control Conference*, Blackpool, England, 141-164.

Andersson L, Milberg P, Noronha A (1997). Germination response of weed seeds to light of short duration and darkness after stratification in soil. *Swedish Journal of Agricultural Research*, **27**, 113-120.

Barker J (2001). *The medicinal flora of Britain and Northwestern Europe,* Winter Press, West Wickham, Kent, UK.

Barralis G & Chadoeuf R (1987). Weed seed banks of arable fields. *Weed Research* **27**, 417-424.

Barralis G, Chadoeuf R, Lonchamp J P (1988). Longevity of annual weed seeds in cultivated soil. *Weed Research* **28**, 407-418.

Baylis J M & Watkinson A R (1991). The effect of reduced nitrogen fertilizer inputs on the competitive effect of cleavers (*Galium aparine*) on wheat (*Triticum aestivum*). *Proceedings of the Brighton Crop Protection Conference – Weeds*, Brighton, UK, 129-134.

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.

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 & Warington K (1933). The weed seed population of arable soil. II. Influence of crop, soil and method of cultivation upon the relative abundance of viable seeds. *The Journal of Ecology* **21** (1), 103-127.

Brenchley W E & Warington K (1936). The weed seed population of arable soil. III. The re-establishment of weed species after reduction by fallowing. *The Journal of Ecology* **24** (2), 479-501.

Brenchley W E & Warington K (1945). The influence of periodic fallowing on the prevalence of viable weed seeds in arable soil. *Annals of Applied Biology* **32** (4), 285-296.

Chancellor R J (1979). The seasonal emergence of dicotyledonous weed seedlings with changing temperature. *Proceedings 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.

Chepil W S (1946). Germination of weed seeds II. The influence of tillage treatment on germination. *Scientific Agriculture* **26** (8), 347-357.

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

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

Cussans J W & Ingle S (1999). The biology of autumn and spring emerging cleavers (*Galium aparine*) individuals. *Proceedings of the 1999 Brighton Conference – Weeds*, 231-236.

Cussans G W, Moss S R, Wilson B J (1987). Straw disposal techniques and their influence on weeds and weed control. *Proceedings of the 1987 British Crop Protection Conference – Weeds,* Brighton, 97-106.

Cussans G W, Raundonius S, Brain P, Cumberworth S (1996). Effects of depth of seed burial and soil aggregate size on seedling emergence of *Alopecurus Myosuroides, Galium aparine, Stellaria media* and wheat. *Weed Research* **36**, 133-141.

Defelice M S (2002). Catchweed bedstraw or cleavers, *Galium aparine* L. – a very 'sticky' subject. *Weed Technology* **16**, 467-472.

Don R (1997). Weed seed contaminants in cereal seed. *Proceedings of the Brighton Crop Protection Conference – Weeds*, Brighton, UK, 255-262.

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.

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

Froud-Williams R J (1985). The biology of cleavers (*Galium aparine*). *Aspects of Applied Biology* **9**, *The biology and control of weeds in cereals*, Cambridge, UK, 189-195.

Froud-Williams R J & Chancellor R J (1987). A survey of weeds of oilseed rape in central southern England. *Weed Research* **27**, 187-194.

Froud-Williams R J, Chancellor R J, Drennan D S H (1984). The effects of seed burial and soil disturbance on emergence and survival of arable weeds in relation to minimal cultivation. *Journal of Applied Biology* **21**, 629-641.

Froud-Williams R J & Ferris-Kaan R (1991). Intraspecific variation among populations of cleavers (*Galium aparine* L.). *Proceedings of the Brighton Crop Protection Conference – Weeds,* 1007-1014.

Gerowitt B & Scharlemann-Busse E (1999). Germination and emergence of *Galium aparine* L. as influenced by soil tillage. *Proceedings 11th EWRS Symposium*, Basel, 104.

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.

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

Grime J P, Mason G, Curtis A V, Rodman J, Band S R, Mowforth M A G, Neal A M, Shaw S (1981). A comparative study of germination characteristics in a local flora. *Journal of Ecology* **69**, 1017-1059.

Guyot L, Guillemat J, Becker Y, Barralis G, Demozay D, Le Nail Fr (1962). *Semences et Plantules des Principales des Mauvaises Herbes.* Association de Coordination Technique Agricole, Paris.

Håkansson S (1979). Seasonal influence on germination of weed seeds. *Proceedings of the EWRS Symposium: The influence of different factors on the development and control of weeds,* 73-80.

Hanf M (1970). *Weeds and their seedlings.* BASF UK Ltd.

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

Hill A L & Courtney A D (1991). The relative influence of genetic variation and provenance on the morphology and herbicide response of selected populations of *Galium aparine*. *Proceedings of the 1991 Brighton Crop Protection Conference – Weeds*, Brighton, UK, 1015-1022.

Hirdina Von F (1959). Beiträge zur biologie und bekämpfung des klettenlabkrautes (*Galium aparine* L.). *Zeitschrift für Acker- und Pflanzenbau* **109** (2), 173-194.

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

Joenje W & Kleijn D (1994). Plant distribution across arable field ecotones in the Netherlands. *BCPC Monograph No.* ***58****: Field margins: integrating agriculture and conservation*, 323-328.

Ligneau L A M & T A Watt (1995). The effects of domestic compost upon the germination and emergence of barley and six arable weeds. *Annals of Applied Biology* **126**, 153-162.

Lintell-Smith G, Watkinson A R, Firbank L G (1991). The effects of reduced nitrogen and weed-weed competition on the populations of three common cereal weeds. *Proceedings of the Brighton Crop Protection Conference-Weeds*, Brighton, UK, 135-140.

Long H C (1938). Weeds of arable land. *MAFF Bulletin* **108**, 2nd edition. HMSO, London, UK.

Lutman P J W, Bowerman P, Palmer G M, Whytock G P (1995). A comparison of the competitive effects of eleven weed species on the growth and yield of winter oilseed rape. *Proceedings Brighton Crop Protection Conference - Weeds*, Brighton, UK, 877-882.

Lutman P J W , Cussans G W, Wright K J, Wilson B J, McN Wright G, Lawson H M (2002). The persistence of seeds of 16 weed species over six years in two arable fields. *Weed Research* **42**, 231-241.

Mahn E-G (1988). Changes in the structure of weed communities affected by agro-chemicals – what role does nitrogen play? *Ecological Bulletins* **39**, 71-73

Malik N & Vanden Born W H (1988). The biology of Canadian weeds. 86. *Galium aparine* L. and *Galium spurium* L. *Canadian Journal of Plant Science* **68**, 481-499.

Marshall E J P (1985). Weed distributions associated with cereal field edges – some preliminary observations. *Aspects of Applied Biology* **9**, *The biology and control of weeds in cereals*, Cambridge, UK, 49-58.

Marshall E J P (1989). Distribution patterns of plants associated with arable field edges. *Journal of Applied Ecology* **26**, 247-257.

Marshall E J P, Brown V K, Boatman N D, Lutman P J W, Squire G R, Ward L K (2003). The role of weeds in supporting biological diversity within crop fields. *Weed Research* **43**, 1-13.

M^c^Closkey M, Firbank L G, Watkinson A R (1991). Interactions between three weed species of winter wheat in response to management practices. *Proceedings of the Brighton Crop Protection Conference – Weeds*, Brighton, UK, 791-798.

McCloskey M C, Firbank L G, Watkinson A R, Webb D J (1998). Interactions between weeds of winter wheat under different fertilizer, cultivation and weed management treatments. *Weed Research* **38**, 11-24.

Milson T P, Turley D, Lane P, Wright B, Donaghy S J, Moodie P (1994). Boundary strips in cereal fields: Dynamics of flora, weed ingress and implications for crop yield under different strip management regimes. *BCPC Monograph No* **58** *Field margin: integrating agriculture and conservations,* (Ed) N Boatman, 179-184.

Mitchelson K R, Knox O, Cheng J, Ford M A, Wilson F, Atkinson D (1995). Molecular markers for genetic diversity in cleavers (*Galium aparine*). *Proceedings of the Brighton Crop Protection Conference – Weeds*, Brighton, UK, 451-458.

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

Pawlowski F, Kapeluszny J, Kolasa A, Lecyk Z (1970). The prolificacy of weeds in various habitats. *Annales Universitatis Mariae Curie-Sklodowska Lublin-Polonia*, **25** (5), 61-75.

Petzgold K (1956). Combine-harvesting and weeds. *Journal of Agricultural Engineering Research* **1**, 178-181.

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.

Salisbury E J (1961). *Weeds & Aliens*. New Naturalist Series, Collins, London.

Salisbury E (1962a). The biology of garden weeds. Part II. *Journal of the Royal Horticultural Society* **87**, 458-470 & 497-508.

Salisbury E (1962b). The biology of garden weeds. Part I. *Journal of the Royal Horticultural Society* **87**, 338-350 & 390-404.

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.

Stace C (1997). *New Flora of the British Isles.* 2nd edition. Cambridge University Press, Cambridge, UK.

Steinmann H H & Gerowitt B (1993). Mechanical control of *Galium aparine* in winter wheat. *Proceedings of the 1993 IFOAM Conference,* 273-277.

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

Storkey J, Cussans J W, Lutman P J W, Blair A M (1997). The importance of mortality in weed populations between autumn and spring on the reliability of yield loss predictions in winter wheat. *Proceedings of the 1997 Brighton Crop Protection Conference – Weeds,* 1025-1030.

Taylor K (1999). Biological flora of the British Isles, *Galium aparine* L. *Journal of Ecology* **87**, 713-730.

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, Band S R, Hodgson J G (1993). Seed size and shape predict persistence in soil. *Functional Ecology* **7**, 236-241.

Tomkins D K, Chaw D, Abiola A T (1998). Effect of windrow composting on weed seed germination and viability. *Compost Science & Utilization* **6** (1), 30-34.

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, 1199-1205.

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. *Journal of the National Institute of Agricultural Botany* **13**, 1-8.

Tóth Á, Benécsné G B, Balázs G (1997). Changes in field weeds in Hungary during the last 46 years. *Proceedings of the 1997 Brighton Conference – Weeds*, 249-254.

Tóth Á, Benécs-Bárdi G, Balzás G (1999). Results of national weed surveys in arable land during the past 50 years in Hungary. *Proceedings of the 1999 Brighton Conference – Weeds*, 805-810.

Van der Weide R Y (1990). Phenology of arable and hedgerow populations of *Galium aparine* L. in relation to climate and soil conditions. *Weed Research* **32**, 249-258.

Warwick M A (1984). Buried seeds in arable soils in Scotland. *Weed Research* **24**, 261-268.

Weber E (2003). *Invasive plant species of the world. A reference guide to environmental weeds*. CABI Publishing, Cambridge, UK.

West T M & Marshall E J P (2001). Increasing botanical diversity and reducing weed abundance in degraded hedge-bases. *Proceedings of the BCPC Conference - Weeds,* Brighton, UK, 727-732.

West T M, Marshall E J P, Arnold G M. (1997). Can sown field boundary strips reduce the ingress of aggressive field margin weeds?. *Proceedings of the Brighton Crop Protection Conference - Weeds,* Brighton, UK, 985-990.

Wheeler H C, Miller P C H, Perry N H, Lutman P J W, Hull R I (2001). A map-based system for patch spraying weeds – system control. *Proceedings of the BCPC Conference - Weeds*, Brighton, UK, 847-852.

Wilson B J & Lawson H M (1992). Seedbank persistence and seedling emergence of seven weed species in autumn-sown crops following a single year's seeding. *Annals of Applied Biology* **120**, 105-116.

Wilson B J & Wright K J (1987). Variability in the growth of cleavers (*Galium aparine*) and their effect on wheat yield. *Proceedings of the British Crop Protection Conference - Weeds*, Brighton, UK, 1051-1058.

Wilson B J & Wright K J (1991). Effects of cultivation and seed shedding on the population dynamics of *Galium aparine* in winter wheat crops. *Proceedings of the British Crop Protection Conference - Weeds*, Brighton, UK, 813-820.

Wright K J (2001). Competition between *Galium aparine* and winter wheat: optimum timing of herbicide application to minimise yield loss. *Proceedings of the BCPC Conference - Weeds*, Brighton, UK, 615-620.

Zanin G, Berti A, Toniolo L (1993). Estimation of economic thresholds for weed control in winter wheat. *Weed Research* **33**, 459-467.