The biology and non-chemical control of Charlock (*Sinapis arvensis* L.)

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Charlock

(bastard rocket, birdseed, field mustard karlock, kedlock, kilk, kinkle, redlock, shallock, yellows, wild mustard, willkail)

***Sinapis arvensis* L**

(*Brassica arvensis* (L.) Ktze, *B. sinapis* Visiani, *B. sinapistrum* Boiss., *B. kaber* (DC.) L.C.)

Occurrence

Charlock is a summer or winter annual. It is distributed throughout the UK but is only plentiful in artificial communities subject to disturbance by human activity. Charlock is possibly native and was once considered the most troublesome weed of arable land in Britain (Long, 1938). Charlock also occurs on wasteland, tips and roadsides (Stace, 1997). It is frequent on clay and heavy soil, also on chalk and occasionally on sand, light loam and peaty agricultural soil. It is especially prevalent on calcareous loams. It was thought to increase with the calcium carbonate content of the soil (Fogg, 1950). Charlock is characteristic of neutral to alkaline soils but it may occur on weakly acid soils. It is not found on acid soils (Hanf, 1970).

In early surveys it was found as often among one type of arable crop as another but was especially dominant in cereals (Brenchley, 1920). However, it is more of a problem in spring-sown than autumn-sown crops (Clapham *et al.*, 1987). It was relatively common in a survey of weeds in spring cereals in N E Scotland in 1985 (Simpson & Carnegie, 1989). In a study of seedbanks in some arable soils in the English midlands sampled in 1972-3, charlock was recorded in 28% of the fields sampled in Oxfordshire and 53% of those in Warwickshire but only in low numbers (Roberts & Chancellor, 1986). Charlock seed was found in 1% of arable soils in a seedbank survey in Scotland in 1972-1978 (Warwick, 1984). In a series of 4 national weed surveys made in Hungary between 1950 and 1997, charlock moved from 22nd to 19th place in the rankings (Tóth *et al.*, 1997). In the UK it was still abundant in cultivated areas in 1950 but charlock became less abundant worldwide following the introduction of hormone weedkillers (Fogg, 1950). However, recently in the USA high densities have been recorded in organic and other low-input systems (Warwick *et al.*, 2000). In trials in Denmark from 1969-1988, charlock was common in spring-sown arable crops (Jensen, 1991). When present it made up a relatively large proportion of the weed biomass.

A high degree of within population variation was observed in 13 populations of charlock in the UK, tested using DNA analysis (Moodie *et al.*, 1997). The populations chosen had been subjected to a range of herbicide and cultural regimes. The level of variation was greater when the assessment was made over two consecutive seasons. A variety with whitish yellow flowers and others forms with glabrous or with hairy pods have been recorded (Fogg, 1950).

Charlock is a carrier of pests and diseases of various crop species (Fogg, 1950). It is susceptible to club root disease and white blister. Many of the insects found on cultivated brassicas also live on charlock. It is a host of turnip fly and the turnip-gall weevil (Long, 1938). It is also a host of turnip flea beetle, cabbage root fly, diamond back moth and leather jackets (Morse & Palmer, 1925). Charlock can carry a number of nematode species that also affect important crops (Thurston, 1970).

Charlock seeds that contaminate oilseed rape at harvest will increase the linolenic and erucic acid levels in extracted oil (Warwick *et al.*, 2000). Charlock is reputed to be poisonous to stock but only after flowering (Chancellor, 1959). The seedpods when present are likely to cause poisoning to stock but rest of the plant is harmless (Forsyth, 1968). The seeds are dangerous if eaten by stock, and have been found to occur in oil cake with serious results for horses and cattle. The seed is an important constituent in the diet of many farmland birds including linnets (*Carduelis cannabina*) (Moorcroft *et al.*, 1997). Charlock can be introduced as a birdseed alien (Hanson & Mason, 1985).

Biology

Charlock generally flowers from May to July, sometimes into the autumn. In plants that germinated the previous autumn, flowering may begin as early as March or April. Plants from successive flushes of germinating seeds mature and flower through the summer (MAFF, 1947). Plants can begin to flower 6 weeks after emergence and will continue to flower for a further 6 weeks (Fogg, 1950). Occasional plants may flower in December. Plants are self-incompatible and cross-pollination is performed by a variety of insects (Mulligan & Bailey, 1975). Insects visit the flowers for both nectar and pollen. Fogg (1950) was of the opinion that insect pollination could both self- and cross-pollinate charlock. Rainfall was also thought to effect self-pollination.

Seed is set from August onwards (Grime *et al.*, 1988). Charlock can be found in fruit 3 months of the year (Salisbury, 1962). It will, however, continue to produce mature pods until the first frosts (Warwick *et al.*, 2000). There are 10-18 seeds per pod. Seed numbers per plant are variously given as 1,000 – 4,000 (Salisbury, 1961), 2,000-3,500, 4,000 (Long, 1938), 500-5,000 (Guyot *et al.*, 1962) 1,200 and 2,700 (Stevens, 1957) and up to 25,000 (Grime *et al.*, 1988). The average seed number per plant is 1,981 (Pawlowski *et al.*, 1970). In winter cereals the average seed number per plant ranged from 590 to 600, in spring cereals from 980-1,012 and in root crops from 1,160 to 1,558 (Pawlowski, 1966). The 1,000 seed weight is 2.1 g (Pekrun & Claupein, 2006). Seed production by charlock growing alone and in various crops has been studied to try and correlate seed numbers with plant dry weight (Lutman, 2002). The correlation gave figures of 40 seeds for a plant with a dry weight of 1 g, 590 seeds for a 10 g plant and 8,200 for a 100 g plant. The seeds may be dark or light brown when ripe (Fogg, 1955). Both seed types are found on the same plant and even in the same pod. The time from germination to fruiting is around 100 days (Guyot *et al.*, 1962).

Some seeds will germinate at once while others remain dormant for long periods and germinate sporadically. Germination of fresh seed is increased after overwintering in the soil (Fogg, 1950). Seed dormancy levels appear to be controlled genetically but there are both maternal and embryonic effects (Garbutt & Witcombe, 1986). The maternal component is of overriding importance and is controlled by a single locus, the dormant allele being dominant over the non-dormant. Scarification of the seedcoat increased the level of germination (Povilaitis, 1956). Germination is also increased by a period of dry storage (Grime *et al.*, 1988).

In laboratory studies with dry stored seed sown on moist paper or soil in the light, germination was well over 80% at a constant temperature of 18-20^{o}C and at alternating temperatures of 20 / 30^{o}C and 8 / 20 / 30^{o}C (Cross, 1930-33). Charlock seed was found to germinate better at 15^{o}C than 25^{o}C (Chakrabarti, 1977). The optimum germination temperature is 21^{o}C and there is little germination below 11^{o}C or above 30^{o}C (Fogg, 1950). Fresh and old seed germinates best in weak light or in darkness. Germination is greater on soil than on moist filter paper. Germination is best when seeds are lightly covered with soil. Light and dark brown seeds differ in germination capacity. The light brown seeds germinate more readily when seed is fresh. They also differ in the response to light and dry storage. Seeds appear relatively indifferent to light but when seeds were put to germinate under a leaf canopy or in diffuse white light there was 37% germination under the canopy and 62% in the light (Górski *et al.,* 1977). The germination of fresh seed was not promoted by light (Wesson & Wareing, 1969). In studies of seeds extracted from field soil, charlock was one of the few species with seeds that germinated and emerged in darkness. However, germination increased with illumination. Seeds kept outdoors in moist soil overwinter, exhumed in darkness and put to germinate in 12 hours of light per day, or in darkness following a 5 second light flash or in complete darkness gave 67%, 76% and 58% germination respectively (Andersson *et al.,* 1997).

Freshly-harvested seed of charlock gave around 30% germination whether in the light or in the dark (Holm, 1972). Seed that had been buried outdoors in soil for 6 months germinated only in the light. Seed buried under laboratory conditions at 25 and 37.5 mm germinated much better when the soil was flushed with air for 2 minutes per day. It was suggested that the air removed volatile inhibitors or CO_2 and renewed O_2 levels. Seeds washed out from the soil seedbank gave 72-97% germination in diffuse light at temperatures ranging from 20-26^{o}C when recovered and tested in April-May (Bibbey, 1948). Seed recovered and tested in September gave 30-40% germination. Low oxygen levels inhibited germination.

When applied singly, light, temperature change, and nitrogen in various forms, had little promotive effect on germination (Goudey *et al*., 1986). However, potassium nitrate + light + temperature change (seeds at 5^{o}C for 2 days then increased to 20^{o}C) induced 90% germination. The period of chilling required was at least 2 days but not much longer. The other treatments needed to be applied after the change in temperature. Ammonium chloride and ammonium nitrate were also effective sources of nitrogen but some compounds were not. Too high a level of ammonium or potassium nitrate inhibited germination and caused stunting of the few seedlings that did emerge. Nitrate can therefore either stimulate or inhibit seed germination depending on concentration (Goudey *et al*., 1988). Applying high rates of fertilizer to crops may reduce germination of dormant seeds in spring at a time when earlier winter chilling, and exposure to light during seedbed preparation might otherwise enhance it. This can result in sporadic germination of the weed and a spread of emergence when nitrogen levels fall later in the season. However, some seedlings may be killed by early frosts (Mulligan & Bailey, 1975).

In the field, seedling emergence is mainly in early spring but some occurs in the autumn and winter (Fogg, 1950). Seedling emergence was recorded at monthly intervals from seeds mixed into the top 20 mm of soil. After recording and removing the seedlings the soil was stirred thoroughly. Seedling emergence took place from November to July with a peak in March-April (Chancellor, 1979). In a 3-year arable field study, seedlings emerged from recently-shed non-dormant seed in the autumn but the seedlings were largely destroyed by climate or cultivation (Edwards, 1980). Spring emerging seedlings developed from dormant seed following cultivation and rainfall once soil temperatures at 100 mm had reached 4.4^{o}C. Emerged seedlings represented 2.5% of the seeds in the soil seedbank. Climatic factors were a major influence on charlock population dynamics. There was an obvious link between weather conditions for seed germination in spring and later for seed production.

In greenhouse studies there was optimal emergence when seeds were at or near the soil surface but moisture was important (Boyd & Van Acker, 2003). In the field 89% of seedlings emerged from the surface 40 mm of clay soils with the odd seedling from down to 70 mm (Chancellor, 1964). In a sandy loam soil, field seedlings emerged from the top 60 mm of soil with a even spread of seedlings emerging down to 50 mm (Unpublished information). After seedling emergence a small leaf rosette is formed and may persist in unfavourable conditions (Fogg, 1950). Growth is stunted if inadequate moisture is available.

Persistence and spread

Seeds can remain dormant in soil for many years (Long, 1938) and may still be viable even after 60 years (Mulligan & Bailey, 1975). Seed recovered from excavations and dated at 20, 25 and 80 years old is reported to have germinated (Ødum, 1974). Seed longevity in dry storage was 12 years and in soil 35 years (Guyot *et al.*, 1962). Charlock seeds gave 87% germination after 10 years in soil and 24% after 10 years in dry storage (Brenchley, 1918). Seed stored dry for 5 years gave up to 80% germination (Kjaer, 1940). The viability of seed buried in soil was 75% after 1 year and there was little change over the next 4 years. Edwards (1980) gave the half-life for the buried seed population as 3 years. Charlock can appear and become prevalent on land ploughed after being under grass for decades (Anon, 1935). Charlock plants appeared in cart tracks made across permanent pasture that had been undisturbed for 23 years (Goss, 1924). Viable charlock seeds have been found in the soil under a pasture that had been undisturbed for 40 years (Fogg, 1950). The number of charlock seeds germinating did not decrease as the number of years under a ley and hence the age of the seed increased (Thurston, 1966). Most variation in seedling numbers was the result of rainfall events in the period after ploughing. A single unchecked seeding every 11 years is sufficient to maintain charlock the weed seedbank (Grime *et al.*, 1988).

The decline of seeds broadcast onto the soil surface and then ploughed in was followed over 6 years of cropping with winter or spring wheat grown on a clay and a silty loam soil. Every effort was made to prevent further seed return to the soil. Charlock had a mean annual decline rate of 23% and an estimated time to 95% decline of 11-14 years (Lutman et al., 2002). Seed numbers in an undisturbed soil under grass declined by 50% over 7 seasons (Warnes & Andersen, 1984). Less than 3% of the original seeds remained after the same period in a soil ploughed 3 times a year with additional tillage through the growing season. However, this was still equivalent to 2.4 million seeds ha^{-1}. Charlock seed sown in the field and followed over a 5 year period in winter wheat or spring barley showed an annual decline of around 40% (Barralis *et al.,* 1988). Emerged seedlings represented 8% of the seedbank.

In a study of post-dispersal seed predation in spring barley the main predators were invertebrates, birds were not important predators at this time (Mauchline *et al.,* 2005). Seed predation was greatest early in the year when up to 70% of the seeds present was lost. Losses gradually declined over the summer and by late September few seeds were taken.

Dehiscence of the dry seedpods is slightly explosive but seed is not normally scattered far from the parent (Fogg, 1950). At cereal harvest some seeds are gathered with the crop but many pods shatter at or before harvest and the seeds fall to the ground (Warwick *et al.,* 2000). In cereal seed samples tested between 1961-68 charlock seed was a frequent contaminant being found in up to 2.5% of rye, 3.1% of oats, 3.5% of barley and 1.1% of wheat samples tested (Tonkin, 1968). In cereal seed sampled in the period 1978 to 1981, charlock seed was found in up to 4% of wheat and up to 3% of barley samples tested (Tonkin, 1982). In a survey of weed seed contamination in cereal seed in drills ready for sowing on farm in spring 1970, it was found in 6% of samples (Tonkin & Phillipson, 1973). Most of these were home saved seed. In clover and grass seed samples tested in Denmark for the period 1966-69, 1955-57, 1939 and 1927-28, charlock seed was a contaminant in 0.8, 7.4, 17.5 and 18.4% of samples respectively (Olesen & Jensen, 1969). In a survey of seed contamination in 1960-61, charlock seed was found in 34% of mustard, 3-11% of vegetable brassica, 4% of leek, 3% of carrot and 2% of sugar beet seed samples tested (Gooch, 1963).

Many species of birds feed on the seeds including skylarks, rooks, woodpigeons, house sparrows and several types of finch (Fogg, 1950). Seeds pass unharmed through the digestive system of certain birds (Grime *et al.,* 1988). Screenings from grain fed to poultry can also serve to aid the dispersal of charlock seed. Apparently-viable seeds were found in samples of cow manure (Pleasant & Schlather, 1994). Charlock seed in manure heaps loses viability after a few weeks (Fogg, 1950).

Management

When land is infested with charlock it is advisable to harrow and cultivate the soil repeatedly and kill each successive flush of seedlings (Anon, 1935). Although seed remains largely dormant until spring it can be encouraged to germinate by shallow cultivations in autumn stubbles (Fogg, 1950). While stubble cleaning may not be appropriate for dealing with the shed seeds of some weed species it can be an effective way of controlling charlock. The surface soil is cultivated to a depth of not more than 5 cm and the operation should be repeated at 14-day intervals. Dormant seeds may be brought to the surface by deep ploughing. Regular, slight disturbance of the soil surface will enhance charlock germination but then control the seedlings of this and other weeds stimulated to emerge (Edwards, 1980). Seedling numbers increase with increasing depth and frequency of tillage (Pollard & Cussans, 1981). Charlock is also associated with zero tillage (Derksen *et al.,* 1993).

Charlock causes yield losses in spring barley (Scragg *et al.,* 1982). Relative time of crop and weed emergence is a major factor in determining the severity of loss. The weed can also be a problem in late spring wheat grown organically (Unwin *et al.,* 1990). In the past, horse hoeing was practiced in drilled cereals (Long, 1938).

Harrowing of cereals and hoeing of root crops will reduce a bad infestation (Mulligan & Bailey, 1975). Early harrowing of fields being prepared for root crops will induce germination and allow seedlings to be killed during subsequent seedbed preparations. In conventional horticultural systems, the frequency of charlock increases following summer brassica crops (Atkins & Burn, 1991).

Seed pods usually remain intact until crop harvest (Mulligan & Bailey, 1975). It is important to ensure that seed is all removed at threshing and none is returned to the land in any way, including straw and farmyard manure. Eliminating the parent plants will diminish the seed population in cultivated soil by an order of magnitude each decade (Edwards, 1980). But, the seedbank population can be restored by a single uncontrolled seeding event every 11 years. In the past, the flower heads were knocked off by means of a switch or special machine to prevent seed production. Hand pulling was also practiced. It is important to sow only crop seed that is free of charlock seed (Morse & Palmer, 1925).

A model has been developed, based on temperature and water potential, that describes the germination time course for charlock seed (Ego *et al.*, 2000). The model could be used to predict the pattern of emergence in the field. Charlock seed will germinate in soil with a low water content but in conditions of moisture stress charlock was found to be less competitive against spring wheat (Marshall *et al*., 1996). The seeds produced by moisture stressed plants were small and had little dormancy. Seed production by charlock is reduced by the presence of winter and spring cereals (Edwards, 1980). The spring wheat cultivar Baldus was more competitive than cv. Canon, possibly because of differences in canopy structure (Wright *et al*., 1999).

Charlock is susceptible to soil solarization. Heating seeds in a loamy soil for 30 minutes at 50^{o}C significantly reduced seedling emergence (Rubin & Benjamin, 1984).

Exposure to an arbuscular-mycorrhizal fungal inoculum has been shown to cause a 60% reduction in biomass in charlock, a non-host weed species (Jordan *et al.*, 2000).

References

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.

Anon (1935). Charlock (or preshaugh) spraying. *Leaflet No.* **6**. Irish Department of Agriculture, Dublin.

Atkins P & Burn A J (1991). The future of weed control in UK horticulture: a growers view. *Proceedings of the Brighton Crop Protection Conference – Weeds*, Brighton, UK, 573-580.

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

Bibbey R O (1948). Physiological studies of weed seed germination. *Plant Physiology* **-**, 467-484.

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

Brenchley W E (1920). *Weeds of Farm Land*, Longmans, Green & Co, London, UK.

Chakrabarti A G (1977). Effects of temperature shift on weed seed germination. *Castanea* **42**, 279-285.

Chancellor R J (1959). Identification of seedlings of common weeds. *MAFF Bulletin No.* **179**. HMSO, London.

Chancellor R J (1964). The depth of weed seed germination in the field. *Proceedings 7th British Weed Control Conference, Brighton*, UK, 607-613.

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.

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

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

Derksen D A, Lafond G P, Thomas A G, Loeppky H A, Swanton C J (1993). Impact of agronomic practices on weed communities: tillage systems. *Weed Science* **41**, 409-417.

Edwards M (1980). Aspects of the population ecology of charlock. *Journal of Applied Ecology* **17**, 151-171.

Ego K B, Thomas A G, Swanton C (2000). Modelling germination of wild mustard (*Sinapis arvensis* L.). *Proceedings of the 2000 National Meeting – Expert Committee on Weeds,* 47-50.

Forsyth A A (1968). British poisonous plants. *MAFF Bulletin No.* **161**, HMSO, London.

Fogg G E (1950). Biological flora of the British Isles. *Sinapis arvensis* L. *Journal of Ecology* **38** (2), 415-429.

Garbutt K & Witcombe J R (1986). The inheritance of seed dormancy in *Sinapis arvensis* L. *Heredity* **56**, 25-31.

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**, 249-259.

Goss W L (1924). The vitality of buried seeds. *Journal of Agricultural Research* **29** (7), 349-362.

Goudey J S, Saini H S, Spencer M S (1986). Seed germination of wild mustard (*Sinapis arvensis*): factors required to break primary dormancy. *Canadian Journal of Botany* **65**, 849-852.

Goudey J S, Saini H S, Spencer M S (1988). Role of nitrate in regulating germination of *Sinapis arvensis* L. (wild mustard). *Plant, Cell and Environment* **65**, 849-852.

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

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.

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

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

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

Holm R E (1972). Volatile metabolites controlling germination in buried weed seeds. *Plant Physiology* **50**, 293-297.

Jensen P K (1991). Weed size hierarchies in Denmark. *Weed Research* **31**, 1-7.

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

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

Lutman P J W (2002). Estimation of seed production by *Stellaria media, Sinapis arvensis* and *Tripleurospermum inodorum* in arable crops. *Weed Research* **42**, 359-369.

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.

MAFF (1947). Destruction of yellow charlock. *MAFF Advisory Leaflet* No. **2**, HMSO.

Marshall M A, Seavers G P, Wright K J (1996). Effect of water stress on the relative competitive abilities of charlock (*Sinapis arvensis*) and spring wheat. Proceedings Xe Colloque International sur la Biologie des Mauvaises Herbes, Dijon, France, 121-126.

Mauchline A L, Watson S J, Brown V K, Froud-Williams R J (2005). Post-dispersal seed predation of non-target weeds in arable crops. *Weed Research* **45** (2), 157-164.

Moodie M, Finch R P, Marshall G (1997). Analysis of genetic variation in wild mustard (*Sinapis arvensis*) using molecular markers. *Weed Science* **45**, 102-107.

Moorcroft D, Bradbury R B, Wilson J D (1997). The diet of nestling linnets *Carduelis cannabina* before and after agricultural intensification. *Proceedings of the 1997 Brighton Crop Protection Conference – Weeds,* 923-928.

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

Mulligan G A & Bailey L G (1975). The biology of Canadian weeds. 8. *Sinapis arvensis* L. *Canadian Journal of Plant Science* **55**, 171-183.

Ødum S (1974). Seeds in ruderal soils, their longevity and contribution to the flora of disturbed ground in Denmark. *Proceedings of the 12th British Weed Control Conference,* Brighton, UK, 1131-1144.

Olesen M & Jensen H A (1969). (Occurrence of weed seeds in seed samples of grasses and clover). *Soertryk af statsfrøkontrollens beretning* **98**, 91-112.

Pawlowski F (1966). Prolificacy, height and ability of producing shoots on some weed species growing among crop plants. *Annales Universitatis Mariae Curie-Sklodowska Lublin-Polonia,* **21** (9), 175-189.

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.

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

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.

Pollard F & Cussans G W (1981). The influence of tillage on the weed flora in a succession of winter cereal crops on a sandy loam soil. *Weed Research* **21**, 185-190.

Povilaitis B (1956). Dormancy studies with seeds of various weed species. Comptes rendus de l'Association Internationale d'Essais de Semances **21**, 88-111.

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

Rubin B & Benjamin A (1984). Solar heating of the soil: Involvement of environmental factors in the weed control process. *Weed Science* **32**, 138-142.

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

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

Scragg E B, McKelvie A D, MacKay J M, Birkinshaw N (1982). Investigations into the effects of annual broad-leaved weed competition on the yield of spring barley. *Aspects of Applied Biology* **1**, *Broad-leaved weeds and their control in cereals*, 233-238.

Simpson M J A & Carnegie H M (1989). Dicotyledonous weeds of spring cereal crops in north-east Scotland. *Weed Research* **29**, 39-43.

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

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

Thurston J M (1966). Survival of seeds of wild oats (*Avena fatua* L. and *Avena ludoviciana* Dur.) and charlock (*Sinapis arvensis* L.) in soil under leys. *Weed Research* **6**, 67-80.

Thurston J M (1970). Some examples of weeds carrying pests and diseases of crops. *Proceedings of the British Weed Control Conference*, 953-957.

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.

Unwin R J, Browning H M, Smith A (1990). Nitrogen uptake as a measure of weed competition in organic cereal crops. *BCPC monograph No.* ***45*** *Organic and Low Input Agriculture*, Cambridge, UK, 201-204.

Warnes D D & Andersen R N (1984). Decline of wild mustard (*Brassica kaber*) seeds in soil following various cultural and chemical practices. *Weed Science* **32**, 214-217.

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

Warwick S I, Beckie H J, Thomas A G, McDonald T (2000). The biology of Canadian weeds . 8. *Sinapis arvensis.* L. (updated). *Canadian Journal of Plant Science* **80**, 939-961.

Wesson G & Wareing P F (1969). The role of light in the germination of naturally occurring populations of buried weed seeds. *Journal of Experimental Botany* **20** (63), 402-413.

Wright K J, Seavers G P, Peters N C B, Marshall M A (1999). Influence of soil moisture on the competitive ability and seed dormancy of *Sinapis arvensis* in spring wheat. *Weed Research* **39**, 309-317.