Session 6C

What makes a Weed a Major Problem? - Case Studies

Chairman	Mr G W CUSSANS
Session Organiser	Dr P B PUTWAIN
Posters	6C-1 to 6C-5

PERENNIAL WEEDS IN CONSERVATION TILLAGE SYSTEMS: MORE OF AN ISSUE THAN IN CONVENTIONAL TILLAGE SYSTEMS?

A. LÉGÈRE

Agriculture Canada and McGill University, Department of Plant Sciences, Macdonald Campus,
21 111 Lakeshore Road, Ste-Anne-de-Bellevue, QC, H9X 1C0, Canada

N. SAMSON

Fondation François Pilote, LaPocatière, QC, G0R 1Z0, Canada

R. RIOUX

Agriculture Canada, Ferme expérimentale, LaPocatière, QC, G0R 1Z0, Canada

ABSTRACT

Perennial weeds are often perceived as an obligate problem tied to the adoption of conservation tillage practices. Results from a five year experiment conducted in spring barley production systems in eastern Québec (Canada) have shown that perennial weed problems are not exclusive to systems using conservation tillage practices but in fact can develop in any other tillage systems if conditions are appropriate. Crop production systems considered in this experiment were characterized by different rotations (barley monoculture vs. barley/red clover rotation), tillage practices (moldboard plow, chisel plow, no-till), and weed management levels (minimum, moderate, maximum). Under specific combinations of factor levels, perennial weed species such as quackgrass (*Elymus repens*), field horsetail (*Equisetum arvense*) and dandelion (*Taraxacum officinale*) were shown to cause major problems, each in different systems. Rotation and weed management level had as much influence as tillage in determining the severity of perennial weed infestations.

INTRODUCTION

Partial or total elimination of tillage brings about major changes in weed communities by influencing species composition, relative importance of individual species, and rates of population growth (Weston, 1990; Hume, 1982). The adoption of conservation tillage practices, particularly in crops such as corn or soybeans, would particularly favour the development of perennial and annual grasses (Buhler & Daniel, 1988). But what holds true for the latter crops may not apply fully to other more competitive crops. Derksen *et al*. (1993) examined tillage effects in different crop rotations typical of western Canada and did not record an increased association of perennial and annual grasses with zero tillage. Within the time frame of their experiments (3 and 5 years), changes in weed communities were influenced more by location and year than by tillage systems, indicating fluctuational rather than directional or consistent changes in community composition.

It has often been suggested that the changes in weed communities triggered by conservation tillage practices could contribute to an increase reliance on chemical weed control (Schreiber *et al.*, 1987). In the opinion of Swanton and Weise (1991), weed communities that evolve as a result of the adoption of such practices need not be more difficult to control than those associated with

RESULTS AND DISCUSSION

Quackgrass populations responded differently to maximum and moderate weed management levels according to whether the plots had been tilled or not, and to the type of rotation ($p = 0.002$). In monoculture, quackgrass densities were very low in all but the tilled/moderate weed management level plots (Figure 1). In these tilled plots where no glyphosate had been applied, quackgrass populations increased to reach densities over 600 stems m^{-2} by the fifth year of experiment. Tillage influences regeneration of quackgrass by favouring fragmentation and dispersal of rhizomes, and by affecting bud dormancy and distribution in the soil profile (Lemieux *et al.*, 1993; Froud-Williams *et al.*, 1981). Quackgrass populations in chisel plow treatments were consistently twice as large as those in moldboard plow treatments, regardless of rotation or weed management level ($p = 0.023$). In the monoculture/no-till/moderate weed management plots, the low rate (2.5 kg AI ha^{-1}) of glyphosate was enough to provide adequate control of quackgrass. Increasing the rate to 4.0 kg AI ha^{-1} in the no-till/maximum weed management treatment did not bring additional benefits in terms of quackgrass suppression.

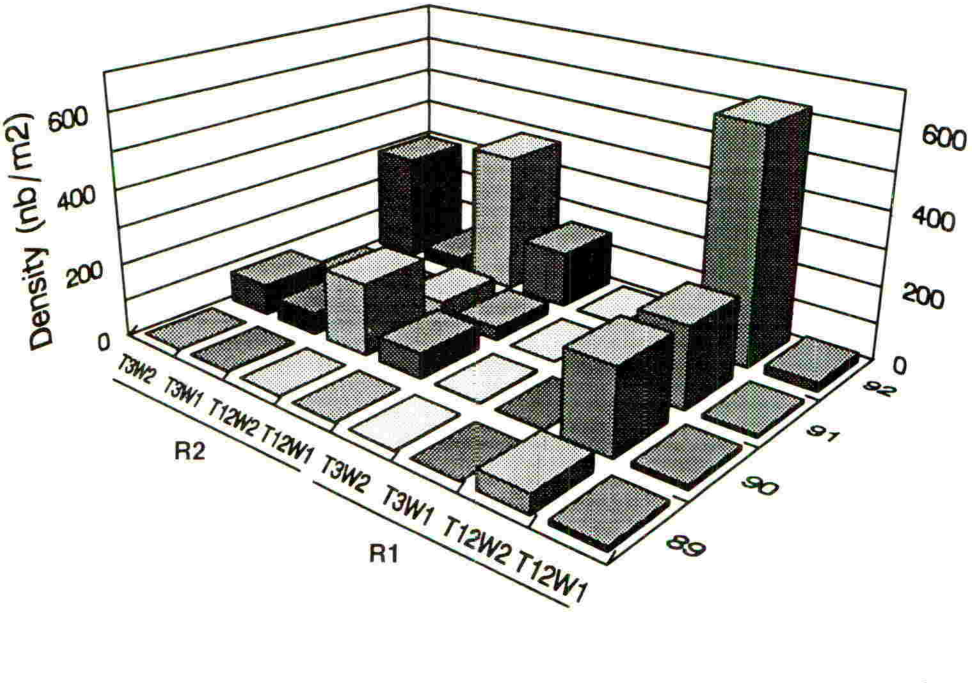


Figure 1. Effects of rotation, tillage and weed management level on quackgrass density (stems m^{-2}). Rotations: R1 - monoculture, R2 - rotation; Tillage: T1 - moldboard plow, T2 - chisel plow, T3 - no-till; Weed management: W1 - maximum, W2 - moderate, W3 - minimum.

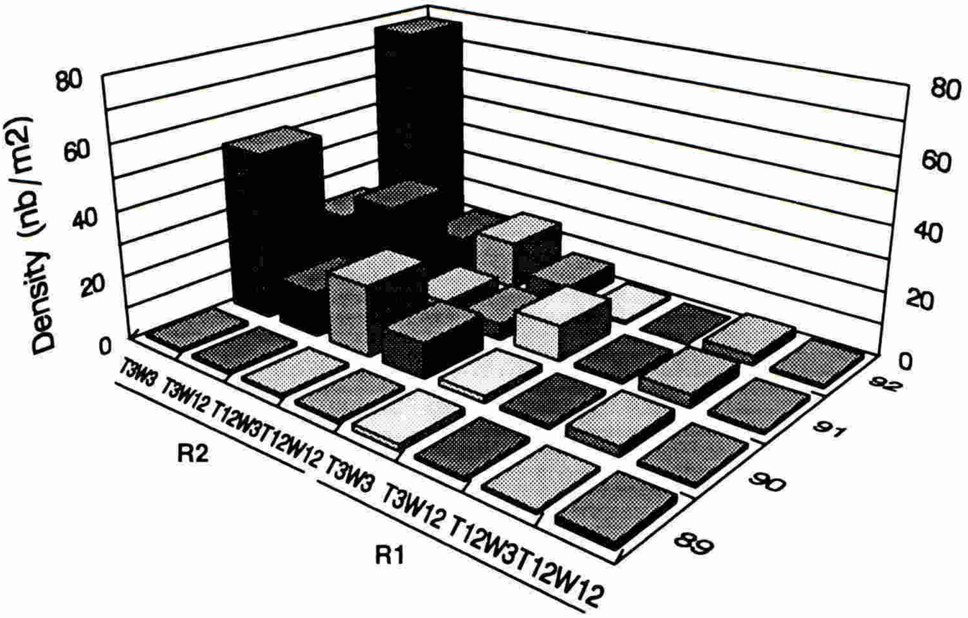


Figure 2. Effects of rotation, tillage and weed management level on dandelion density (plants m^{-2}). Rotation: R1 - monoculture, R2 - rotation; tillage: T1 - moldboard plow, T2 - chisel plow, T3 - no-till; weed management: W1 - maximum, W2 - moderate, W3 - minimum.

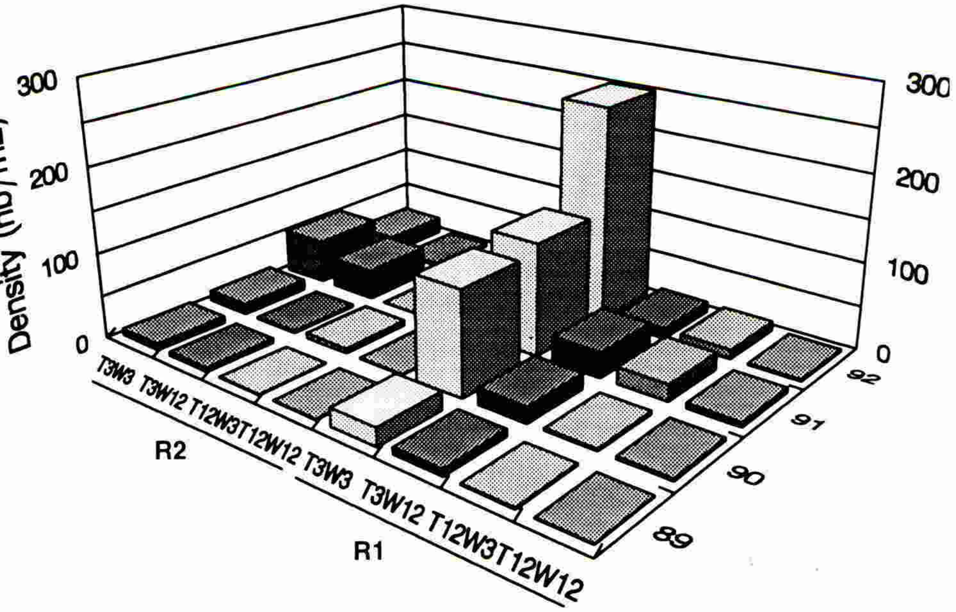


Figure 3. Effects of rotation, tillage and weed management level on horsetail density (stems m^{-2}). Rotation: R1 - monoculture, R2 - rotation; tillage: T1 - moldboard plow, T2 - chisel plow, T3 - no-till; weed management: W1 - maximum, W2 - moderate, W3 - minimum.

conventional tillage systems. Management practices other than tillage can be instrumental in determining the making of a weed community (Légère *et al.*, 1993). Any departure from optimum practices has the potential of leading up to major weed problems, even in conventional systems. The development of perennial weed problems is by no means exclusive to conservation tillage systems, nor is it an obligate outcome of the adoption of such practices. This paper attemps to demonstrate that, in competitive cropping systems such as small grains, the reduction or elimination of mechanical destruction of weeds consequent to the adoption of reduced tillage pratices can somewhat be compensated for by other forms of weed control provided indirectly by sound agronomic practices, and that chemical weed control programs required for adequate weed control in such tillage systems need not be more intensive than those applied to the so-called conventional systems.

MATERIALS AND METHODS

The experiment was conducted at the Agriculture Canada Experimental Farm, located at La Pocatière, from 1988 to 1992. Plots were established on a Kamouraska clay soil(Orthic humic gleysol) and arranged according to a split-split plot design with rotation as the main factor, tillage practices as the subplot factor and weed management level as the sub-subplot factor. Treatments were replicated 4 times. The sub-subplot size was 5 by 9 m.

The rotation factor included either a continuous spring barley monoculture (**R1**) or a short two-year rotation of spring barley underseeded with red clover followed by one year of forage production (**R2**). Tillage treatments consisted of **T1**: moldboard plow in the fall (15-18 cm), followed by spring secondary tillage, **T2**: chisel plow in the fall (12-15 cm) followed by spring secondary tillage, and **T3**:) direct seeded no-till. Weed management levels (**W3**: minimum, **W2**: moderate and **W1**: maximum) were obtained by combining different herbicides (glyphosate, cyanazine/MCPA, MCPB/MCPA), rates and times of application. In tilled areas (moldboard and chisel plow), glyphosate was only applied to maximum weed management plots at a rate of 2.5 kg AI ha^{-1}. In no-till plots, glyphosate was applied at rates of 2.5, 2.5, and 4.0 kg AI ha^{-1} in minimum, moderate and maximum weed management treatments. Glyphosate was applied in the fall of every year in the monoculture and every two years in the rotation. Minimum, moderate and maximum weed management treatments included a yearly post-emergence application of cyanazine/MCPA at rates of 0, 0.3 + 0.6, 0.3 + 0.6 kg AI ha^{-1} for the monoculture, and a post-emergence application of MCPB/MCPA at rates of 1.1 + 0.07, 1.6 + 0.1 kg AI ha^{-1} every other year for the rotation. From 1989 to 1992, sampling of weed communities was conducted two to three weeks following spring herbicide treatment. Two quadrats, 33 by 75 cm, were positioned according to random coordinates, 1 m from the outer edges of the plot. Random coordinates were chosen as to exclude those from previous years so that an area was sampled only once during the course of the experiment. Weeds found in quadrats were counted, cut at ground level, oven dried and weighed.

Weed density data were analyzed using a polynomial regression method (Légère and Schreiber, 1989). For each weed species, a third-degree polynomial was fitted to density data from each cell of the experimental design. A MANOVA analysis was performed on the regression coefficients thus obtained in order to test the effects of rotation, tillage, weed management level and their interactions. The polynomials were of the form: $y=b_0+b_1x+b_2x^2+b_3x^3$, y being weed density, x being time in years after the beginning of experiment. Significance levels were determined according to Wilks'criterion. Contrast analysis was used to determine the significance of certain hypotheses. Results concerning densities of quackgrass (*Elymus repens*), dandelion (*Taraxacum officinale*), and field horsetail (*Equisetum arvense*) will be reported.

In rotation/no-till plots, the high rate of glyphosate included in the maximum weed manegement treatments provided better suppression of quackgrass populations. The combination of tillage and low rate of glyphosate in tilled/maximum weed management plots gave better results than the use of glyphosate alone at the same rate in no-till/moderate weed management plots. Under monoculture, control of quackgrass populations required herbicide input in both tilled and no-till treatments but control in no-till did not require any more input than in tilled plots. In the moderate weed management treatment where no glyphosate had been applied, quackgrass populations from rotation/tilled plots progressed more slowly compared to those from the monoculture/tilled plots. Rotation allowed for tillage to be performed only once every two years and therefore provided for less fragmentation and dispersal of rhizomes. Under rotation, the inclusion of the forage break year also implied that, where appropriate, glyphosate would only be applied once every two years. This favoured the progression of quackgrass in rotation/no-till plots compared to that of monoculture/no-till plots. Whereas both rates of glyphosate had comparable effects on quackgrass control in monoculture/no-till plots, the higher rate was required in the rotation to obtain adequate quackgrass control.

The effects of minimum weed management on dandelion populations differed from that of the other two weed management levels (moderate, maximum), also according to whether the plots had been tilled or not, and to the type of rotation ($p = 0.004$). Populations of dandelion were fairly low in all treatments in the monoculture as compared to those in the rotation (Figure 2). In the latter, the absence of tillage favored the development of dandelion stands, especially in the minimum weed management treatment. Reduced tillage has been reported to favour the development of dandelion populations (Derksen *et al.*, 1993; Froud-Williams *et al.*, 1981). Moderate and maximum weed management levels provided somewhat better dandelion suppression than the minimum level, regardless of the presence or absence of tillage.

The forage break year in the rotation provided the opportunity of a more stable environment in all treatments and thus allowed dandelion populations to develop more than in the monoculture. The absence of tillage in the rotation was particularly favorable to dandelion especially when only a low-rate fall glyphosate treatment was applied (minimum level). In the rotation/no-till plots, destruction of dandelion stands by tillage every other year slowed the development of these populations compared to that in no-till.

As for dandelion, effects of minimum weed management on horsetail populations differed from that of the other two levels according to presence or absence of tillage, and to rotation ($p = 0.001$). The way this interaction translated into effects on horsetail stands was nevertheless quite different from that on dandelion. In both the monoculture and the rotation, fairly good suppression of horsetail was obtained in tilled plots, regardless of weed management level (Figure 3). Horsetail populations also remained low in the monoculture/no-till plots with either moderate or maximum weed management levels. Large populations of horsetail developed in the minimum weed management/no-till plots.

Large horsetail populations were only found in the monoculture/no-till/minimum weed management plots where lack of soil disturbance would have favoured its vegetative development (Vézina, 1990). Forage break years in the rotation did not favor the development of horsetail populations, regardless of tillage or weed management. It is possible that the regular removal of aboveground biomass due to forage harvests in the rotation could have impaired growth of horsetail populations.

Each perennial species under investigation developed large populations under very specific combinations of factor levels. The development of such large populations was not unique to systems using conservation tillage practices. Maximum weed management input was only required for the management of quackgrass. Effects of rotation on the development of infestations were tightly linked to the biological characteristics of each perennial species.

ACKNOWLEDGEMENTS

This study was financed by the 'Entente auxiliaire Canada-Québec pour la conservation des sols en milieu agricole' (#3B1-47722640-006), by the 'Entente auxiliaire Canada-Québec pour le développement économique des régions de l'Est du Québec' (#EE-2870114-077), by Agriculture Canada and by the Fondation François Pilote Inc.

REFERENCES

Buhler, D.D.; Daniel T.C. (1988) Influence of tillage systems on giant foxtail, *Setaria faberi*, and velvetleaf, *Abutilon theophrasti*, density and control in corn, *Zea mays*. *Weed Science*, **36**, 642-647.

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*, in press.

Froud-Williams, R.J.; Chancellor, R.J.; Drennan D.S.H. (1981) Potential changes in weed floras with reduced-cultivation systems for cereal production in temperate regions. *Weed Research*, **21**, 99-109.

Hume, L. (1982) The long-term effects of fertilizer application and three rotations on weed communities in wheat (after 21-22 years at Indian Head, Saskatchewan). *Canadian Journal of Plant Science*, **62**, 741-750.

Légère, A.; Schreiber M.M. (1989) Competition and canopy architecture as affected by Soybean (*Glycine max*) row width and density of redroot pigweed (*Amaranthus retroflexus*). *Weed Science*, **37**, 84-92.

Légère, A.; Lemieux, C.; Simard R.R.; Lapierre C. (1993) Response of weed communities to fertility and tillage. *Proceedings EWRS Symposium Braunschweig 1993: Quantitative approaches in weed and herbicide research and their practical application*, pp.41-48.

Lemieux C.; Cloutier D.C.; Leroux, G.D. (1993) Distribution and survival of quackgrass (*Elytrigia repens*) rhizome buds. *Weed Science*, in press.

Schreiber, M.M.; White M.D.; Shasha D.S. (1987) Efficacy of controlled-release formulation of trifluralin in no-till soybeans (*Glycine max*). *Weed Science*, **35**, 407-411.

Swanton C.J.; Weise S.F. (1991) Integrated weed management: The rationale and approach. *Weed Technology*, **5**, 657-663.

Vézina, L. (1990) Efficacité de divers programmes d'interventions herbicides uilisés dans des régimes de cultures d'orge et de maïs-grain sur des peuplements d'*Equisetum arvense* L. du Québec, Canada. *Weed Research*, **30**, 71-79.

Weston, L.A. (1990) Cover crop and herbicide influence on row crop seedling establishment in no-tillage culture. *Weed Science*, **38**, 166-171.

WHAT MAKES BROOM A MAJOR PROBLEM?

JANE MEMMOTT

Leverhulme Unit: Centre for Population Biology, Imperial College at Silwood Park, Ascot and International Institute for Biological Control, Silwood Park, Ascot, UK

SIMON V. FOWLER

International Institute for Biological Control (CAB International), Silwood Park, Ascot, UK.

PAULINE SYRETT

Manaaki Whenua-Landcare Research Ltd, PO Box 69, Lincoln, New Zealand.

JOHN R. HOSKING

NSW Agriculture, RMB 944, Tamworth, NSW 2340, Australia.

ABSTRACT

Broom, *Cytisus scoparius* (L.) Link, is a woody shrub which is native to Europe. It has been introduced to a number of countries including New Zealand, Australia, the USA and Canada and has become a serious pest. Twelve long term population dynamics plots have been set up in New Zealand and England to determine why broom is an invasive weed in the former country but not in the latter. In each country experiments will establish the impact of herbivory, seed limitation, intra- and interspecific plant competition and microsites on the population dynamics of broom. In New Zealand and Australia, broom is the subject of a biological control programme and data on the plant's dynamics will help to give an ecological basis for the selection of control agents.

INTRODUCTION

This paper consists of four sections: Firstly it outlines the natural history of broom, secondly it documents the status of broom in England, New Zealand and Australia, thirdly it examines some of the potential explanations accounting for why broom has become a problem in some exotic habitats. Finally it outlines the experimental protocol and the first results of a set of experiments, the aim of which is to determine why the plant is a serious pest in an exotic but not a native habitat. The experiments are at a very early stage, the UK plots have been running only two years and the first data from the New Zealand plots will be gathered in October 1993.

(1) BROOM NATURAL HISTORY

Broom is a much branched, leguminous shrub with green glabrous twigs and small leaves. The plant is free standing when young but its stems are weak and larger plants are generally partly prostrate. In England the bushes grow to a height of 1.8-2.4m (Waloff 1968) although it is reported as growing more vigourously in its exotic habitats (Williams 1981). Plants generally start to flower in their third year with yellow, scented inflorescences which develop into seedpods. The pods dry and dehisce, scattering the seeds up to several metres (Hinz 1992). The plants life-span is 10-15 years in England (Waloff 1968) but Australian broom has been reported to live for longer than 23 years (Smith & Harlen 1991).

(2) STATUS OF BROOM IN BRITAIN AND IN NEW ZEALAND AND AUSTRALIA

In Britain, broom is found on heaths, open woods etc, on acid soils and is locally abundant, except on Orkney and Shetland (Clapham, Tutin and Warburg 1981). Its European distribution stretches from Spain and the Canary Isles to Scandinavia, its southern distribution being limited by drought and its northern by winter cold (Hegi 1926).

In New Zealand, broom is a listed noxious weed occupying large tracts of native grassland, river-bed, wasteland and previously forested hill country. It is a particular problem in commercial forestry as it competes with establishing plantations (Syrett 1989). It grows more vigorously in New Zealand compared to Europe (Williams 1981). Broom is estimated to be present on 173,516 hectares of South Island and 14,447 hectares of North Island (National Water and Soil Conservation Organization 1979). In South Island it has been estimated to occupy 0.92% of land suitable for farming (Bascand & Jowett 1981) and is still spreading. In Australia, broom occurs in south eastern areas and is a noxious weed in Victoria and South Australia as well as in parts of New South Wales and Tasmania (Parsons & Cuthbertson 1992). The largest infestation of broom, covering about 10,000 hectares, occurs on the Barrington Tops, in New South Wales (Waterhouse 1988). Broom is still spreading and according to Parsons & Cuthbertson (1992) it is a much underrated weed in Australia.

(3) WHAT MAKES BROOM A MAJOR PROBLEM.

(a) Changes in Interspecific Plant Competition.

A difference in the level of interspecific plant competition could lead to broom being a problem in one country but not another. In the United Kingdom, broom is generally considered to be a plant of early successional stages which is out-competed by later vegetation. New Zealand and Australian native plants many not be as competitive as European plants leading to broom remaining as a dominant for a much longer period of time. Frick (1962) proposed that lower interspecific competition was the reason for brooms success on the Pacific coast of North America compared to on the Atlantic coast.

There are two studies of broom's status in plant succession in New Zealand known to the authors. Williams (1983) describes a broom-elder-native forest succession and Partridge (1992) experimentally manipulated plots of bracken and broom plants and seeded them with elder and four species of native plant. Partridge reported that broom outcompeted bracken and, contrary to Williams (1981), found no evidence that broom facilitated the successful dispersal of other species at the site.

It is believed that the competitive ability of a plant can be weakened by attack from herbivorous insects (Goeden & Kok 1986, Schroeder & Goeden 1986). However, few manipulative experiments have been carried out and it is easy to overlook other less obvious factors that might be the direct cause of the plants decline (Crawley 1989).

(b) Lack of Herbivores.

Waloff and co-workers have published extensively on the insect herbivore fauna and associated natural enemies on broom at Silwood Park. At Silwood Park, broom supports 35 species of phytophagous insect and a large complex of their parasitoids and predators (Waloff 1968). These phytophagous insects occupy a diversity of niches, including seed feeding, pod feeding, gall forming, folivores, sap feeders, stem mining, leaf mining and bark mining and one species feeding underground on the root nodules. In contrast the fauna of broom in New Zealand is meagre (Syrett 1993). The few damaging species recorded include leaf roller species and the introduced twig mining moth, *Leucoptera spartifoliella*.

A large scale, but unreplicated, application of insecticide to broom at Silwood Park indicated that insect herbivores have a substantial effect on growth, reproduction and survival of broom (Waloff & Richards 1977). Two plots of broom were planted and for 11 years one plot was sprayed with insecticides. The unsprayed bushes, which had higher numbers of herbivore, did not attain full growth and their mortality was higher compared with the sprayed bushes. The seed yield of unsprayed broom over the average 10 year life span of a bush was also reduced by 75% (Waloff & Richards 1977).

Consequently, it is generally believed that herbivory is an important factor in the difference in the status of broom in England and in New Zealand/Australia (eg. Williams 1981, Waterhouse 1992, Syrett 1993). However, it is one thing to show that herbivorous insects affect plant performance, it is an entirely different matter to demonstrate that herbivory affects plant population dynamics (Crawley 1989). Because we have so little information on the regulation of broom populations in the wild, we do really not know whether herbivory is an important factor. The experimental plots described in the final section of this paper are designed to answer this type of question.

(c) Seed limitation.

Large seed banks have been reported from broom stands in both England (Figure 2) and New Zealand (Partridge 1989). However, Williams (1981) experimentally demonstrated that seeds buried at a depth greater than 100mm did not germinate and so it appears that germination from the seed bank is dependent on soil disturbance. Whether broom is seed limited is unknown and so we cannot predict whether the recent introduction of a seed feeding predator to New Zealand will affect the population dynamics of broom. If broom is not seed limited (ie. if sowing extra seed has no effect on recruitment) then herbivores that cause only moderate reductions in plant fecundity may have no measurable impact on plant abundance or on population stability (Crawley 1990).

(d) Microsite limitation.

Observations indicate that broom is exploiting new microsites in New Zealand. For example, in England it is rarely seen in river beds, at high altitude or as a forest understory. The braided river-beds, typical of South Island, New Zealand are a habitat simply not found in England. They contain large, open areas of gravel which, because the rivers flow underground for much of the summer, are unflooded for much of the time. The result is a hot, dry habitat - but one to which broom is well suited with its sparse leaves and photosynthetic stems bearing sunken stomata beneath thick epidermal wax (Kerner 1902).

(4) EXPERIMENTAL PROTOCOL

Six plots have been established in both New Zealand and England with the aim of determining why broom in an invasive pest in the former country but not the latter. In each country, the six plots are located in three types of site: (a) two plots in areas with existing broom populations, (b) two plots in areas with no existing broom stands, but with a history of broom and with a seed bank and (c) two plots in areas with no known history of broom. The plots are 20x20m, half of which is fenced to exclude rabbits and hares and each half is divided into eight treatment plots. In each plot, experiments will establish the impact of the four factors described above on the population dynamics of broom:
(a) Intra- and interspecific plant competition - by the selective weeding of plants around young broom plants.
(b) Herbivory, both vertebrate and invertebrate - by fencing and insecticide applications respectively.
(c) Seed limitation - by sowing extra seed.
(d) Microsite limitation - by single and annual cultivations.

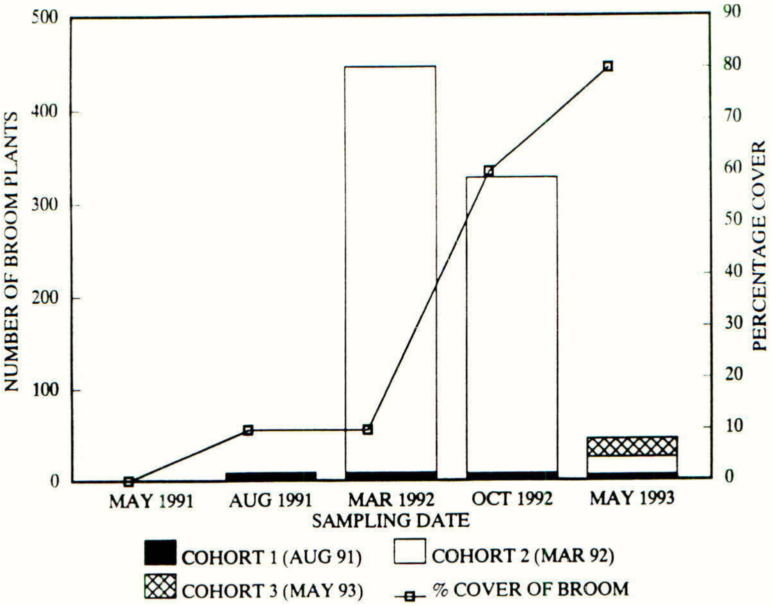


Figure 1. The recruitment of three cohorts of broom into a fixed quadrat.

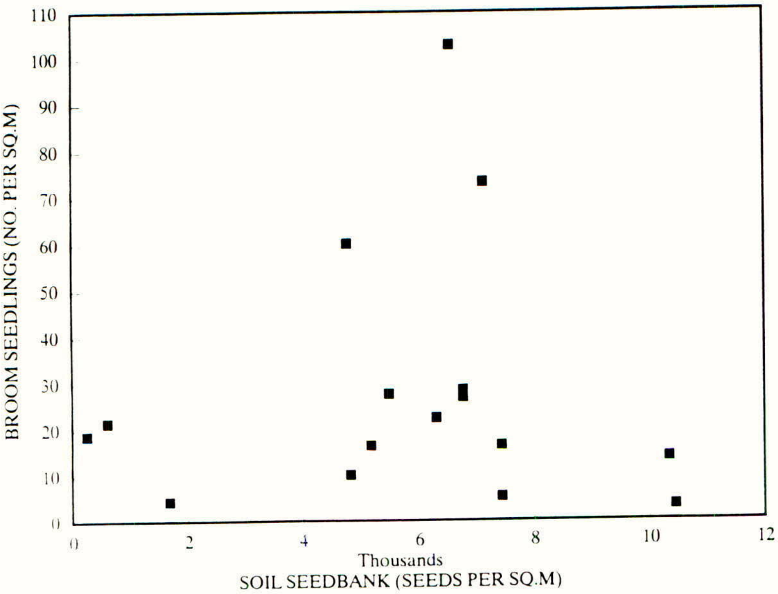


Figure 2. The relationship between the number of seeds in the seedbank and the number of seedlings.

Broom plants will be censused three times a year from four random and two fixed quadrats in each treatment plot and their survivorship and growth compared to plants in untreated plots left as controls. Data collection from the plots in England started in spring 1991 and will start in the plots in New Zealand in October 1993. Modified versions of this experimental protocol are being carried out near Montpellier in southern France and in Australia at the Barrington Tops and near Braidwood, south west of Canberra.

Analysis is only just beginning on the data from the English plots. Figure 1. shows the recruitment of three cohorts of broom seedlings into one of the fixed quadrats in one of the plots. The $0.25m^2$ permanent quadrat was situated in a treatment plot subject to a single digging treatment which took place in May 1991. Cohort 1 is small (nine plants) and shows little mortality over the subsequent two seasons. Cohort 2 shows a considerably greater level of recruitment and a considerably greater level of mortality: from 1748 seedlings per $1m^2$ in March 1992, to 76 per $1m^2$ by May 1993. Cohort 3, shows a very low level of recruitment and its survivorship is currently unknown. The percentage cover increases from zero immediately after the digging to 80% over the two year period with broom being the dominant plant in the quadrat.

Cohort 1 is small because the digging treatment was not carried out until May, the main germination period is the early spring. The much higher level of recruitment in Cohort 2 is most probably the effect of two factors (1) The fact that the seed bank had been exposed for longer: broom seeds are protected by a tough seed coat which needs to be damaged before the seeds will germinate (2) the fact that the second cohort includes the spring germination, rather than just the post May germination. The high mortality seen in Cohort 2 will be due to a number of causes, the main one being self thinning - it is impossible for 1800 broom seedlings per $1m^2$ to survive to adulthood. There is no evidence for self thinning in Cohort 1, presumably because the plants are at such low density. Recruitment is low in 1993 as the disturbance effect was two years previously and few new seeds will have been exposed. There is also a fairly complete broom canopy in place and the young plants would receive very little light.

Figure 2 shows the relationship between the number of seeds in the seedbank and the number of seedlings. The seedbank data is the mean of 10 soil cores from each of the enclosed plots, (adjusted per m^2). The seedling data is the mean from ten quadrats from the same areas. The seedbank can reach more than 10,000 seeds per m^2 but there is no relationship between the size of the seedbank and the number of plants germinating ($r^2=0.0018$, $p<0.001$). These results suggest that broom is not seed limited, although to test this conclusively, one would have to sow extra seeds and monitor recruitment.

These are only a tiny fraction of the results available for analysis. Once the effects of all the treatments are analysed from both countries we will have a good understanding of the population dynamics of broom in its native habitat and in an exotic habitat. From this we hope to be able to deduce what makes scotch broom a pest in New Zealand and locally common plant in the UK. This information will be of enormous value when planning a control strategy for the plant in New Zealand and Australia.

ACKNOWLEDGEMENTS

Research into the biological control of broom is supported by National Parks and Wildlife Service of NSW, Forestry Commission Of NSW (Australia), Manaaki Whenua-Landcare Research (New Zealand) and the Leverhulme Trust (Great Britain). Staff at IIBC, Imperial College, NSW Agriculture, CSIRO and Manaaki Whenua-Landcare Research assisted with programme.

REFERENCES

Bascand, L.D.; Jowett G.H. (1981) Scrubweed cover of South Islands agricultural and pastoral land. *New Zealand Journal of Experimental Agriculture*, **9**, 307-327.

Clapham, A.R.; Tutin, T.G.; Warburg, E.F. (1981) *Excursion Flora of the British Isles*, Third Edition, Cambridge University Press.

Crawley, M.J. (1989) Insect herbivores and plant population dynamics. *Annual Review of Entomology*, **34**, 531-564.

Crawley, M.J. (1990) The population dynamics of plants. *Philosophical Transactions of the Royal Society of London*, **330**, 125-140.

Frick, K.E. (1962) A three week study of *Bruchidius villosus* the seed beetle that attacks seeds of *Cytisus scoparius* in the Eastern United States. *U.S. Department of Agriculture, Special Report.*

Goeden, R.D.; Kok, L.T. (1986) Comments on a proposed "new" approach for selecting agents for the biological control of weeds. *Canadian Entomologist*, **118**, 51-58.

Hegi, G. (1926) *Illustrated Flora of Central Europe*. **4**, 1182-1189, Carl Hanser, Munich.

Hinz, H.L. (1992) Studies on the two seed feeding beetles *Apion fuscirostre* Fabricius (Coleoptera: Apionidae) and *Bruchidius villosus* Fabricius (Coleoptera: Bruchidae) : potential biological control agents for broom (*Cytisus scoparius*). MSc Thesis, University of London.

Kerner, A.V.M. (1902) The Natural History of Plants. Translated by F.W.Oliver. London, Blackie & Son.

National Water and Soil Conservation Organisation (1979) Our land resources. Water and Soil Division, New Zealand Ministry of Works and Development. 78 pp.

Parsons, W.T.; Cuthbertson, E.G. (1992) *Noxious Weeds of Australia*. Inkata Press: Melbourne.

Partridge, T.R. (1989) Soil seed banks of secondary vegetation on the Port Hills and Banks Peninsula, Canterbury, New Zealand and their role in succession. *New Zealand Journal of Botany*, **27**, 421-436.

Partridge, T.R. (1992) Successional interactions between bracken and broom on the Port Hills, Canterbury, New Zealand. *Journal of Applied Ecology*, **29**, 85-91.

Schroeder, D.; Goeden, R.G. (1986) The search for arthropod natural enemies of introduced weeds for biocontrol - in theory and practice. *Biocontrol News and Information*, **7**, 147-155.

Smith, J.M.B.; Harlen R.L. (1991) Preliminary observations on the seed dynamics and ecology of broom (*Cytisus scoparius*) at Barrington Tops, New South Wales. *Plant Protection Quarterly*, 6, 73-78.

Syrett, P. (1989) *Cytisus scoparius* (L.) Link, broom (Fabaceae). In: A Review of Biological Control of Invertebrate Pests and Weeds in New Zealand 1874 to 1987. P.J. Cameron, R.L.Hill, J.Bain and W.P.Thomas (Eds). CAB International and DSIR.

Syrett, P. (1993) The insect fauna of broom, *Cytisus scoparius*, in New Zealand. *New Zealand Entomologist,* 16, 75-83.

Waloff, N. (1968) Studies on the insect fauna on Scotch Broom, *Sarothamnus scoparius* (L.) Wimmer. *Advances in Ecological Research*, **5**, 87-208.

Waloff N.; Richards, O.W. (1977) The effect of insect fauna on growth, mortality and natality of broom, *Sarothammnus scoparius*. *Journal of Applied Ecology*, **14**, 787-798.

Waterhouse, B.M. (1988) Broom (*Cytisus scoparius*) at Barrington Tops, New South Wales: *Australian Geographical Studies*, 26, 239-248.

Williams, P.A. (1981) Aspects of the ecology of broom (*Cytisus scoparius*) in Canterbury, New Zealand. *New Zealand Journal of Botany*, **19**, 31-43.

Williams, P.A. (1983) Secondary vegetation succession on the Port Hills Banks Peninsula, Canterbury, New Zealand. *New Zealand Journal of Botany*, **21**, 237-247.

COMPARATIVE ANALYSIS OF THREE CRUCIFEROUS WEEDS: RESPONSE TO TEMPERATURE AND COMPETITION.

D. A. WALL

Agriculture Canada, Research Station, P.O. Box 3001, Morden, Manitoba, Canada, R0G 1J0

ABSTRACT

Studies were conducted to investigate the competitiveness and response to temperature of *Sinapis arvensis* L., *Erucastrum gallicum* (Willd.) O.E. Schulz, and *Neslia paniculata* (L.) Desv. *E. gallicum* and *N. paniculata* displayed optimum growth at maximum daily temperatures of 26 to 28 °C. *N. paniculata* plant height, biomass and leaf area was markedly reduced at temperatures above 28 °C and indicated that this species is poorly adapted to high temperature environments. S. arvensis also exhibited reduced plant height at temperatures above 26 °C, but produced more biomass and greater leaf areas at temperatures between 28 and 34 °C and suggested that this species may be better adapted to high temperatures than *E. gallicum* or *N. paniculata*. Replacement series experiments indicated that *S. arvensis* was more competitive than either *N. paniculata* or *E. gallicum*.

INTRODUCTION

S. arvensis, *E. gallicum*, and *N. paniculata* are common annual cruciferous weeds in western Canada. Introduced species, *S. arvensis*, *N. paniculata* and *E. gallicum* were first reported in western Canada in 1875 (Scoggan, 1957), 1891 and 1922 (Scoggan, 1978), respectively. While these species are now found across western Canada, only *S. arvensis* occurs regularly as a serious agricultural weed. (Thomas and Wise, 1984 and 1987). This may be due to differences in the length of time since introduction, mechanisms of dispersal, adaptation, or their respective abilities to compete with crops and other weeds. The objective of this study was to investigate the response of *S. arvensis*, *N. paniculata* and *E. gallicum* to temperature and competition as factors which may contribute to their relative success in western Canada.

MATERIALS AND METHODS

Response to temperature

The response of *S. arvensis*, *N. paniculata* and *E. gallicum* to temperature was investigated in a controlled environment experiment. Seed of each species was planted separately in 15 cm diameter plastic pots filled with a sandy clay loam soil. Pots were watered daily and a water soluble fertilizer applied as required to sustain normal plant growth. One week after seedling emergence, pots were thinned to a single plant. Plants were grown at 34/26, 28/20, 22/14, 16/8, and 10/2 °C day/night temperature regimes, with an 18 hr photoperiod. Light intensity was 375 μ E m^{-2} s^{-1} photon flux density.

Six plants of each species were harvested on a weekly basis for 6 weeks, beginning 1 week after seedling emergence. Plant height, leaf area per plant and total plant dry weight were determined at each harvest. Growth analysis was conducted twice and results combined for analysis. The growth response of each weed species to temperature over time was analyzed by stepwise multiple regression (SAS, 1985) and the surface response graphed.

Replacement series

The competitive relationships between *S. arvensis*, *N. paniculata* and *E. gallicum* were investigated using a replacement series experimental design. Three separate replacement series were investigated: *S. arvensis* vs. *N. paniculata*; *S. arvensis* vs. *E. gallicum*; and *N. paniculata* vs. *E. gallicum*. Four plants each of species were grown in monoculture or as mixed populations in 12.5 cm diameter plastic pots filled with a sandy clay loam soil. Each series consisted of two monocultures and three mixtures; 75:25, 50:50 and 25:75 planting ratios. Planting ratios were replicated five times in a Latin Square design. Each series was grown in the green house at 22 °C.

The replacement series were harvested 6 weeks after planting, by cutting shoots level with the soil surface and separating the species. Plants were dried at 60 °C for 24 h and total shoot biomass for each species determined. The experiment was conducted twice and results combined for analysis. Relative yields and relative yield total were calculated according to DeWit and Vandenberg (1965) and replacement diagrams constructed according to De Wit (1960).

RESULTS

Response to temperature

Regression models used to predict weed response to temperature over time are presented in Table 1.

S. arvensis plant height increased from emergence to 42 days from emergence (DFE), while *N. paniculata* and *E. gallicum* exhibited a lag phase prior to shoot extension during which time the plants exhibited compressed growth habits (Figure 1). At maximum daily temperatures from 22 to 28 °C, this lag phase lasted until approximately 21 DFE. However, at 10 °C *E. gallicum* exhibited minimal shoot extension throughout the 6 week period, while *N. paniculata* plant height began to increase by 35 DFE. Maximum plant heights for all species occurred at 24 to 26 °C. Above 26 °C plant height decreased for all species. At the end of 6 weeks and at optimum growing temperatures, *S. arvensis* plants were markedly taller than either *N. paniculata* or *E. gallicum*.

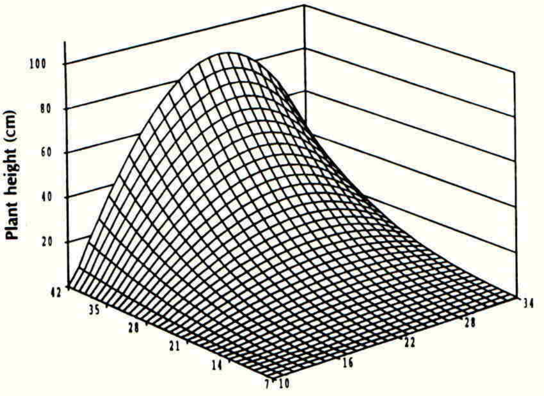
The response of plant dry weight to temperature differed markedly between species (Figure 2). At 42 DFE, total plant dry weight for *S. arvensis* and *E. gallicum* were greatest at 31 to 32 °C and 27 to 29 °C, respectively. But, for *N. paniculata*, maximum plant dry weights 42 DFE occurred at 24 to 26 °C, and dry weight decreased rapidly at temperatures above 28 °C.

Within the range of temperatures examined, *S. arvensis* exibited a linear increase in leaf area with increasing temperature (Figure 3). Maximum leaf area 42 DFE for *E. gallicum* and *N. paniculata* occurred at 27 to 29 °C and 26 to 28 °C, respectively. As with dry weight, *N. paniculata* leaf area decreased rapidly at temperatures above 28 °C.

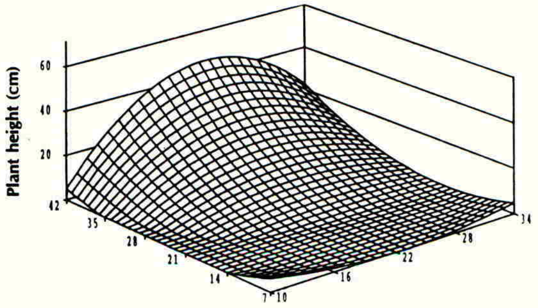
Replacement series

Replacement diagrams indicated competitive relationships existed among all 3 species (Figure 4). The species in decreasing order of competitiveness were *S. arvensis* > *N. paniculata* > *E. gallicum*.

Sinapis arvensis



Neslia paniculata



Erucastrum gallicum

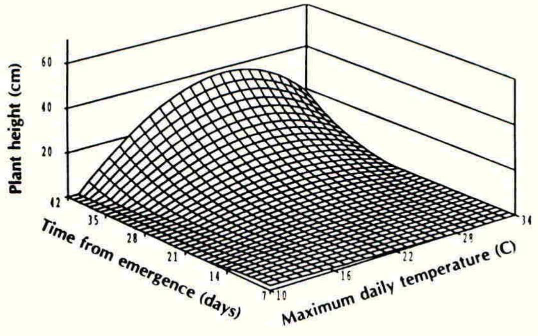
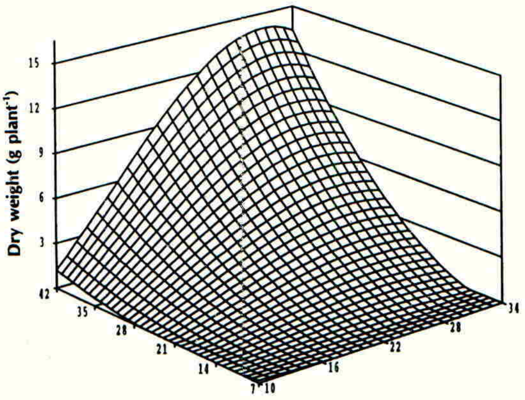
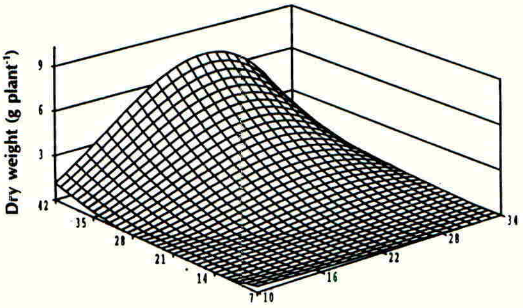


Figure 1. Response of *S. arvensis*, *N. paniculata*, and *E. gallicum* plant height to maximum daily temperature (°C) over time (days from seedling emergence).

Sinapis arvensis



Neslia paniculata



Erucastrum gallicum

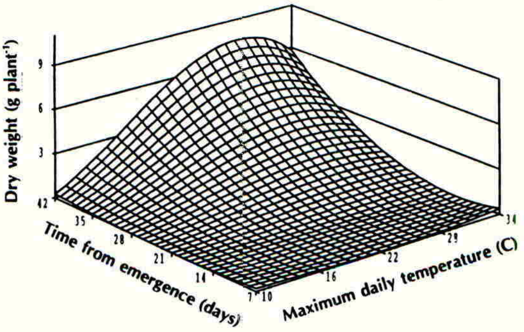
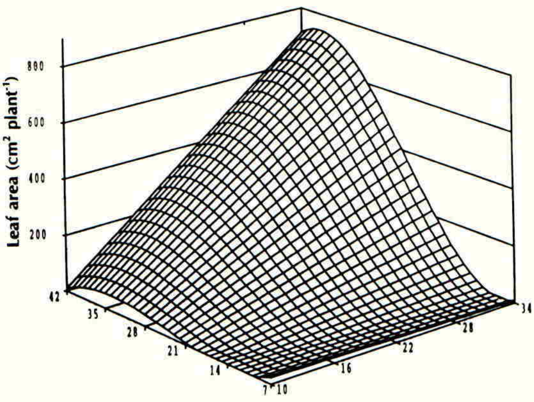
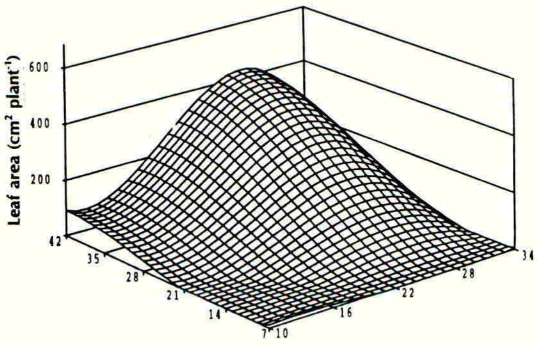


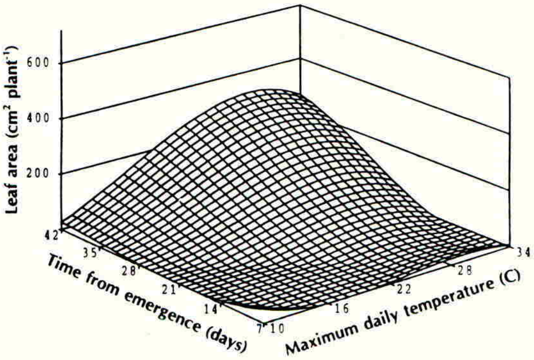
Figure 2. Response of *S. arvensis*, *N. paniculata*, and *E. gallicum* plant dry weight to maximum daily temperature (°C) over time (days from seedling emergence).



Sinapis arvensis



Neslia paniculata



Erucastrum gallicum

Figure 3. Response of *S. arvensis*, *N. paniculata*, and *E. gallicum* leaf area to maximum daily temperature (°C) over time (days from emergence).

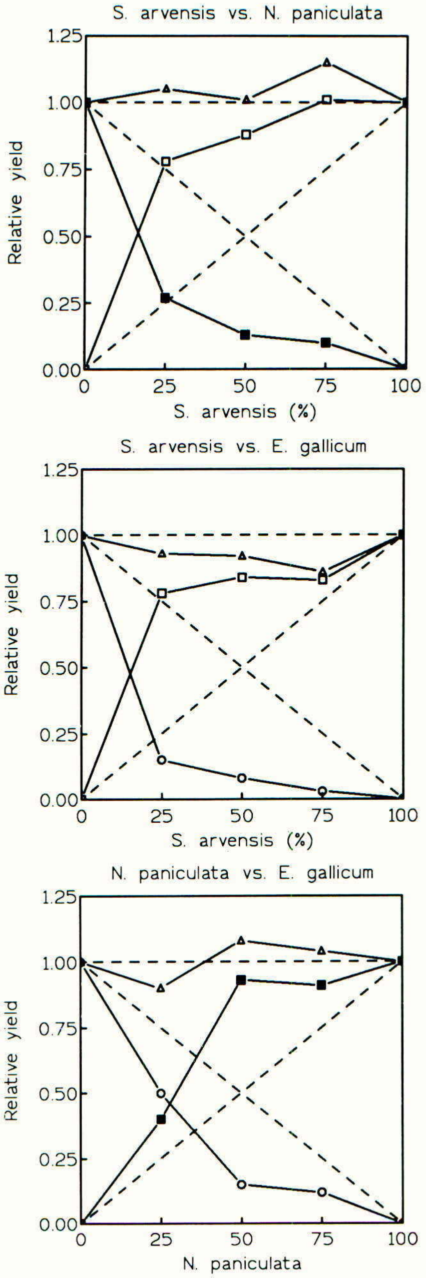


Figure 4. Replacement diagrams showing relative yields for *S. arvensis* (□), *N. paniculata* (■) and *E. gallicum* (○) and relative yield totals (△). Dashed lines represent theoretical relative yields and relative yield totals if no competition occurs between species.

TABLE 1. Regression models for predicting the effect of temperature on plant height, dry weight, leaf area, leaf area ratio, and specific leaf area of *S. arvensis*, *N. paniculata* and *E. gallicum* over time.

Species	Model[a]	R^2
Plant height (cm)		
S. arvensis	$Y = -3.01 + 0.096D + 0.074T - 1.65 \times 10^{-3} D^3 + 1.67 \times 10^{-4} D^3 T - 9.00 \times 10^{-8} D^3 T^3$	0.93
N. paniculata	$Y = 29.63 - 1.401D - 1.981T - 0.027D^2 + 0.044T^2 + 0.007D^2 T - 1.52 \times 10^{-4} D^2 T^2$	0.94
E. gallicum	$Y = 1.31 + 0.618D - 0.131T - 0.049D^2 + 7.9 \times 10^{-5} D^3 T - 4.0 \times 10^{-8} D^3 T^3$	0.86
Dry weight (g plant^{-1})		
S. arvensis	$Y = 1.17 - 0.093D - 0.047T + 3.18 \times 10^{5} D^2 T^2 - 6.80 \times 10^{-7} D^2 T^3$	0.75
N. paniculata	$Y = 0.77 + 0.013D + 0.048T - 6.52 \times 10^{5} T^3 - 0.016DT + 1.39 \times 10^{-5} DT^3 + 4.51 \times 10^{-5} D^2 T^2 - 1.31 \times 10^{-6} D^2 T^3$	0.92
E. gallicum	$Y = -0.005 + 0.026D + 0.042T - 3.85 \times 10^{-4} D^2 T - 8.05 \times 10^{-4} DT^2 + 1.79 \times 10^{-5} DT^3 + 5.84 \times 10^{-5} D^2 T^2 - 1.23 \times 10^{-6} D^2 T^3$	0.90
Leaf area (cm^2 g^{-1})		
S. arvensis	$Y = 89.83 - 8.850D + 5.086T - 1.591DT + 0.124D^2 T - 0.0017D^3 T$	0.62
N. paniculata	$Y = -281.14 + 30.620D + 71.984T - 3.984T^2 + 0.064T^3 - 8.861DT + 0.112 D^2 T - 0.001D^3 T + 0.462DT^2 - 0.007DT^3 - 0.002D^2 T^2 + 6.40 \times 10^{-7} D^3 T^3$	0.82
E. gallicum	$Y = 458.50 - 13.33D - 54.51T + 0.068D^2 + 2.394T^2 - 0.031T^3 + 0.040D^2 T - 4.74 \times 10^{-4} D^3 T - 4.09 \times 10^{-4} DT^3$	0.84

[a] For each model, Y = predicted response, D = days from emergence, and T = maximum daily temperature (°C).

CONCLUSIONS

The three species investigated in this study exhibited marked differences in response to temperature and competitiveness. In this study, *E. gallicum* exhibited slow initial growth, and produced shorter plants with less biomass, and lower leaf areas than either *S. arvensis* or *N. paniculata*. *E. gallicum* and *N. paniculata* exhibited optimum growth at maximum daily temperatures of 26 to 28 °C. *N. paniculata* exhibited marked reductions in height, biomass and leaf area at temperatures above 28 °C and indicated that this species is poorly adapted to high temperature environments. S. arvensis exhibited reduced plant height at temperatures above 26 °C, but produced more biomass and greater leaf areas at temperatures between 28 and 34 °C and suggested that this species may be better adapted to high temperatures than *E. gallicum* or *N. paniculata*. Replacement series experiments indicated that *S. arvensis* was more competitive than either *N. paniculata* or *E. gallicum*. All three species grew well at maximum day time temperatures normal for western Canada between May and August. It is unlikely that temperature alone is a major factor determining the distribution of these species in western Canada. However, the ability of *S. arvensis* to produce taller plants with more biomass and greater leaf areas over a wide range of temperatures has no doubt contributed to it's success as a major agricultural weed.

REFERENCES

DeWit C. T. (1960) On competition. Versk. Landbk. Onderz. No. 66.8.

DeWit C. T. and VandenBerg J. P. (1965) Competition between herbage plants. *Netherlands Journal of Agricultural Science* **13**, 212-221.

SAS Institute, Inc. (1985) SAS User's Guide: Statistics, Version 5 ed. Cary, N.C., SAS Institute, 956 pp.

Scoggan, H. J. (1957) Cruciferae (Mustard Family). In: *Flora of Manitoba*, Ottawa, National Museum of Canada, Bulletin No. 140, pp. 305-327.

Scoggan, H. J. (1978) Cruciferae (Mustard Family). In: *The Flora of Canada: Part 3 - Dicotyledoneae (Saururaceae to Violaceae)*, Ottawa, National Museums of Canada, Publ., pp. 778-848.

Thomas, A. G. and Wise, R. F. (1984). *Weed Surveys of Manitoba Cereal and Oilseed Crops, 1978, 1979 and 1981*. Weed Survey Series, Publ. 84-1. Regina, Agriculture Canada, 230 pp.

Thomas, A. G. and Wise, R. F. (1987) *Weed Survey of Saskatchewan Cereal and Oilseed Crops, 1986*. Weed Survey Series, Publ. 87-1, Regina, Agriculture Canada, 251 pp.

THE EFFECTS OF FRAGMENTATION AND DEFOLIATION ON *RUMEX OBTUSIFOLIUS* AND ITS IMPLICATION FOR GRASSLAND MANAGEMENT.

C.N.G. HUGHES, R.J. FROUD-WILLIAMS, R.T.V. FOX

School of Plant Sciences, University of Reading, 2 Earley Gate, Reading RG62AU

ABSTRACT

Vegetative regeneration of *Rumex obtusifolius* (Broad-leaved Dock) is only possible from intact root and shoot meristems, the position of which varies with plant age. Plants at different growth stages respond differently to grassland management intensity. Seedlings were encouraged in frequently cut swards but were inhibited in lax cut treatments. Conversely, leaf growth and seed set in adults was favoured by lax defoliation, whereas frequent cutting prevented seed production but encouraged regeneration of tap roots and aerial branching (increasing the potential for future seed production). The implications for sward management are discussed.

INTRODUCTION

Rumex obtusifolius (Broad-leaved Dock) is an erect perennial weed of short term leys and permanent pastures worldwide. Intra-specific variation, a large perennating taproot, a vertical underground stem capable of vegetative regeneration and the potential to produce up to 60,000 seeds/plant per annum, of high viability and the capacity of remaining so in undisturbed soil for several decades enable the weed to be successful (Cavers & Harper, 1964). Seed longevity and their ability to pass through the digestive tract of cattle unharmed (Hance & Holly, 1989) enables seed banks of up to 5 x 10^6 seeds to accumilate in the top 15 cm of soil, far in excess of grass seed (Hurt & Harkess, 1988). *R. obtusifolius* is also capable of vegetative regeneration following crown fragmentation, allowing rapid growth following cultivation. In the U.K., docks infest up to 0.7 x 10^6 ha of grassland (Peel & Hopkins, 1980), particularly in intensive dairy pastures (Haggar, 1980) competing directly with grasses (Oswald & Haggar, 1983) and impairing livestock production through its lower palatability and digestibility (McGhie *et. al.*, 1983).

Experiments were carried out to assess the ability of *R. obtusifolius* to recover from fragmentation and defoliation. Strategies of juveniles and adult plants to various sward management practices were compared.

MATERIALS AND METHODS.

Regeneration from seedling fragments.

Seeds were soaked in 5% sodium hypochlorite for five minutes, washed in sterile water prior to incubation in light at ambient temperature. Seven days after the onset of germination, seedlings were transferred to Petri dishes containing sterile water and dissected as follows. (i) 20mm of seedling root with the root tip intact, (ii) shoot plus 20mm of root minus root tip, (iii) shoot only, (iv) complete root plus 10mm of shoot base minus cotyledons, (v) intact seedling. The various fragments were incubated at 15°C in the light and re-examined fourteen days later. Root and shoot measurements were recorded before and after the second incubation period.

Regeneration of juvenile rosette plants.

Seeds in John Innes compost (JI 2) in 10cm diameter pots were incubated in an unheated glass house for four months. The plants were then subjected to various pruning treatments before fresh weights and lengths were measured and the plants replanted. The treatments were as follows: (i) 30mm of tap root only (minus the crown), (ii) 10mm of crown plus the petiole base, (iii) 70mm of lateral root (minus tap root and crown), (iv) 30mm of tap root plus 10mm of crown, (v) complete root system plus 10mm of crown and petiole base.

There were two harvest dates and ten replicates per treatment arranged in a completely randomised design. Destructive harvesting occurred after four and eight weeks, when the following measurements were made: (i) foliage height, (ii) shoot fresh weight, (iii) root fresh weight and (iv) leaf area.

Effects of frequency and intensity of defoliation.

Pots ($0.05m^{2)}$ were filled with a sandy-loam soil. Nitrogen fertiliser was applied as Nitram at a rate of $400kgNha^{-1}$ in four split-applications and seed of *Lolium perenne* cv. Melle sown at a rate of $30kgha^{-1}$. Two Broad-leaved Dock seedlings were transplanted into each pot and thinned to one per pot when established. The swards were then subjected to three cutting frequencies (one, three or five cuts per annum) and two cutting intensities (2cm and 6cm above ground level). *R. obtusifolius* were harvested after one growing season.

Measurements of foliar development were made in July and where seed set occurred, percentage germination was determined by imbibing four replicates of fifty seeds in sterilised water for fourteen days. In September the following measurements were recorded; (i) photosynthetic area (leaves, green stem and green inflorescence), (ii) leaf dry weight, (iii) seed production, (iv) root length, (v) root diameter, (vi) root dry weight.

Effects of nitrogen and defoliation.

An area of grassland free of *R. obtusifolius* on the University farm at Shinfield was chosen for study. The sward was divided into 12 plots consisting of three nitrogen treatments ($0,200,400kgha^{-1}$) replicated 4 times. Each plot measured $4m^2$ in size and contained 4 subplots ($1m^2$) and consisted of a combination of cutting treatments (one cut or three cut system) and seed density (indigenous seed bank, or indigenous seed bank plus 125 additional seeds).

Seedling emergence was monitored monthly and individual cohorts of emergence ringed, allowing mortality of previously emerged seedlings to be recorded. Seeds were sown in October 1990 and emergence was recorded from November onwards. In March 1993 a final destructive harvest was carried out. The following measurements were taken: (i) plant number, (ii) leaf number,

(iii) leaf area, (iv) leaf dry weight and (v) shoot number (the number of growing points on the crown).

RESULTS

Seedling regeneration

Both the root tip and root plus shoot base treatments failed to regenerate within fourteen days, the former becoming brown and necrotic, the latter showing variable regrowth. Shoot growth was significantly reduced if the cotyledons (and subsequently the leaf meristem) were removed, whereas the loss of the root tip did not significantly affect root or shoot growth although, seedlings with roots removed completely failed to regenerate. If the epicotyl was still intact, root regeneration occurred. (Table 1.)

Seedlings are capable of regeneration following fragmentation only if the hypocotyl remains intact.

Regeneration of juvenile rosettes.

Because the amount of root and shoot present at the beginning of the experiment differed for each treatment, straight forward analysis of the dry weights was not possible. The percentage of the original root fresh weights were calculated and compared. As the 'crown only' treatment initially lacked roots, fresh weights were not included in the comparison. The results indicate marked root fresh weight reduction in the control treatment over the study period. These losses are thought to be inflated by the technique used to estimate the initial root fresh weights of the controls. In all cases, root fresh weight decreased over the first four weeks (Table 2.). After eight weeks, the taproot plus crown treatment had recovered and there was a net increase in fresh weight. This treatment had significantly greater fresh weights for both harvests. Once again 'root only' treatments failed to regenerate during the study period although taproots did form some fresh laterals. After eight weeks, many of the taproots had begun to decay.

Both the 'crown' and 'crown plus taproot' treatments exhibited reduced shoot weights after four weeks but, by eight weeks, they showed net increases. The non-defoliated control treatment exhibited net increases at both harvests,

TABLE 1. Seedling regeneration of *R. obtusifolius* after fourteen days as a percentage of the original length.

Treatment	Root	Root (log Transformation)	Shoot	Total
Root tip only	103.8	4.642	----	----
Minus root tip	114.1	4.734	195.0	147.0
Shoot only	----	----	154.8	----
Root plus shoot base	103.8	4.642	----	----
Control	133.0	4.877	177.8	134.0
LSD 5%	----	0.162	49.6	17.7

TABLE 2 Effects of fragmentation on juvenile plants of *R. obtusifolius* .

	Root Weights		% Shoot Change		Height (mm)		Leaf Area (mm^2)	
	4wks	8wks	4wks	8wks	4wks	8wks	4wks	8wks
Tap root	2.56	2.45	----	----	-----	-----	-----	-----
Lateral root	2.19	2.06	----	----	-----	-----	-----	-----
Crown	----	----	71.1	123.3	142.8	211.3	85.7	213.1
Crown + tap root	4.23	4.93	97.2	148.4	184.4	225.8	218.7	305.8
Control	2.97	3.16	178.4	189.3	178.0	210.1	245.5	262.7
Trans	log	log	none	none	none	none	none	none
LSD 5%	0.38		50.4		25.5		61.68	

having significantly larger fresh weights at all times than the 'crown only'. Most of this occurred in the first four weeks, with only 12% occurring subsequently. The other two treatments showed a similar, but lesser response. (Table 2.) Seedling height of the 'crown only' treatment was significantly less after four weeks, but by eight weeks there was no significant difference between treatments. Of all plants that produced leaves, the 'crown only' treatment had a much reduced leaf area than the others after four weeks. Both it and the 'crown plus taproot' treatment significantly increased their leaf areas during the following four weeks, although the latter produced a significantly higher area than the 'crown only' treatment by week eight. The control treatment did not increase its leaf area greatly within this period.

Fragmented mature seedlings will only regenerate if the crown is intact. The crown contains both root and shoot meristems capable of regeneration. An isolated root will not regenerate albeit the root may appear healthy for many weeks before decaying. The amount of root attached to the crown following fragmentation will affect the rate of regrowth, the two being positively correlated.

The effects of cutting frequency and intensity on adult plants.

Frequent defoliation significantly affected root dry weight. Cutting once only produced roots four times heavier than those cut three or five times a year and this effect was even greater if cut at a height of 6cm, although

TABLE 3. Effects of defoliation on *R. obtusifolius* roots.

	Root Dry weight(g)		Root area (mm^2)		Root length (mm)		Root diameter (mm)	
	3cm	6cm	3cm	6cm	3cm	6cm	3cm	6cm
1 cut	2.31	3.15	67.6	25.5	419	256	18.9	10.2
3 cut	1.48	1.27	70.9	34.3	321	266	20.2	13.0
5 cut	1.34	0.56	34.4	12.4	300	115	12.5	8.6
Trans	sqrt	sqrt	none	none	none	none	none	none
LSD 5%	0.81	0.81	24.4	24.4	99.0	99.0	3.7	3.7

overall there was no effect of cutting intensity at other frequencies (table 3.). Frequent cutting (5 times a year) also produced smaller root areas and root lengths. Cutting the plants at 3cm as opposed to 6cm produced larger totalroot areas, larger tap root diameters and longer roots, yet surprisingly had no effect on overall dry weight. At the two harvests (July 5th and September 23rd) cutting closer to the ground increased leaf area and number, especially if cut infrequently. Lax cutting (once a year) allowed plants to produce seed in July whereas seed production did not occur at the other frequencies of defoliation. Flowering plants produced on average 5000 seeds (s.e. = ±743), ranging from 1000 to over 8000 per plant. Germination within 6 weeks of harvesting ranged from 3 - 89% with an average of 45%. Seed was only recovered from one plant at the second harvest, none of which germinated.

The increased root diameter, root length, root area, leaf number and leaf area produced by intense cutting (3cm in height) may have occurred because the low cut excised the main apical growth point of the plant, causing several new growth points to develop. Plants cut at 6cm would retain the main apical meristem thus maintaining apical dominance and so suppress axillary growth. The expansion of new apices around the periphery of the crown would increase tap root diameter and the increased leaf area would allow increased translocation of materials to the roots promoting increased growth.

The effects of nitrogen application and cutting frequency on the growth and survival of *R.obtusifolius* seedlings in the field.

Seedlings emerged over a six month period in both years, commencing in April and terminating in September. The numbers of emerged seedling were positively correlated with nitrogen application, but unaffected by cutting regime. Overall, only 12% of the seeds emerged over the two years and 82% of these in the first year. Once emerged, seedlings showed great sensitivity to treatments. Only 18% of the seedlings survived to the end of the study (1% of the total seed added). Although nitrogen had no effect on the seedling survival, swards with high nitrogen produced larger leaf areas and leaf dry weights (Table 4.). Frequent cutting of the sward enabled a higher percentage of seeds to survive. These seedlings were significantly larger than those from infrequently cut swards. At 0 and 200 kg N / ha, there was no significant difference between cutting regimes, indicating that the grass could only out compete docks in an infrequently cut sward at higher levels of fertility (Table 5.)

TABLE 4. Effects of defoliation of *R. obtusifolius* leaf production.

	Photosynthetic area (mm^2)		Foliar dry weight (g)		Leaf number	
	3cm	6cm	3cm	6cm	3cm	6cm
1 cut	15.6	9.2	0.93	0.59	7.86	7.86
3 cut	23.9	8.7	1.35	0.53	9.67	4.33
5 Cut	18.2	4.1	1.26	0.57	9.83	2.50
Trans	Square root		Square root		None	
LSD 5%	0.81	0.81	0.61	0.61	3.73	3.73

TABLE 5. Effects of nitrogen regime and defoliation on *R. obtuifolius*.

	Total DW (g)		Total LA (mm^2)		Plant number		DW plant^{-1}		LA plant^{-1}		Leaf number	
Cut	3	5	3	5	3	5	3	5	3	5	3	5
Nit												
0	0.0	0.1	0.0	0.6	0.0	0.5	0.0	0.1	0.0	9.6	0.0	0.9
200	0.3	0.7	0.7	0.29	1.0	2.25	0.0	0.3	3.7	12.9	0.6	3.1
400	>0	1.5	0.2	2.3	0.2	4.25	>0	0.6	1.2	31.5	>0	5.0
Trans	SQRT		Log		None		None		None		SQRT	
LSD	1.3		2.2		3.9		0.5		32.4		3.2	

DISCUSSION

The response of *R. obtusifolius* to sward management practices is growth stage dependent. Seedlings and adults may regenerate following fragmentation but newly emerged seedlings are more sensitive because the root and shoot meristems are distinct and thus easier to separate. They are more prone to death through cultivation and may only regenerate into a single seedling. In mature plants, the two meristems are located together and capable of multiple regeneration on fragmentation and thus more likely to survive cultivation.

In high nitrogen input swards, Broad-leaved Dock seedlings benefit from frequent cutting with greater numbers of larger plants surviving. Infrequently cut grass excludes dock seedlings preventing them from attaining maturity but, frequent defoliation prevents seed set and drastically reduces root growth.

R. obtusifolius seedlings favour uncultivated, frequently cut swards whereas adults prefer either cultivated or infrequently cut swards. Thus, irrespective of sward management programme, *R. obtusifolius* will be favoured.

REFERENCES

Cavers, P.B.; Harper J.L. (1964) *Rumex obtusifolius* and *Rumex crispus*. *Journal of Ecology*, 52, 737-766.

Haggar, R.J. (1980) Survey of the incidence of docks (*Rumex spp.*) in grassland in ten districts of the United Kingdom in 1972. *ADAS Quarterly Review*, 39, 256-270.

Hance, R.J.; Holly, K. (1989) *Weed Control Handbook: Principles*.Blackwell 8th Edition, Blackwell, 550 pp.

Hurt, I.V.; Harkess, R.D. (1986) Docks in grassland. *Scottish Agriculture*, 47 (3), 160-162.

McGhie, D.A.; Sprivulus, R.; Dixon, F.F.; Sawyer, G.J.; McMullen, G.; Silcock, J.; (1983) Dock - Weed or Pasture plant, *Journal of Agriculture Western Australia*, 24 (3), 87-89.

Oswald, A.K.; Haggar, R.J. (1983) The Effects of *Rumex obtusifolius* on the seasonal yield of two mainly perennial ryegrass swards. *Grass and forage science*, 38, 187-191.

Peel, S.; Hopkins,A. (1980) The incidence of weed in grassland. *Proceedings of the 1980 British Crop Protection Conference on Weeds* 1,219-223.

BRIGHTON CROP PROTECTION CONFERENCE - Weeds - 1993 6C-5

THE RISE OF BARREN BROME *BROMUS STERILIS* IN UK CEREAL CROPS

N.C.B. PETERS

Department of Agricultural Sciences, University of Bristol,
AFRC Institute of Arable Crops Research, Long Ashton Research Station,
Bristol BS18 9AF, UK

R.J. FROUD-WILLIAMS

Department of Agricultural Botany, University of Reading, Earley Gate,
Whiteknights, Reading RG6 2AU, UK

J.H. ORSON

ADAS Boxworth, Cambridge CB2 2AZ, UK

ABSTRACT

Barren brome (*Bromus sterilis*) has become a prominent weed in winter cereals since the 1970's. Although most populations of the weed display little innate seed dormancy, dormancy can be enforced by light and dry conditions which, coupled with a high seed production, allow sufficient seed to be carried over ungerminated into a following autumn crop, subsequently causing an infestation in that crop. In cereal crops, selective control with currently available herbicides is unreliable, resulting in the perpetuation of infestations. Although ploughing can provide very good control of the weed by allowing germination and not emergence, it is often difficult to bury all the seed deeply enough to prevent emergence. This is particularly true on shallow stony soils, or where dense mats of seed have to be incorporated, the long awns on the seeds assisting in the re-dispersal of the seed from these mats during ploughing. Some populations also have the ability to survive ungerminated in small but important numbers in some soils from one cropping season to another. These factors, together with others, which have made *B. sterilis* a prominent weed despite it not having all the attributes normally associated with a major weed, are described in this paper.

INTRODUCTION

B. sterilis is an annual, occasionally biennial or rarely perennial grass of widespread occurrence in roadsides and waste places. Although previously of little agronomic importance, since the late 1970's it has become a prominent weed in winter cereals. This was at a time when profit margins in winter cereals were relatively high and herbicides were providing effective control of black-grass (*Alopecurus myosuroides*). This encouraged the growing of continuous winter cereals established after non-ploughing tillage.

A survey of grass weeds in central southern England during 1981 indicated that 9% of winter cereal fields were infested with *B. sterilis*, whilst a further 7% had *B. sterilis* confined to the field margin. By 1982, the level of infestation had increased to 15% of winter cereal fields (Chancellor & Froud-Williams, 1984). A more recent survey of brome grasses in England, Wales and Scotland indicated that 12% of the cropped area was infested by *B. sterilis* (Cussans *et al.*, 1989), comparable to the 13% reported by Whitehead & Wright (1989). In addition, the 1981 survey found that 42% of cereal farms had infestations of brome grasses, the majority of which were *B. sterilis*.

Despite its current status, *B. sterilis* lacks a number of the attributes normally associated with a successful weed. This paper outlines the agronomic circumstances and the attributes of *B. sterilis* that have enabled it to become a troublesome weed.

WHAT MAKES A SUCCESSFUL WEED ?

Baker (1974) lists the attributes of the 'ideal' weed, fortunately for which there are no current contenders. These characteristics may be simplified and summarised as, non-exacting germination requirements, discontinuous germination, rapid switch from vegetative to reproductive development, self-compatible but not completely autogamous, high fecundity, extended seed production, efficient dispersal mechanism, phenotypic plasticity and competitive ability. Holzner (1982) has expanded and extrapolated these attributes further to include seed dormancy and persistence, short generation time, genetic plasticity and ploidy, responsiveness to and tolerance of high fertility. A number of other factors also require consideration, including mortality and susceptibility to herbicides. From a knowledge of such attributes, it is possible to consider reasons for the success of *B. sterilis* as an arable weed.

GERMINATION REQUIREMENTS AND DISCONTINUOUS GERMINATION

A successful weed usually has an extended period of emergence in any one season and a dormancy system to maintain a reservoir of seed in a seed bank which subsequently germinate over a number of years. *B. sterilis* is a winter annual which germinates in the autumn. Autumn germination is necessary because the seedlings of most populations must be vernalised in order to flower and set seed. The increased acreage of winter cereals has, therefore, favoured the build-up of this weed. In contrast, spring cropping tends to reduce infestations because firstly, if seedlings emerge in the spring, it is too late for them to be vernalised, and, secondly, much of the seed shed the previous year will have germinated and been destroyed by the pre-cultivation and drilling of a spring crop. Hence, the lack of a spring germination ability is a clear weakness in this weed's armoury. In addition, autumn germination also confers a long generation time on the weed, in contrast to other weeds such as *Senecio vulgaris*, where the weed can have more than one generation in a year allowing an exceedingly rapid build-up of its population.

Most populations of *B. sterilis* have been found to emerge over a relatively short period in the autumn (i.e. have little innate dormancy) and can germinate over a wide temperature range (0 -30°C) Froud-Williams (1981), provided that sufficient moisture is available. However, recent investigations have indicated that a few populations (3 out of 23 farms) are more dormant, and although the main flush of emergence occurs as soon as the seed is buried and has sufficient moisture, a small proportion remains dormant and emerges over an extended period (Fig. 1).

As a consequence of the lack of innate dormancy, seed of the majority of populations can be destroyed in wet autumns before the autumn crop is planted. However, the period of emergence can be extended even in relatively non-dormant populations by the lack of sufficient moisture for germination. It is then not possible to destroy the seeds through killing their seedlings by either cultivation or a non-selective herbicide applied either pre- or post-drilling. Clearly in dry autumns more seed will be carried over into a following autumn crop, resulting in higher infestations in the crop. If dry conditions persist, then emergence may take place over a longer period making the timing of herbicide application difficult.

Despite a lack of innate dormancy, the most effective contribution that the dormancy mechanism makes to seed persistence is through the acquisition of light enforced dormancy (Fig. 2). (Enforced dormancy occurs when the seed is deprived of its basic requirements for germination, e.g. absence of water or darkness.) The majority of populations shed a proportion of seed which is not able to germinate in the presence of light (Hilton, 1982). Thus some seed can remain ungerminated on the soil surface throughout the autumn when the next crop is planted. Clearly, if these seeds are left on the soil surface until just before drilling, and are then incorporated into the soil either by pre-drilling cultivations or during drilling they are subsequently able to emerge within the crop. This explains the rapid build-up of *B. sterilis* populations in minimum cultivation and direct drilling systems, particularly where effective herbicide control is not achieved and where lack of moisture enforces dormancy.

To illustrate the extent of survival of ungerminated seed on the soil surface, the following examples are given. When seed was placed on the soil surface in early August, the number of seed remaining viable, but ungerminated by mid-October ranged between 4% and 10% for low dormancy populations, and between 28% and 54% for high dormancy populations. Seasonal factors can influence the numbers of seed remaining ungerminated, for in another year 57% - 85% of the seed from the same high dormancy populations remained viable and ungerminated by mid-October. Only one of the low dormancy populations was tested in the same year, but 40% of this population remained ungerminated by mid-October compared with 7% in the previous year. It is certain that seed of some of the more dormant populations can remain ungerminated on the soil surface from one cropping season to another, for in one population, 36% of the original number of viable seed on the surface was still ungerminated and viabie by June of the following year. Therefore, leaving seed on the soil surface for a year, as possibly the case in some set-aside situations, is no guarantee of complete seed loss.

DORMANCY AND SEED SURVIVAL IN SOIL

Light-induced dormancy has been found only in a few populations. (Induced dormancy occurs if a seed that would normally germinate is placed in an environment which results in the seed no longer being able to germinate when subsequently placed in conditions in which it would normally germinate.) In laboratory tests with these populations, light-induced dormancy could not be relieved by subsequently placing the seed in darkness. This suggests that, in the field, such populations would be able to survive ungerminated for longer when buried after light exposure than populations not possessing such inducible dormancy. However, inducible dormancy may play a greater role in the survival of this species if the seed is exposed to a combination of light, wet and cold. In an experiment where seed, left on the soil surface over winter where these conditions were experienced, was retrieved the following spring and incubated in darkness, little

Fig. 1 Germination of two populations of *B. sterilis* seeds buried immediately after shedding

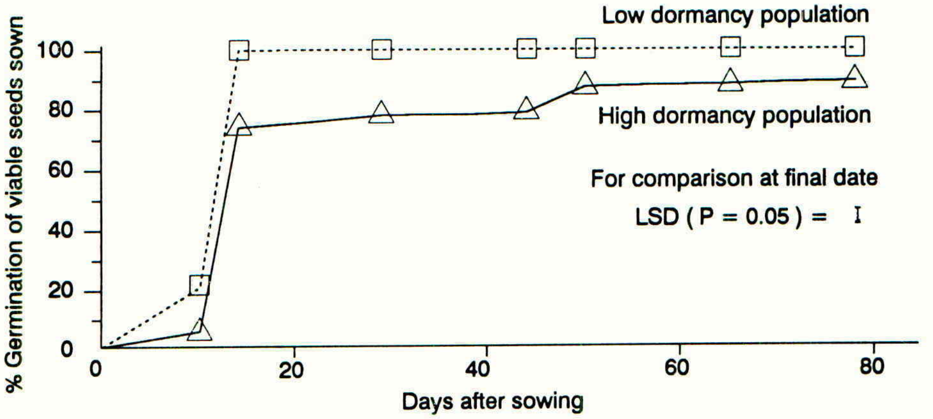


Fig. 2 Germination of two populations of *B. sterilis* seeds on the soil surface

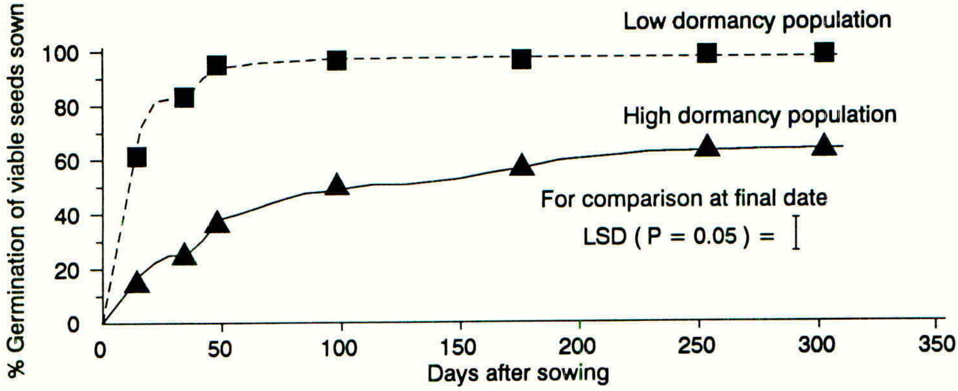
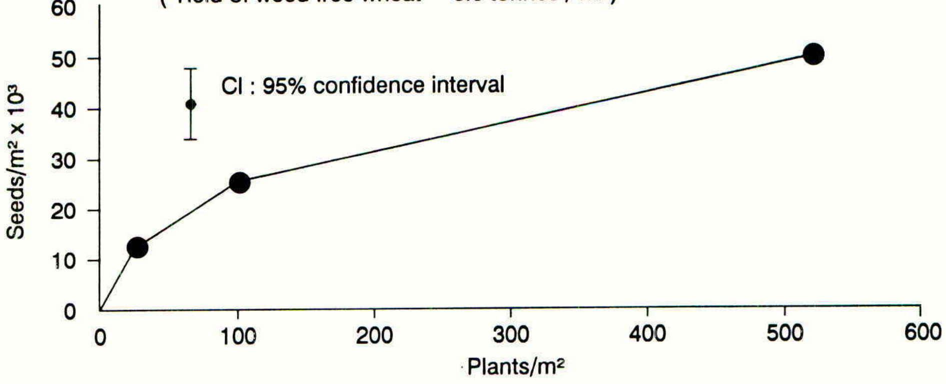


Fig. 3 Seed production by *B. sterilis* in winter wheat

(Yield of weed free wheat = 8.0 tonnes / ha)



germination occurred, although the seed was still viable, which supports the finding of Pollard (1982a). Further investigation is needed to determine if such seed can remain ungerminated in soil, but dormancy induced in this way certainly provides the seed with a potential mechanism for long-term survival.

Many investigations have been made in order to determine the longevity of *B. sterilis* seeds in various soil types. It can be concluded that burial of seed to plough depth in autumn after harvest should result in seed depletion of all low dormancy populations (which are by far the majority in England) from light soils within a year of burial. Autumn ploughing should result in good control of the weed, because the seed will germinate at plough depth (Froud-Williams *et al.*, 1980) but fail to emerge except in very open textured soils. This is a severe weakness in the survival strategy of *B. sterilis* or indeed of any plant with little innate seed dormancy or dormancy which is difficult to induce. Nevertheless, ploughing the seed down to below 15 cm on some soils is difficult to achieve, and on headlands seed tends to be ploughed up after being ploughed down due to cross ploughing or the meeting of plough furrows. Moreover, the long seed awns tend to mat seed together making it difficult to bury all of the seed. Infestations can therefore subsequently arise from this ungerminated seed which is left on the soil surface. Very early ploughing, particularly in dry years, would also mean that large numbers of seed would be present on the soil surface, and again for the reasons given above it would be difficult to bury all of the seed.

In addition, very small (0.06% of the seeds sown) but important numbers of seed of more dormant populations have been found to survive ungerminated for at least one year in light soils and at least two years in heavy soils. Indeed, in heavy soils, even the low dormancy populations have been found to survive (0.06% of the seeds sown) for at least two years. Soil texture or other factors, such as moisture, are thought to be responsible for the increased survival of seed in heavy soil. Although only small percentages of seeds survive, they are very important because of the high numbers of seed which can be initially shed (Fig. 3). For example, if 10,000 seed/m^2 are shed, which can occur in even moderate infestations, then 0.06% would represent 6 plants/m^2.

Therefore, under certain soil conditions some populations can remain ungerminated and viable from one cropping season to another, resulting in a much longer-term control problem akin to black-grass or wild-oats. It may also explain why in the brome grass survey of 1989, a high proportion of first wheats and ploughed land had infestations of *B. sterilis*.

COMPETITIVENESS, SEED PRODUCTION AND SPREAD

In its vegetative state, *B. sterilis* is highly competitive with cereal crops, albeit at high densities less competitive on a plant-for-plant basis than wild-oat (Cousens *et al.*, 1984). In a very high infestation (1000/m^2), Gray (1981) reported a yield reduction in wheat of 45%. Cousens *et al.* (1985) found that a density of 123 *B. sterilis* plants/m^2 could reduce yield by 14% in a low density barley crop (115 plants/m^2) and in a high density barley crop (280/m^2) by 8%. In winter wheat, losses from similar numbers of *B. sterilis* were higher, being 47% and 35% in low and high density crops, respectively. Reductions in grain quality and contamination of grain also occur (Cousens *et al.*, 1985, 1988) and lodging of the crop in highly infested areas results in harvesting difficulties. Seed numbers produced by *B. sterilis* are large and in a vigorously growing crop of winter wheat (8 tonnes per hectare) (Fig. 3), 25 plants per m^2 produced 12,000 seeds. Likewise, in winter barley Froud-Williams (1983) found that seed numbers exceeding 12,000/m^2 could be shed, and as many as 53,400/m^2 have been reported by Pollard (1982b). Thus, only a small proportion of seed needs to survive for populations to perpetuate from year to year.

Even where *B. sterilis* has been eradicated from a field there is always the danger of re-introduction from hedgerows and field boundaries, which are important habitats for this weed. Although the situation is now much improved, many farmers used to spray field boundaries with non-selective herbicides to discourage the ingress of rhizomatous perennial weeds into the field. This action created large swathes along hedgerows where an annual weed such as *B. sterilis* could colonise and build up large populations. The passage of farm machinery, particularly combine harvesters, along the edges of fields soon re-introduces the seed into the main area of the field (Rew, 1993). The presence of the long awns on the seeds is a particularly advantageous adaptation in this transfer process. In the past, the situation was aggravated when straw was raked away from hedge lines into the field prior to stubble burning. As the presence of the long awn on the seed makes it difficult to clear seed from combine harvesters, transfer of seed from field to field by the combine can be an important factor in spreading the weed on a farm (Howard, 1991).

OTHER FACTORS FAVOURING THE WEED

(a) Lack of straw/stubble burning

Following the ban on stubble/straw burning in 1993, the question arises as to how this may affect *B. sterilis* infestations. Burning consumed many seeds in the straw and on the soil surface and was a very useful method of reducing seed numbers (Froud-Williams, 1983). As a consequence of the straw burning ban, it is likely that infestations could become more severe. However, straw cover provides both darkness and moisture retention, so that in wet autumns the presence of straw encourages seed loss through germination. Even in dry years the effect is present, presumably due to retention of sufficient moisture under the straw (Blair, pers. comm.).

(b) Autumn weather

Dry autumns are a considerable advantage to the weed, or to any weed which has a low innate dormancy, such as *B. sterilis,* for as previously described more seed can survive into the following autumn crop. In such years, there can be large build-ups of populations; this happened in a series of dry autumns in the 1970's. In contrast, in wet autumns which favour seed germination, provided the seedlings are destroyed prior to sowing the following crop, there can be large reductions in plant density. There can, therefore, be large fluxes in populations because of the high seed production and considerable vigilance is therefore needed to avoid farmers being caught unawares.

(c) Herbicides

One of the greatest current strengths of *B. sterilis* as a weed is the unreliability of the herbicides currently available for its selective removal in cereals. As no herbicides have been specifically developed for selective control of *B. sterilis* in cereals, it is not surprising that those herbicides used are not totally reliable because they are at the limit of their selective activity with brome species. In some instances, the unreliability can be attributed to longer periods of emergence under dry conditions, which allows soil-applied herbicides (e.g. isoproturon) to degrade significantly before full emergence of the population. A sequence of herbicides is therefore necessary not only to counter the protracted emergence but also because an individual herbicide may not provide reliable control. The alternative strategy is to rotate cereals with broad-leaved crops, e.g. oilseed rape, in which effective herbicide control can be achieved. However, until a reliable late post-emergence selective herbicide is introduced *B. sterilis* will be a difficult weed to control in cereals. Fortunately, the plant is an inbreeder, which limits the possibility of crosses occurring which might be resistant to the available herbicides, although some cross-pollination can sometimes occur (Beddowes, 1931) and inbreeding can preserve recessive genes which may confer resistance. There is certainly evidence to suggest that populations do differ in their response to herbicide treatment (West & Peters, 1992).

(d) Time of crop sowing

A feature which has helped the growth of *B. sterilis* populations indirectly has been the increase in the acreage of winter cereals since the 1970's. To ensure that the increased acreage is planted in time, autumn sowing has been started earlier which in turn has meant that there is less time for seed of *B. sterilis* to germinate and be destroyed before the autumn crops are planted.

(e) Set-aside

Seed becomes viable 3 - 7 days after anthesis (Froud-Williams, 1983; Rind, 1990). This has implications for the management of set-aside, for it means that cutting must take place before anthesis, to be sure that no viable seeds are produced. In practice, this is difficult to observe because anthesis/fertilization takes place before emergence of the anthers. It is, therefore, best to cut the plants when the first panicles are seen emerging from their sheaths, which is a clearly observable stage.

In set-aside, the capacity of the plant to re-tiller after cutting, particularly if cutting is carried out before the main stems have flowered, allows plants to produce seed unless the tillers are also cut. The latter is sometimes difficult to achieve because tillers are often prostrate. Seed can, therefore, be produced in set-aside situations where mechanical cutting is the main method of control. If any seed is produced in this way, it is, thus, essential either to plough or be very vigilant in any following crops.

ACKNOWLEDGEMENTS

The work described in this paper was funded by the Ministry of Agriculture, Fisheries and Food and the Home-Grown Cereals Authority for which the authors are most grateful. Thanks also go to A.M. Blair, J. Rule (ADAS, Boxworth) and D.H.K. Davies (Scottish Agricultural College) who were jointly involved with the research on *B. sterilis* for the Home-Grown Cereals Authority.

REFERENCES

Baker, H.G. (1974) The evolution of weeds. *Annual Review of Ecology and Systematics,* **5**, 1-24.

Beddowes, A.R. (1931) Self- and cross-fertility and flowering habits of certain herbage grasses and legumes. *Welsh Plant Breeding Station Publication Series H No. 12, 1921 - 1930,* 32-34.

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

Cousens, R.; Firbank, L.G.; Mortimer, A.M.; Smith, R.G.R. (1988) Variability in the relationship between crop yield and weed density for winter wheat. *Journal of Applied Ecology,* **25**, 1033-1044.

Cousens, R.; Pollard, F.; Denner, R.A.P. (1985) Competition between *Bromus sterilis* and winter cereals. *Aspects of Applied Biology,* **9**, 67-74.

Cousens, R.; Peters, N.C.B.; Marshall, C.J. (1984) Models of yield loss - weed density relationships. *COLUMA-EWRS. 7th International Symposium on weed biology, ecology and systematics,* 367-374.

Cussans, G.W.; Cooper, F.B.; Davies, D.H.K. (1989) BCPC-funded survey of Brome Grasses. *Preliminary Report to the British Crop Protection Council* pp. 1-10.

Froud-Williams, R.J. (1981) Germination behaviour of *Bromus* species and *Alopecurus myosuroides. Association of Applied Biologists Conference: Grass Weeds in Cereals in the United Kingdom,* 31-40.

Froud-Williams, R.J. (1983) The influence of straw disposal and cultivation regime on the population dynamics of *Bromus sterilis. Annals of Applied Biology,* **103**, 139-148.

Froud-Williams, R.J.; Pollard, F.; Richardson, W.G. (1980) Barren Brome: a threat to winter cereals? *Agricultural Research Council, Weed Research Organization, 8th biennial report,* 43-51.

Gray, G.R. (1981) Aspects of the ecology of barren brome (*Bromus sterilis* L.). *PhD Thesis, University of Oxford.*

Hilton, J.R. (1982) An unusual effect of the far-red absorbing form of phytochrome: Photoinhibition of seed germination in *Bromus sterilis* L. *Planta,* **155**, 524-528.

Holzner, W. (1982) In: *Biology and Ecology of Weeds,* W. Holzner and M. Numata (Eds.). Published by Dr. W. Junk, The Hague.

Howard, C.L. (1991) Comparative ecology of four brome grasses. *PhD Thesis, University of Liverpool.*

Pollard, F. (1982a) Light induced dormancy in *Bromus sterilis. Journal of Applied Ecology,* **19**, 563-568.

Pollard, F. (1982b) A computer model for predicting changes in a population of *Bromus sterilis* in continuous winter cereals. *Proceedings British Crop Protection Conference, Weeds,* 973-979.

Rind, A. (1990) Aspects of seed viability and development in *Bromus sterilis* (L.). *Project Report for the M.Sc. Degree in Crop Protection, University of Bristol.*

Rew, L.J. (1993) Spacial and on competitive aspects of arable field margin flora. *PhD Thesis, University of Reading.*

West, T.M.; Peters, N.C.B. (1992) Response of *Bromus sterilis* plants grown from different seed stocks, to post-emergence herbicide treatments of isoproturon and metoxuron. *Annals of Applied Biology. Tests of Agrochemicals and Cultivars,* **13**, 62-63.

Whitehead, R.; Wright, H.C. (1989) The incidence of weeds in winter cereals in Great Britain. *Proceedings Brighton Crop Protection Conference, Weeds,* 107-112.