UNIVERSITY OF SOUTHAMPTON

FACULTY OF SCIENCE

BIOLOGY

THE ECOLOGY AND CONSERVATION OF RARE ARABLE WEED SPECIES AND COMMUNITIES

Thesis submitted for the degree of Doctor of Philosophy

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ABSTRACT

FACULTY OF SCIENCE

BIOLOGY

Doctor of philosophy

THE ECOLOGY AND CONSERVATION OF RARE ARABLE WEED SPECIES AND COMMUNITIES

Philip John Wilson

Since 1940, considerable changes have occurred in both arable farming practices and arable weed floras in Britain. The aim of this project was to investigate the ecology of a range of annual weed species in relation to farming practices, in order to suggest some reasons for the decline in frequency of some species, and to propose some methods by which populations may be conserved.

A survey of the sites at which eight uncommon species are still found, demonstrated the strong association of the weed communities and the presence of individual species, with the cropping history and soil characteristics of fields. Climatic factors and the long-term histories of sites were also found to be important. Another survey demonstrated the tendency for the seed-banks of most weed species to be greatest at the extreme edge of fields.

Four herbicides were tested against ten weed species, and the effects of levels of nitrogen application on 18 weed species were investigated. It is believed that herbicide use and the high levels of nitrogen applied to modern crop varieties have favoured their growth at the expense of weeds.

The type of crop sown and the date of sowing also had a great influence on the development of the weed flora. Some species rely on a post-harvest stubble in order to set seed.

Changes in arable weed communities and the status of rare species is thought to be a result of changes in the farming practices described above in addition to others not investigated. Management guidelines based on the experimental investigations are proposed.

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SUMMARY

Chapter 1.

1. Britain's arable weed flora has undergone great changes since 1940, and many once common species are now rare.

2. Arable weed species originated from several sources, and the present flora is a result of more than 5000 years of evolution. Little attention however has been given to its conservation.

4. Recent changes in the status of arable weed species are believed to be due to changes in farming practices.

5. Arable weeds possess many features which enable them to survive in the arable environment. Most species are annuals, able to persist through periods of unfavourable conditions as a "bank" of dormant seeds. Effects of management practices must be considered in terms of seed production.

6. Eight species were selected for detailed study, and research was directed towards the formulation of conservation management guidelines for rare weed species and communities.

Chapter 2.

7. Sites from which the selected species were known were studied in relation to environmental and farming factors.

8. Soil type, in particular texture, was the most important factor influencing the composition of weed communities and the presence of most of the species

studied.

9. Climatic factors and cropping practices were also important.

10. The length of time for which a field had been in cultivation was associated with the number of rare species present.

Chapter 3.

11. Weed distribution was studied in relation to distance from the field edge.

12. Most species were most frequent within four metres of the crop edge. Viola arvensis was an exception.

13. Species-richness was greatest near the field edge.

14. The seed-bank was compared with the number of seedlings in the field. The two were closely associated.

Chapter 4.

15. Ten weed species were sprayed with four herbicides.

16. Ioxynil/bromoxynil mixture caused the death of all species tested. Mecoprop and chlortoluron were also very effective, but MCPA only affected Papaver rhoeas and Scandix pecten-veneris.

17. The use of herbicides had significantly reduced the numbers of seeds of seven out of fourteen species recorded in the seed-bank of the Broadbalk winter wheat experiment.

Chapter 5.

18. The germination periodicity of twenty one species was investigated in relation to soil disturbance.

19. Eight species were autumn and winter germinating; three were spring and summer germinating, and five germinated in both periods. Four species showed little dormancy and periodicity.

20. Soil disturbance promoted seed germination.

Chapter 6.

21. The effects of nitrogen application and crop sowing density on the performance of weed species was studied.

22. Increasing levels of nitrogen fertiliser reduced the numbers of plants of nine species surviving to produce seed. Numbers of seed produced per plant of four species were increased by addition of nitrogen.

23. Density of crop sowing had few effects on weed growth, but omission of the crop increased seed production by five species.

Chapter 7.

24. The date of cultivation and crop sowing was investigated in relation to the performance of nineteen weed species.

25. Weeds were most productive in winter cereals sown between the middle of October and the beginning of November, and in spring barley sown at the end of March.

26. Torilis arvensis and Petroselinum segetum only produced ripe seed in post-harvest stubbles.

Chapter 8.

27. Winter germinating species have declined most, mainly as a result of increased herbicide and fertiliser use. Changes in crops sown have been partly responsible for the declines of some species.

28. Seed dormancy mechanisms have determined the sensitivity of species to management changes.

Chapter 9.

29. The ecology and current status of the selected species are described in relation to changes in farming practices.

Chapter 10.

30. Management guidelines are proposed for rare weed species and communities. These involve reduction or elimination of fertiliser and herbicide use, and alteration of crop rotations and post-harvest practices, according to the requirements of individual species and localities.

Species nomenclature follows Clapham A.R., Tutin T.G. and Moore D.M. (1987). Flora of the British Isles, Third Edition. Cambridge University Press, with the exception of *Buglossoides arvensis* (L.) I.M. Johnston, formerly *Lithospermum arvense* (L.)

CHAPTER 1.

INTRODUCTION

Aims of the project.

The aims of this project were:

1. To determine the roles of changes in farming practices in the decline of traditionally occurring arable weed species and communities.
2. To propose a set of management guidelines by which the conservation of the remaining populations of endangered weed species and communities may be achieved.

Changes in Britain's traditional weed flora.

Until very recently, any suggestion that the conservation of endangered arable weed communities was desirable, would have met with considerable disbelief, and a certain amount of derision. This attitude was in many ways unsurprising. Agriculture has for many millenia, been a struggle against the forces of nature, not least among which were the large number of weed species favoured by the conditions of low competition and annual disturbance required by arable crops. There is evidence for the problems caused by weeds in agriculture in the past (Salisbury, 1961), and even today, poor farming practices can still result in considerable crop loss due to weed growth.

The nature of the weed flora has however undergone considerable change in recent decades. The dicotyledonous species such as Chrysanthemum segetum and Sinapis arvensis that were once the bane of the arable farmer (Salisbury, 1961; Fryer & Chancellor, 1970), are less well adapted to modern agriculture, and are now relatively easily controlled by herbicides. Other species such as Galium aparine, Bromus sterilis and Alopecurus myosuroides, have been able to take advantage of the opportunities offered by changes in agricultural practice, and have become much more abundant (Chancellor & Froud-Williams, 1986). There is evidence that other species such as Phalaris paradoxa and Bromus commutatus, may become additional problems of the future (Rule, 1987).

The gradual impoverishment of the weed flora has included the disappearance of a number of species from the countryside, and the serious decline of many others. It is probable that among the arable weeds there are more endangered and extinct species than in any other group within the flora of lowland Britain (Perring & Farrell, 1983; Table 1). In addition to the loss of individual species from the arable farming landscape, recent years have also seen the disappearance and impoverishment of traditionally occurring arable weed communities as modern farming practices have imposed greater uniformity on environmental conditions, both in Britain and in much of Europe (Holzner 1978).

Table 1. Numbers of species of various habitats found in fewer than 15 10km. grid squares in Britain. Data from Perring & Farrell, 1983, Smith, 1986 and pers. comm..

Habitat	Status			
	Extinct	Endangered	Vulnerable	Rare
Montane	2	0	12	46
Woodland, scrub etc.	1	8	12	12
Man-made open habitats	3	6	7	10
Lowland grassland	1	9	29	34
Heath.	0	3	3	12
Wetland.	5	7	16	16
Aquatic.	1	1	2	8
Maritime.	2	7	6	14
Arable.	6	17	8	2

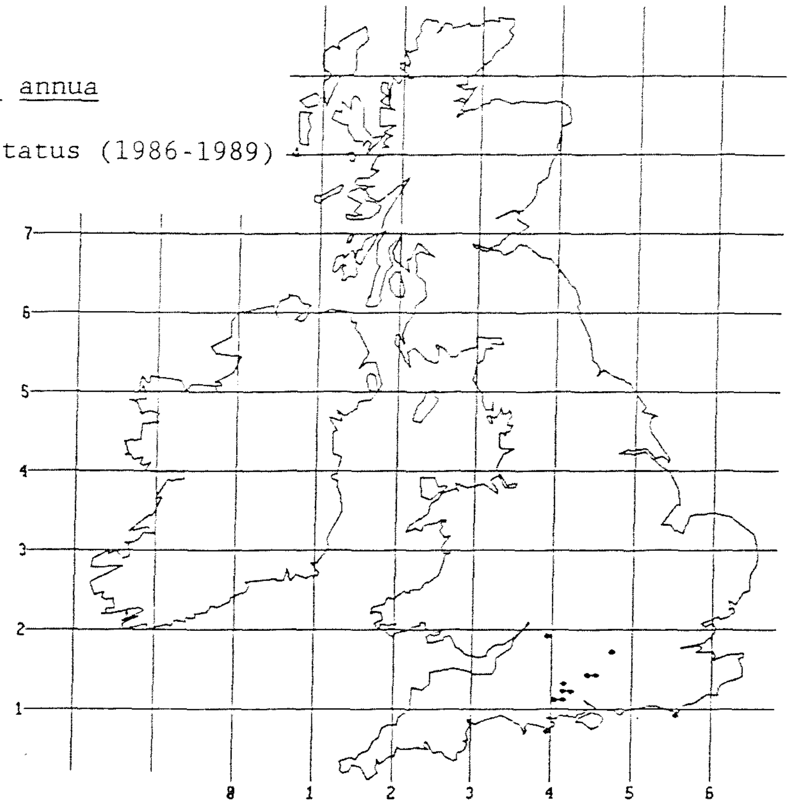
In 1985, as part of the quinquennial review of the Wildlife and Countryside Act (1981), a preliminary survey of endangered species of disturbed habitats was initiated by the Nature Conservancy Council (N.C.C.). This concluded that a number of species in Britain had become extinct, and provided the basis for a further survey by the B.S.B.I. of a list of 25 arable weeds that were thought to have declined (Smith, 1986). This survey formed an essential base for further work on the conservation of the arable flora. Some results are summarised in Table 2.

Figure 1 plots the distributions of three species. Comparison of the two maps for each species (status between 1930 and 1960, and current status), the general patterns of decline may be seen.

Figure 1. The numbers of 10km squares in which three arable weed species were recorded between 1930 and 1960 (from Perring & Walters, 1962), and 1986 and 1989 (data from A. Smith, pers. comm.). Current status maps created by "DMAP", a computer programme for distribution and Coincidence map plotting, written by A.Morton).

a. Adonis annua

Current status (1986-1989)



1930-1960

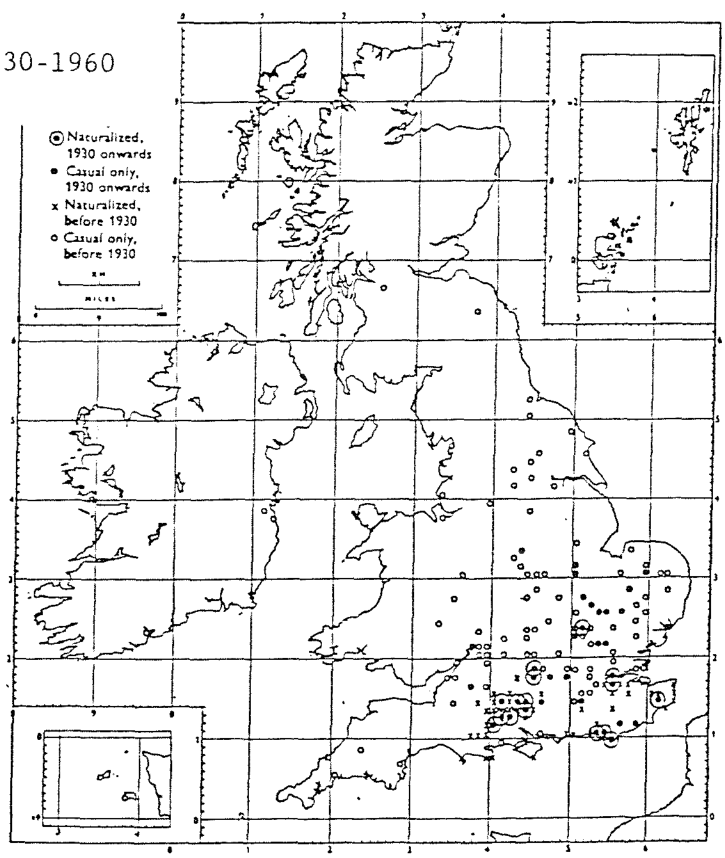
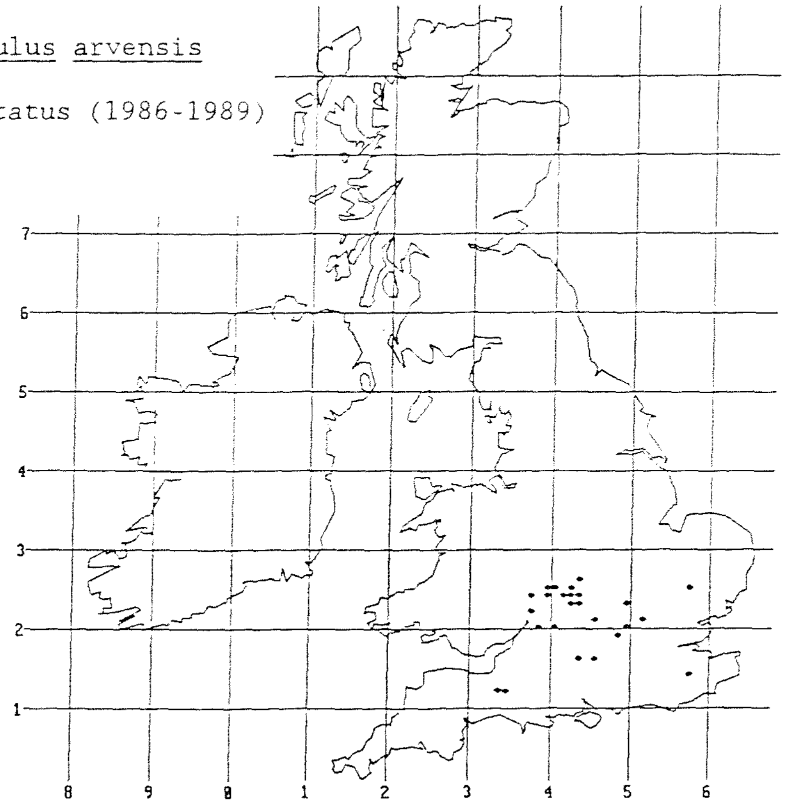


Figure 1. Continued.

b. Ranunculus arvensis

Current status (1986-1989)



1930-1960

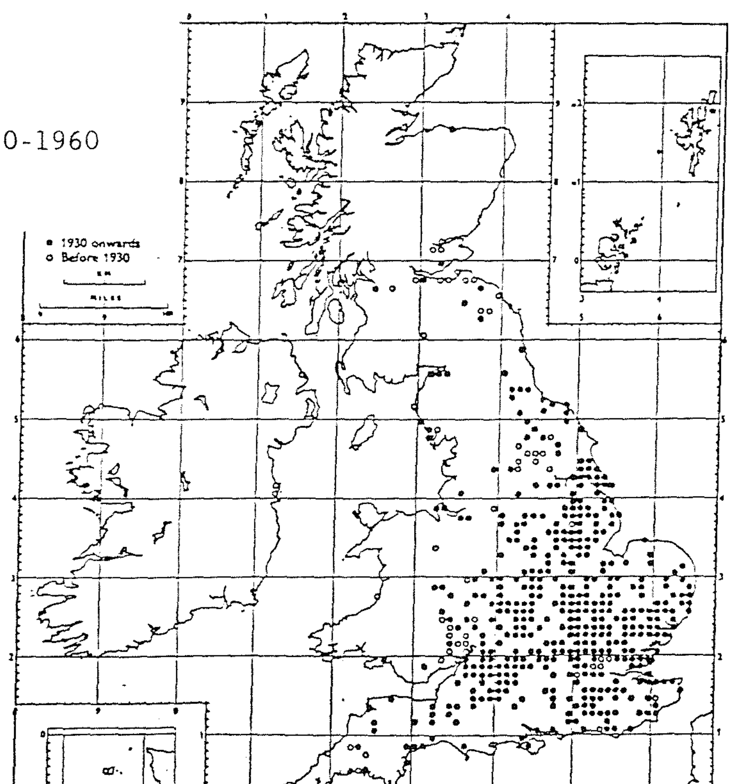
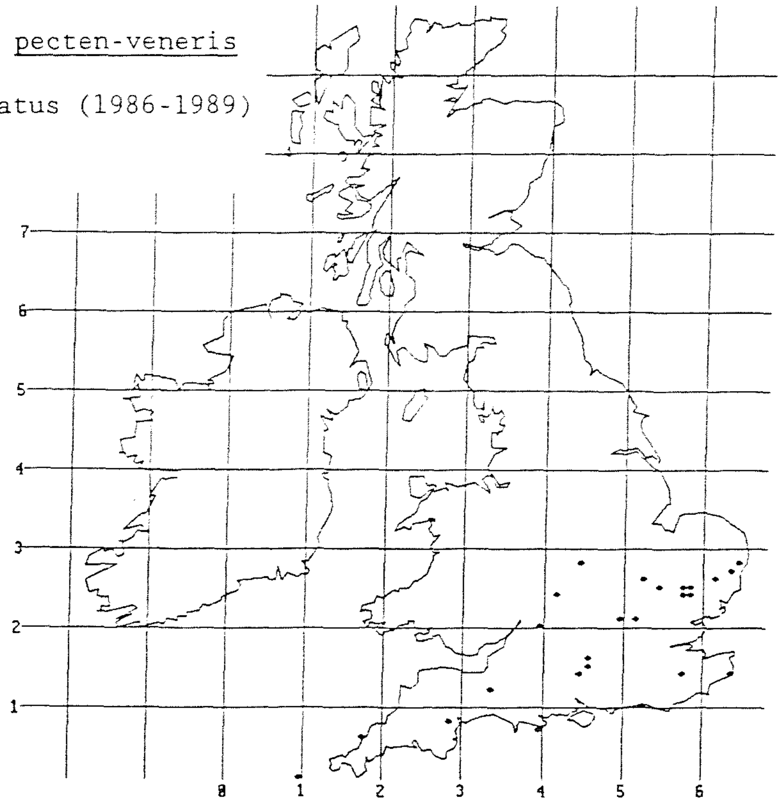


Figure 1. Continued.

c. Scandix pecten-veneris

Current status (1986-1989)



1930-1960

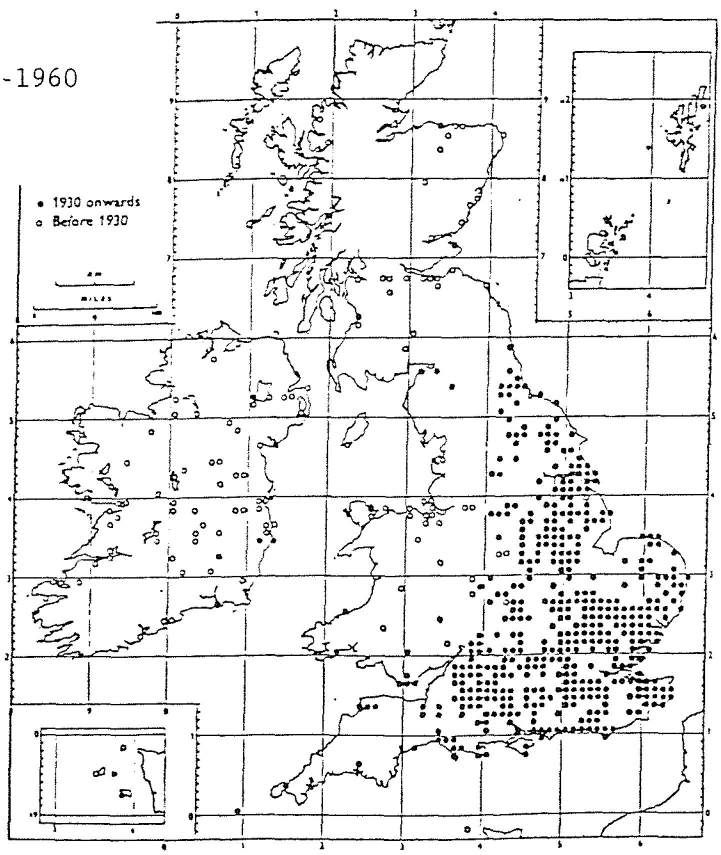


Table 2. Declines of some rare weed species in Britain, based upon the numbers of 10km grid squares in which they occur (Perring & Walters, 1976; Smith, 1986; A. Smith pers. comm.).

Species.	No. of 10km.² grid squares.			
	1930-60	1960-75	1976-85	1986-89
Adonis annua	36	34	13	12
Agrostemma githago	>150	14	17	0
Apera interrupta	21	23	-	9
Buglossoides arvense	310	-	<150	42
Bupleurum rotundifolium	17	8	1	0
Caucalis platycarpos	13	5	0	0
Centaurea cyanus	264	<100	<50	2
Galeopsis angustifolia	238	-	-	18
Galium tricornutum	77	16	7	2
Myosurus minimus	59	64	55	13
Ranunculus arvensis	432	169	71	22
Scandix pecten-veneris	426	86	<20	20
Silene gallica	132	-	-	5
Torilis arvensis	136	35	16	10
Valerianella rimosa	60	17	11	5

This decline has also been recorded on a regional level, where the local extinction of many species has been recorded. For example, changes in the status of some species in Bedfordshire were described by Dony (1977), who recorded the extinction of seven arable species out of a total of 84 species listed in Abbott's flora of 1798. It is almost certain that further species such as *Scandix pecten-veneris* and *Ranunculus arvensis* have disappeared since 1977. More recently, a similar comparison has been carried out for Warwickshire (P.Copson, pers comm.; Table 3). Although the periods of the surveys were different, the figures give an interesting comparison.

Table 3. Changes in the number of records of some arable weed species in Warwickshire, between the 1960s and 1987. From P. Copson, pers. comm..

Species.	Numbers of records. 1960s	1986-7
Euphorbia exigua	150	56
Kickxia elatine	47	47
Kickxia spuria	50	42
Buglossoides arvense	29	13
Papaver argemone	38	7
Ranunculus arvensis	140	7
Myosurus minimus	13	6
Legousia hybrida	11	6
Silene noctiflora	9	3
Torilis arvensis	12	2
Galeopsis angustifolia	9	1
Scandix pecten-veneris	55	2
Misopates orontium	3	0
Petroselinum segetum	5	0

The development and evolution of Britain's arable weed flora.

There is evidence from the sub-fossil record of the emergence of a characteristic weed flora in Britain from very early times (Godwin, 1956; Grieg, 1988), although it is apparent that the composition of this weed flora has undergone a number of changes since agriculture began, around 3000 B.C. (Edwards & Hirons, 1984). Many of the species concerned were present in this country long before arable agriculture commenced (Table 4, after Godwin, 1956). Godwin recorded 78 species of disturbed habitats from the mid- to late- Weichselian period (50,000 to 10,000 years b.p.), of which 31 are now largely to be found in arable land. These included such species as *Centaurea cyanus* and *Valerianella dentata*, which are now rare in Britain. While there is no direct evidence to suggest a continuity of

Table 4. Species of annual weed, and historical records of their occurrence. Data from Godwin (1956) and Greig (1989).

Species.	Pre neo-lithic	Neo-lithic	Bronze -age	Iron-age	Roman	Saxon
Aphanes arvensis	*		*	*	*	*
Arenaria serpyllifolia	*					
Atriplex sp.	*		*	*	*	*
Capsella bursa-pastoris	*		*	*	*	
Centaurea cyanus	*				*	*
Chaenorhinum minus	*					
Chenopodium album	*		*	*	*	*
Erysimum cheiranthoides	*		*		*	
Galeopsis tetrahit	*					
Odontites verna	*		*	*	*	*
Polygonum aviculare	*					
Polygonum lapathifolium	*	*				
Polygonum persicaria	*		*	*	*	*
Scleranthus annuus	*			*	*	*
Spergula arvensis	*	*	*	*	*	*
Stellaria media	*		*	*	*	*
Valerianella dentata	*		*	*	*	*
Bromus secalinus		*	*	*	*	*
Fumaria officinalis		*	*	*	*	*
Galium sp.		*	*	*	*	*
Papaver rhoeas		*				
Raphanus raphanistrum		*		*	*	*
Sherardia arvensis		*	*	*		*
Sinapis arvensis		*		*		*
Thlaspi arvensis		*	*	*	*	*
Veronica hederifolia		*	*	*	*	
Solanum nigrum			*	*	*	*
Urtica urens			*	*	*	*
Anagallis arvensis			*	*	*	*
Buglossoides arvense			*	*	*	*
Ranunculus parviflorus			*	*	*	
Fallopia convolvulus			*	*	*	*
Papaver argemone			*	*	*	*
Chrysanthemum segetum				*	*	*
Anthemis cotula				*	*	*
Valerianella rimosa				*	*	
Scandix pecten-veneris				*		*
Silene noctiflora				*		
Lolium temulentum					*	*
Ranunculus arvensis					*	
Anthemis arvensis					*	
Agrostemma githago					*	*
Bupleurum rotundifolium						*

existence for any of these species in Britain, Godwin considered that suitable habitat could have remained throughout the period between the last glaciation and associated open conditions, and the start of agriculture. With the exception of plants of waterlogged habitats, the preservation of plant fossils is a rare event, and will only record the most abundant species (Hall, 1988; Van der Knaap, 1990). It is therefore possible that other segetal species may have been present in smaller quantities before the advent of arable farming.

Many "arable" species may still be found flourishing in "semi-natural" disturbed habitats, for instance, Galeopsis angustifolium and Polygonum aviculare on marine shingle, Petroselinum segetum and Ranunculus parviflorus in dry, sub-maritime grassland and Galeopsis tetrahit and Stellaria media in woodland clearings. It is easy to see how some annual species might have persisted through the time before agriculture opened up further areas for their colonisation. It has been suggested that one method by which weed species became established in arable land, was with soil or turf from elsewhere which was introduced for fertiliser (Groeneman Van Waateringe, 1979).

It is probable that, as well as making habitat available, the spread of cereal growing to Britain in the late Neolithic also imported a number of weed species (Godwin, 1956; Holzner, 1978), and this process has continued to the present day.

The origin of these species has varied according to the patterns of human movement at the time. Many of the earliest introductions are thought to have originated from the seasonal grassland vegetation of the Mesopotamian "cradle of agriculture", from where the cereal crops themselves are thought to have come, additional species being added as arable farming gradually spread westwards between 10,000 B.C. and 3,000 B.C.(Holzner, 1978; Barker, 1985). There is some controversy about the precise origin of arable agriculture, and it has been suggested that it originated during this period over a much wider area around the Mediterranean (Barker, 1985).

The maintenance of populations of some species probably relied on their regular reintroduction with crop seed. Such species tend to be extremely closely adapted to growing with their "host" crop, having very similar phenologies and seed characteristics, and showing little of the persistence in the soil associated with other weed species. Examples are *Agrostemma githago* with rye and other cereals (Firbank, 1988), *Camelina spp*. with flax (Kornas, 1988), and *Cuscuta trifolii* with clover (Salisbury, 1961). The decline of these species is thought to have been mainly associated with the improvement in seed cleaning techniques during the last century, and the abandonment of particular crops in areas in which they were traditionally grown. This predates the more recent developments in agriculture that have been responsible for more widespread changes in weed communities (Broad, 1952, Wellington 1959, Salisbury 1961, Kornas 1961). Such species have become highly susceptible to any disruption of farming systems (Kornas 1988), and few of these species can now be considered as part of the British flora.

Most of the more recent introductions have come from the Americas; for instance, Matricaria matricarioides, Amsinckia spp., Coronopus didymus, and Galinsoga spp., although Veronica persica is of Asian origin. It may be noted that the weed floras of the other temperate cereal growing regions of the world are similar in composition to those of Europe, having largely originated from sowings of contaminated grain imported by early settlers (Salisbury, 1961).

It is probably rather idle to speculate on the dates of introduction of weed species as a justification for their conservation. Britain's flora is largely a result of man's activities, and the arable weeds, whether truly native or not, represent a unique historical and ecological record of man's agricultural activities. Most species have been present in our flora for considerably longer than the historical record (some exceptions are described above). They can perpetuate themselves without human assistance in this country, and now form part of recognisable plant communities with distinct ecological bases.

Botanical conservation in the arable ecosystem.

The conservation of biodiversity has been justified by other authors (Ratcliffe, 1977; N.C.C., 1984; Usher, 1985), and its general desirability may be assumed. The development of attitudes towards plant conservation in Britain has been reviewed by Sheail (1982). Conservation of the arable ecosystem has however been the subject of some debate and controversy. Tansley (1949) did not refer to the arable flora at all in his pioneering work on British vegetation, and Ratcliffe (1977) also ignored the arable ecosystem in his work which set the scene for modern wildlife conservation. The conservation evaluation of agricultural environments was discussed by Cobham & Rowe (1986), although they ignored arable habitats in general, and arable weeds in particular. Despite the inclusion of 22 arable weed species in the British Red Data Book for Vascular Plants (Perring & Farrell, 1983), and the inclusion of two species (Alyssum alyssoides and Melampyrum arvense) in schedule 8 of the Wildlife and Countryside Act of 1981, the attitude of many conservationists remained indifferent (N.C.C., 1984; Smith, 1986).

The necessity of ensuring the continued survival of arable weed species has only been realised very recently. Traditionally, where weeds were the subject of study, the emphasis was on the development of ways in which to eliminate them (Chancellor, 1979; Orson 1987). Where the increasing rarity of some species was remarked upon

(Salisbury, 1961; Chancellor, 1976a; Kornas, 1960), no mention was made of the possibility of their conservation. Even where the effects of modern agriculture on farmland ecology were being observed (Moore, 1970; Madel, 1970), the weeds that were being directly affected by herbicides and other agricultural practices were considered only in terms of their value as food-plants for insects and other animals.

It is possible to extend the principles of botanical conservation to the arable ecosystem, although it is largely anthropogenic in its origins, depends on intensive management for its perpetuation, and owes its very existence to its ability to produce arable crops efficiently. If these provisos are considered in the context of other semi-natural habitats, then the contradictions are not so striking. The landscape of North-Western Europe is largely modified by man's activities, and habitats such as coppiced woodland and chalk grassland with high conservation status owe their existence to the long-term effects of human management, just as much as does the arable ecosystem.

Such "semi-natural" habitats have declined catastrophically in area within the last 50 years, and for the most part, these changes have been due to their irrevocable transformation into arable land. One consequence of this has been to diminish the appreciation by conservationists of the potential of arable land as a wildlife habitat in its own right, and to regard all arable land as a desert, devoid of any wildlife value. While there is some justification for this view, especially in areas where modern arable farming is practised at its most intensive, it is by no means the universal condition (Potts, 1986 & 1989).

Large-scale arable farming has been a feature of some parts of Britain for many years, and in some cases, millenia. In many areas, the antiquity of arable farming is similar to that of other more highly regarded habitats. Arable farming is thought to have begun in Britain before 3000 B.C. (Edwards & Hirons, 1984; Barker, 1985), and this date has also been given for the start of settled livestock farming and the intensive use of woodland (Colebourn, 1983). Although the first areas to be farmed were in the more easily cleared upland areas of the south of England, arable farming had spread to Shetland within 1000 years (Cunliffe, 1985). Although it is wrong to imply any causal relationship, it is interesting to note the great concentration of neolithic farming settlement in Wessex, an area which still boasts some of the richest arable weed and calcareous grassland plant communities in Britain.

It is important to emphasise the effect of continuity through time of land use on the relative species richness of a plant community, a connection demonstrated for several groups of plants in many different habitats (Peterken, 1974 & 1977; Rose & James, 1974; Wells et al; 1976). Any connection between continuity of land use and floristic diversity will be more complex for the arable flora than for many other habitats. This is partly because of the ability of arable weeds to survive long periods of unfavorable conditions as a dormant seed-bank, but is also due to the poorly understood nature of the isolation mechanisms that separate populations of uncommon species, and the great variety of ecological and managemental factors that operate on individual fields. If such a connection does exist, it is evidence that arable weed communities can exhibit considerable stability, and can persist, albeit with fluctuations, in the same place with little overall change for many years.

Direct evidence supports the hypothesis that weed communities can be stable and persistent, providing there are no changes in management. Some of the most important evidence comes from the long-term winter wheat experiment on Broadbalk field at the Rothamsted Experimental Station. This experiment was set up in 1843, and with a few changes, has remained intact until the present day. The weed flora has been assessed since 1925 by sampling the soil and determining the size and composition of the seed-bank (Thurston, 1968). Large fluctuations in the populations of several weed species have been recorded, especially after the introduction of herbicides in 1957, but as far as is known, no species have actually become extinct (Thurston, pers.comm.). This site now contains isolated populations of species such as *Torilis arvensis*, *Scandix pecten-veneris*, *Ranunculus arvensis*, and *Galium tricornutum*.

Chancellor (1976b; 1985) also found that the weed populations of two fields in Oxfordshire were also relatively stable in species composition, and that all of the major changes could be attributed to changes in management pattern. Other sites with uncommon species have been known for long periods of time. A field near Rochester in Kent, containing *Althaea hirsuta*, *Ajuga chamaepitys*, *Filago spathulata* and *Anagallis arvensis* ssp. *foemina* has been known since the end of the 18_{th} century.

The existence of well defined vegetation communities or continua related to environmental factors is in itself evidence for their stability. The association between weed vegetation and environmental factors has been long appreciated (Brenchley, 1920), and well-defined communities have been described from Britain and Northern Europe (Hafliger & Brun-Hool, 1971; Silverside, 1977; Oesau, 1987).

This connection is an important criterion to be considered when assessing the conservation requirements of a habitat. There is some justification for the view that the conservation of early successional communities should take a relatively low priority. The plants that characterise early stages in the colonisation of exposed ground tend to produce large numbers of extremely mobile seed, but tend to be relatively non-competitive, and to be non-persistent at any one site (Harper, 1977; Grime, 1979;

Jefferson & Usher, 1985). Such communities often have little relationship to climate or soil, are strongly influenced by the availability of seed, and are frequently rich in alien species (Salisbury, 1961). Their existence is ephemeral, and providing that sufficient open sites exist, there is little threat to their continued existence. The difference between such ephemeral, ruderal communities and the segetal flora of regularly cultivated arable land is considerable. The flora of arable fields is not ephemeral. It derives almost entirely from the soil seed-bank, with relatively little contribution from other sources (again providing that management practices remain constant), and the seeds produced by the majority of arable weed species tend to be large, heavy, and with poor powers of self-dispersal (Salisbury, 1961).

From the moment at which a field enters into arable cultivation, the size and composition of the seed-bank begins to evolve, in response to the selective pressures of environmental factors and farming practices. The natural course of succession will be arrested by ploughing, and the arable flora may be considered as an extreme form of plagioclimax. It is therefore analogous to other plant communities such as calcareous grassland, in which succession to woodland is arrested by grazing (Grime, 1979).

It was not until the early 1970s. that any concern for the loss of traditional weed communities was expressed

(Perring, 1973). Despite surveys carried out by the B.S.B.I. in the 1970s (Chancellor, 1977), which demonstrated the decline of many species, little effort was made to safeguard the remaining relics of these communities. The prevailing attitude of most conservationists until the beginning of the 1980s. was that arable land was of little ecological interest, that conservation management would be far too difficult to attempt, and that all of the plants present were introduced by man anyway and therefore unworthy of attention. It was considered far easier to conserve these "alien" species in the museum context of artificially maintained plots.

1985 saw the scheduling of the first "Site of Special Scientific Interest" (S.S.S.I.) by the N.C.C., for the specific purpose of the conservation of endangered arable weed species. This site contained two "Red Data Book" species (present in fewer than 15 10km. squares), Althaea hirsuta, and Filago spathulata (Perring & Farrell, 1983), and two others, Ajuga chamaepitys and Anagallis arvensis ssp. foemina now thought to be of similar status. It is probable that other sites will follow, although to be effective, their management must have a scientific basis.

Also in 1985, The Game Conservancy's Cereals and Gamebirds Research Project (C.G.R.P.), found that an experimental technique for the management of the grey partridge on arable farmland, seemed to have an effect on the abundance of less common arable weed species (Wilson, 1987). This technique, known as the "Conservation Headland", involved the omission of broad-spectrum herbicides from arable field headlands (Boatman & Sotherton, 1988), and further work carried out between 1986 and 1988, demonstrated the considerable potential of this technique for the conservation of the botanical interest of arable farmland (Wilson, 1987, Boatman et al; 1988).

A greater upsurge of interest in the conservation of the wildlife of arable farmland has been shown in a number of other European countries. In West Germany particularly, much attention has been paid to the conservation of the arable flora. Of approximately 300 plant species recorded as growing in arable land in Germany, 90 are listed in the German Red Data Book as either extinct or endangered (Eggers, 1987). Government funding has been available since 1982 in several West German Federal States, to compensate farmers who are willing to leave field margins untreated with herbicides specifically to benefit the arable flora. In some areas, fertiliser inputs are also reduced (Schumacher, 1987; Born, 1987; Helfrich, 1988; Oesau, 1988). Work is also in progress in Switzerland, Austria, Denmark, Sweden and Holland (Schumacher, 1987; Hald et al 1988; P.Chiverton, pers.comm. and G.de Snoo, pers. comm.).

Another important factor in the development of conservation strategies in the arable areas of Europe, has been the accumulation of massive surpluses of stored grain in E.E.C. countries (Potts, 1989). A consequence of this over-production has been the formulation of a range of policies for reducing cereal production that can be classified into two categories, "set-aside" (Anon 1988a.), and "extensification". These measures may represent much potential for change in the management of the arable countryside, which may, if approached correctly, have beneficial consequences for the future of endangered traditional weed communities.

Recent changes in arable farming practice, and possible effects on the arable weed flora.

Communities of annual species occurring in association with arable farming are strongly influenced by farming practices, and in order to design a programme of investigation, it was necessary to consider those practices which have changed in recent years, and the ways in which such changes might have affected weed populations. As the chief aim of this project was to propose a set of practical guidelines, particular emphasis was laid on those factors which could be altered within the context of normal agricultural practice.

Great changes have occurred during recent years in arable farming, and specific aspects are considered in detail in the introductions and discussions to the individual chapters. It will be useful here to give a brief resume of some of these changes.

Improvements in agricultural systems have been continuous ever since the first pre-Celtic farmer realised the advantages to be gained from the deliberate cultivation of cereal crops in about 10,000 B.C.. The most rapid changes have occurred since 1940. In 1930, the world was experiencing an agricultural depression, and much of the less productive arable land in Britain was out of production (Stamp, 1948). Mechanisation had not become widespread, and although the tractor had been developed at about the time of the First World War, and the steam plough had been in use on a limited scale for many years, the horse was still the main source of agricultural power (Warren, 1940; Ewart-Evans, 1960; Hall & Clutton-Brock, 1989), and in some areas the ox was still valued (Tregorran & Aldridge, 1981; Hall & Clutton-Brock, 1989). Weed control was largely carried out by means of efficient cultivations to destroy seedlings which germinated before the crop was drilled, by crop rotation to ensure that a species which was well adapted to one crop did not get out of hand, by hand weeding of some species, and by occasional fallowing.

Cereal crop varieties tended to be long-strawed, and performed best with relatively low supplies of nitrogen, but yielded less than modern varieties (Fischbeck, in press; Karpenstein-Machan & Scheffer, 1989). There was a very high risk of yield loss from lodging at high levels of nitrogen supply. Consequently, the amounts of fertiliser applied were considerably less than those used today, and much of this would have been in the form of farmyard manure, partially derived from the large number of horses in use.

Crops were grown in rotation, in order to control weeds and disease, and to conserve soil nutrients. Some examples of rotations used during the 1920s are given by Ainsworth-Davies (1920)(Table 5). Cereals were never grown continuously, grass leys frequently formed a part of the rotation, and leguminous plants played an important role in maintaining soil fertility.

Table 5. Some examples of crop rotations used in the 1920s. (After Ainsworth-Davies, 1920). W Wheat, B Barley, Be Beans, C Clover, F Fallow, G Grass ley, O Oats, R Roots, V Vetches, u undersown with grass or clover.

	Area and soil type.					
	Gloucs. Heavy	Midlands Loams	Cotswolds limestone	North-W	Cheshire Loams	Wiltshire Chalk
Year						
1	V	R	R	R	R	V/R
2	O	B/u	B	O/u	W/u	R
3	Be	C	G	G	G	W
4	W	W	G	G	G	B
5	F	O	W	G	O	R
6	O	R	R	O/W	R	B/u
7	C	B	B	R	W	G/C
8	W	C	G	O	G	W

Crop seed would still have been broadcast on smaller farms, although the horse-drawn seed drill had been widely used for many years. The spacing of the rows in which cereals were drilled was considerably wider than that used now, in order to facilitate hand weeding (Johnston & Garner, 1968). Overall sowing densities were however similar to those employed now (Ainsworth-Davies, 1920;

Ewart-Evans, 1960; Dadd, 1963)

While the scythe had been replaced by the reaper-binder, hand-harvesting would still have been common on smaller farms, where crops were badly lodged, and where a headland had to be cleared to allow access for the reaper (Ainsworth-Davies, 1920). Harvesting of winter wheat and spring barley crops tended to start a little earlier in the autumn, and to finish later, as the process took longer to complete (Cobbett, 1830). After harvest, the crop was stooked in the field in order to allow it to ripen and dry, a process which usually took between one and two weeks. The stooks were then stacked away from the field, and threshed over the winter (Warren, 1940). Threshing machinery also incorporated seed-cleaning riddles, and it is probable that the effects of the Seeds Act of 1920, which laid down standards for crop seed purity, had already contributed to the declines of some weed species.

Since 1930, agriculture has undergone a revolution, and most of the individual changes have had consequences for other aspects of farming practice.

The Second World War provided the stimulus for Britain to become self-sufficient in food (Stamp, 1962). As a result of this, large areas of permanent grassland and neglected former arable land were taken into cultivation, and the overall intensity of crop production was greatly increased. The shortage of labour during this period encouraged the development of agricultural machinery and the agrochemical industry, although controversy about the true consequences of "industrial" versus "holistic" farming methods was current even then (Portsmouth, 1938; Balfour, 1953). The processes of agricultural intensification have continued until the present day, encouraged by the Agriculture Act (1947) which guaranteed high prices for cereals, and the Common Agricultural Policy subsequent to Britain joining the E.E.C. in 1973 (Orson, 1987). The pace of change has slowed recently, as Europe has become more than self-sufficient in many of the major agricultural products.

Crop breeding has resulted in the development of cereal varieties that are very responsive to applications of nitrogen greatly in excess of that which was formally applied as animal manure (Fischbeck, in press). Yields are much higher, and it is possible that the competitive abilities of modern crop varieties are greater in relation to most weed species.

The horse has been replaced by the tractor as the major source of motive power on the farm. Half a million horses were working in 1947, and were slaughtered at a rate of 100,000 per year (Hall & Clutton-Brock, 1989). The loss of this source of manure contributed to the rise of the artificial fertiliser industry.

Herbicides have largely superceded other methods of weed control, and although the traditional methods of efficient cultivation and crop rotation have persisted, they have lost their former importance. In some modern farming systems, ploughing has been abandoned entirely, and crop seed is drilled directly into an uncultivated seed bed, which has been cleaned by burning and herbicide application. This method has had considerable local effect on weed populations, leading to increases in the numbers of grass weed species with poor dormancy and high herbicide resistance, but to decreases in numbers of dicotyledonous species which generally have a higher degree of dormancy and tend to be more susceptible to the herbicides used (Froud-Williams, Chancellor and Drennan, 1981). Herbicides have also meant that there is little need for hand-weeding, and crop row spacing has narrowed to about 14cm..

Since crop rotations have lost their importance for weed and disease control and the maintenance of soil fertility, farmers have been able to grow the same crop in several consecutive years, with the inevitable effect that those weeds that are best suited to growing in that particular crop have increased, and that those that are not have decreased (Orson, 1987). The area sown to winter wheat has increased at the expense of that sown to spring cereals, grass and root crops, and oil-seed rape and winter barley, both of which are sown early in the autumn, are now widely grown.

Harvesting methods have also changed radically. The reaper-binder is now only used for the harvest of long-strawed varieties of wheat used for thatching, and all the remainder is harvested by combine harvester. The period of harvesting has become much shorter, and sheaves of crop and weeds are no longer stooked to ripen on the field. This has meant that there is no need to leave a stubble after harvest on which to stand the stooks, and ploughing now frequently commences directly after harvest, especially where winter barley or rape are to be grown.

These factors are believed to be among the most important changes that have occurred in modern arable farming in relation to changes in the arable weed flora.

The ecology of arable weeds.

Hitherto, most research into arable weed biology has been devoted to aspects of weed control, and has consequently been confined to those species that have been seen as problems to the farmer. Much of this work however has been concerned with the basic biology and ecology of weed plants, and is applicable to many of the rarer species also. Some aspects of weed biology that are of direct relevance to specific areas of investigation are discussed in greater detail in the introductions to each chapter, but it is of value here to consider the general factors which enable some plant species to coexist with arable crops.

The arable environment may be distinguished from most other habitats by the exceptionally high degree of regular disturbance (Grime, 1979). Not only is the arable field ploughed each year before the crop is drilled, but additional cultivations may occur, and generally some attempt is made to eliminate weeds by the use of herbicides. After the crop has reached the desired state, it is either cut (cereals, pulses, linseed etc.), or dug from the ground (potatoes, sugar beet, other root vegetables). It is therefore apparent that a successful arable weed must in some way be preadapted to survive these various forms of disturbance, and must be sufficiently "flexible" to withstand any yearly variation in the patterns of disturbance. Various "weed" strategies may be found in the arable ecosystem.

Most arable weeds have annual life-cycles, and depend on the production of seed for the perpetuation of populations. Some perennial species do occur in arable situations, and can pose serious agronomic problems, as they possess extensive underground vegetative systems which are encouraged by cultivation, and which are often difficult to eradicate with herbicides (Mortimer, 1990). Examples of such species include Elymus repens, Agrostis gigantea, Sonchus arvensis, Convolvulus arvensis and Equisetum arvense. None of these species have shown any decline in recent years, and were not included in this investigation.

Many annual plants can survive periods of adverse conditions as a bank of dormant, viable seed in the soil (Salisbury, 1961). The nature, mechanisms and implications of seed dormancy and the formation of seed-banks have been extensively described for a number of species in several different habitats (Thompson & Grime, 1979; Roberts, 1981). The seed-bank is an important adaptation for an annual plant growing in an environment which experiences disturbance that is not always predictable. The seed-bank tends to act as a buffer, mediating the effects of any environmental variable on the weed population (Firbank, 1989). Changes in the size of the seed-bank due to mortality, germination and seed-return are of fundamental importance to the understanding of the population dynamics of an arable weed species, and the effects of environmental variables on weed populations must always be considered in terms of seed production and the return of seed to the seed-bank (Mortimer, 1987).

The ability of a weed to return seed to the soil depends on the synchronisation of the cycles of germination, flowering and seed production with the cycles of farming practice. The seed of a weed species must germinate at a time close to that of crop sowing, or it will not be able to compete successfully with the crop plants. Similarly the production of seed must occur before the crop is harvested, or if occurring after harvest, must be borne on parts of the plant that are beneath the height at which the crop is cut. All phases of the life-cycle must be completed before the field is prepared for the next crop. It is probable that the type of crop sown and the date on which it is drilled and the field cultivated, may be critical to the success of a weed species, and a long-term change in cropping patterns may have considerable effects on the weed flora.

As well as phenological synchronisation, another essential preadaptation to the arable habitat is an ability to compete with the crop for nutrients and light. If a weed plant is under conditions of competitive stress, then seed production will be reduced, and depending on the degree of competition death of the plant may result (Grime, 1979). The plasticity of many arable plants is well known (Salisbury, 1961; McNaughton & Harper, 1964; Grime, 1979), and many species of weed are capable of survival and seed production under extreme conditions. Modern cereal varieties have been selectively bred to be highly responsive to the amount of nitrogen supplied (Fischbeck, in press), and the course of crop/weed competition may therefore be strongly influenced by the amount of nitrogen supplied to the crop, and its effect on the relative competitive abilities of weed species and the crop. Competitive interactions between weeds and crops have been extensively studied, and a variety of responses have been demonstrated by different species when the nitrogen supply is varied. Some species such as *Avena* spp., *Galium aparine*, *Alopecurus myosuroides*, and *Agrostemma githago* have been found to respond better than the crop to increased nitrogen supply, whereas most others, such as *Spergula arvensis*, *Viola arvensis*, *Legousia hybrida*, *Descurania sophia* and *Lamium amplexicaule* have been found to respond less well (Thurston, 1968; Mahn, 1984; Firbank & Watkinson, 1985; Pulcher-Haussling & Hurle, 1986; Wilson, 1986; Mahn, 1988; Mahn & Muslemanie, 1989).

On the majority of farms, herbicides are used to control weeds. The chemicals used are selectively phytotoxic, being designed to eliminate the targetted weed species while leaving the crop unharmed. Herbicide use will have a profound effect on the return of weed seed to the soil, either by complete elimination of the weed plants, or by altering the balance of competition in favour of the crop. The degree of resistance of different weed species to different herbicides will effect their relative abundances.

The selection of species for detailed study.

A programme of research work was designed, in which the effects of a number of farming variables on the growth and productivity of a range of arable weeds were investigated. These investigations were considered in terms of those factors which could be manipulated within the context of modern arable farming, and which could be incorporated into a set of realistic management guidelines.

Over 300 species of vascular plant have been recorded as occurring as arable weeds in Britain, and around 60 of these can reasonably be regarded as rare or local in their distribution. Because of the limited amount of time available, the number of species under intensive study was limited to eight (Table 6). This list was not intended to be exclusive, and other species have been included as opportunity allowed. These included a selection of common species for comparison purposes.

Table 6. Species selected for detailed investigation.

Adonis annua L.
Chrysanthemum segetum L.
Buglossoides arvensis (L.) John
Misopates orontium (L.) Rafin.
Papaver hybridum (L.)
Ranunculus arvensis (L.)
Scandix pecten-veneris (L.)
Silene noctiflora (L.)

The selected species were chosen primarily on the basis of their decline in numbers and contraction in range in recent years (Table 2). Information on distribution before 1960 was obtained from Perring & Walters (1976), and information on present distribution, from the B.S.B.I. survey and other published works.

Other criteria were considered when making this selection. Chief among these was the suitability of the species as a representative of a particular weed community type, although at the time, much of the basis for this was conjectural. Some edaphic preferences of these species have been mentioned by Salisbury (1961) and other authors. A. annua is said to be found mainly on calcareous loam soils in the south of England (Silverside, 1977), and B. arvensis and P. hybridum on chalky soils, while C. segetum (Brenchley, 1920; Howarth & Williams, 1972) and M.orontium have been associated mainly with acidic and freely draining soils. Published information about R.arvensis and S. pecten-veneris seems rather contradictory, but a general concensus among most authors is that they were both most frequent on the heavier chalky soils (Long, 1910; Brenchley, 1920; Salisbury, 1961; Silverside, 1977). Both Salisbury (1961) and Brenchley (1920) considered S.noctiflora to be most frequent on sandy soils.

With the exception of C.segetum, very little experimental work has been carried out on any of these species. Relevant previous work is discussed fully in the introductions to each chapter, but a brief review is given below.

The control of C.segetum with herbicides has been the subject of much study (Aamisepp, 1973, 1974 & 1977; Mayes et al, 1976; Quere et al, 1977; Erskine, 1974; Cahill, 1982, etc.). C.segetum can still pose many problems to farmers, and shows considerable resistance to many of the more commonly used of the earlier developed herbicides. Some information has been published on the susceptibilities of B.arvensis, R.arvensis and S.pecten-veneris to some hebicides (Flint, 1987).

The physiology and ecology of C. segetum were described by Howarth & Williams (1972), and its germination periodicity by Roberts & Neilson (1981b). P. hybridum was briefly included in the account of the genus Papaver (McNaughton & Harper, 1964).

Some species have been included coincidentally in field experiments. The Broadbalk winter wheat experiment included populations of a number of uncommon species such as S. pecten-veneris and R. arvensis. The response of S. pecten-veneris to different combinations of mineral nutrients, its restricted period of germination, and poor seed dormancy were described by Brenchley and Warington (1930). The declines of these two species after the introduction of herbicides was recorded by Thurston (1964). Milijic (1981) reported the reduction in R. arvensis in relation to increased supply of nitrogen.

B. arvensis was included by Wilson (1986) in his field investigations of competition between winter wheat and weeds, and C. segetum was included in similar field trials in Ireland with spring barley (Courtney & Johnston, 1988). Both of these species were found to be highly competitive in relation to the crops sown, which may partly account for their continued persistence in some parts of Britain.

Structure of this project.

An extensive survey of sites at which the eight species were known to occur was initiated in 1987. The aim of this survey was to discover to what extent ecological factors such as soil and climate underlie the present distributions of arable weeds, to identify some of the agricultural and historical factors that may have contributed to these distributions, and to find out whether these factors have resulted in the formation of distinct phytosociological communities (Chapter 2).

An additional survey was carried out to determine the distributions of arable weed populations in relation to distance from the field edge (Chapter 3).

Experimental investigations were based on the results of previous work, results of the survey of rare weed plants, and on consideration of the ways in which changes in farming practices may have affected weed populations.

The following factors were examined experimentally:

Chapter 4. The effects of herbicides on arable weed species and communities.

Chapter 5. Investigation of the periodicity of germination of rare arable weed species.

Chapter 6. The effects of different levels of nitrogen supply and density of crop on competition between crops and weeds.

Chapter 7. The effects of different dates of cultivation, crop sowing and crop type on competition between crops and weeds.

The results of the survey and experimental work are discussed in general in Chapter 8, and in relation to the ecology and conservation of individual species in Chapter 9. Some suggestions for the conservation management of populations of rare arable weeds and arable weed communities are considered in Chapter 10.

CHAPTER 2.

A SURVEY OF RARE WEED SITES IN SOUTHERN ENGLAND.

INTRODUCTION

In relation to the attention given to other comparable groups of plant species, the phytosociology and ecology of British arable weed communities have been little studied. Tansley (1949) included no mention of segetal or ruderal vegetation in his work on British vegetation, and most early studies of weed communities approached them from an agricultural point of view rather from a botanical one. The first attempts to relate weed species and communities to environmental factors were made by Long (1910) and Brenchley (1920). This information is of considerable value when considering the results of more recent surveys.

The only attempt to produce a comprehensive account of British weed communities, was made between 1969 and 1973 (Silverside, 1977). The methods used followed those of the Zurich-Montpellier school of plant sociology (Braun-Blanquet, 1932), and demonstrated the existence of readily detectable and clearly defined weed communities with considerable affinities to those recorded from North-Western Europe (Hafliger & Brun-Hool, 1971). Factors involved in determining the occurrence of these communities and in their change were suggested, although no attempt was made to investigate them further.

Most other recent surveys of arable weeds in Britain have been concerned with quantifying the status of species in response to a demand for knowledge of changes in the status of economically important species as a basis for weed control practices (Chancellor & Froud-Williams, 1984; Whitehead & Wright, 1989).

Of greater interest have been two recent surveys carried out at the instigation of the Botanical Society of the British Isles (B.S.B.I.). These were designed to establish the status and extent of decline of a number of species of arable weed thought to be becoming rarer in response to changing farming practices. The first of these surveys was carried out in the 1970s (Chancellor, 1976), and the second, carried out in conjunction with the Nature Conservancy Council (N.C.C.), during 1986 and 1987 (A.Smith, pers comm.). The findings of the second of these are discussed in Chapter 1, and this has given a valuable picture of the status of 25 of Britain's less common segetal species. It has also provided an indispensible register of sites upon which to base further work, an essential prerequisite when considering the ecology of uncommonly occurring plants in a habitat of vast extent, which on superficial examination appears to be highly uniform.

The survey described below, extended over three years, and took the 1986-87 B.S.B.I. survey as its basis. Its aims were to relate the present distribution of rare arable weed species and species-rich weed communities to environmental factors, with particular emphasis being placed on the agricultural history of the survey sites. The survey also provided information on which to base experimental investigations, and simultaneously served a retrospective role, testing in field situations the predictions given by experiment.

METHODS

Survev method.

METHODS

Survev method.

the knowledge of local botanists. An attempt was made to include at least 10 sites for each of the eight selected species, covering as much of their known geographical and

and illustrated in Figure 2.

The landowner or manager of each site was contacted prior to survey, in order to obtain permission for access, and to collect details of the recent cropping and herbicide use in each field. In most cases, site details were

and to collect details of the recent cropping and herbicide use in each field. In most cases, site details were

was kept to a minimum. Additional information would have been desirable, but it was felt that this would have been too complex both to obtain and to interpret.

The quantification of segetal vegetation presents

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problems not encountered in the survey of other vegetation types. Chief among these, is the variability of the observable weed flora between seasons and years. Most weed species show a strong periodicity of germination (Chapter 5), and the same field may exhibit a different weed flora in successive years depending on the season of cultivation. For similar reasons, examination of a field at different times of the same year may lead to different impressions. A survey of seedlings during the winter in an autumn-sown field will miss spring germinating species, whereas a survey of the same field in late summer might miss many species that senesce in early summer, but record others which germinate late (Hafliger & Brun-Hool, 1971; Silverside, 1977; Chapter 7).

Another difficulty associated with the assessment of weed communities in conventionally farmed situations, is the selective elimination of a large proportion of the weed flora by the use of herbicide and mechanical means. Considerable distortion of the apparent species composition and abundance will occur, and for this reason, any estimate of abundance of any species must be treated with caution.

The only way of obtaining a reliable measure of the composition of a weed community is by determining the weed seed content of the soil (Debaeke & Sebillotte, 1988), This approach has been taken by many workers (Brenchley & Warington, 1930; Roberts, 1962; Thurston, 1968; Warwick, 1984; Marshall, 1989; Wilson, 1989), but is extremely laborious, requires much space, and is unrealistic for a wide-scale survey such as that described here, although it is essential where precise quantitative estimations are required.

In addition to these difficulties, climatic and other factors make annual vegetation relatively unpredictable, especially where the probability of seed of rare species being present in the upper layers of the soil is small. The methods used for the assessment of vegetation were therefore designed to be as rapid and simple as possible, while still ensuring the collection of meaningful data.

The seed-banks of most annual weed species tend to be concentrated near the edges of arable fields (Marshall, 1989; Wilson, 1989; Chapter 7). Most effort was therefore focussed on the field margins and corners, with digressions made to other areas of potential value. A species list was made, including all species occurring within the cultivated area of the field, ignoring any anomalous areas (e.g. partially ploughed grassland, gateways with compacted soil etc.). Abundance of all species was estimated using a "DAFOR" scale (D=dominant, A=abundant, F=frequent, O=occasional, R=rare), and a sketch map of the site showing the location of rare species and other features was drawn. In addition to examining the fields in which the rare species was known to occur, an attempt was made to survey at least one comparable adjacent field that did not contain the rare species, to act as a comparison.

The "conservation value" of each site was assessed by counting the number of uncommon species present at each site, weighting each species by a value inversely related to the number of occurrences in 10km squares in Britain (Table 7; A. Smith, pers. comm.) and calculating their sum.

Table 7. Values used for calculating the "rarity index" for sites included in the survey of rare weed sites.

Value = 4 . Number of 10km. squares <20.

Adonis annua	*Anagallis arvensis* ssp. *foemina*
Filago spathulata	*Fumaria occidentalis*
Ranunculus arvensis	*Scandix pecten-veneris*
Torilis arvensis	*Valerianella rimosa*

Value = 3. Number of 10km. squares <50 but >20

Briza minor	*Bromus secalinus*
Chenopodium ficifolium	*Euphorbia platyphyllos*
Fumaria densiflora	*Fumaria parviflora*
Fumaria vaillantii	*Geranium columbinum*
Myosurus minimus	*Papaver hybridum*
Petroselinum segetum	*Ranunculus parviflorus*
Silene gallica	*Vicia tenuissima*

Value = 2. Number of 10 km. squares <150 but >50.

Chrysanthemum segetum	*Galeopsis angustifolia*
Buglossoides arvensis	*Misopates orontium*
Papaver argemone	*Silene noctiflora*
Valerianella dentata	*Veronica agrestis*

Value = 1. No. of 10 km. squares >150, but still locally uncommon.

Anchusa arvensis	*Nepeta cataria*
Anthemis cotula	*Papaver lecoquii*
Anthriscus caucalis	*Sison amomum*
Arabidopsis thaliana	*Kickxia elatine*
Arenaria serpyllifolia	*Kickxia spuria*
Chaenorhinum minus	*Lamium amplexicaule*
Chenopodium rubrum	*Lamium hybridum*
Descurania sophia	*Legousia hybrida*
Diplotaxis tenuifolia	*Lepidium campestre*
Erodium cicutarium	*Malva neglecta*
Erysimum cheiranthoides	*Stachys arvensis*
Euphorbia exigua	*Torilis nodosa*
Geranium pusillum	*Veronica polita*

This value is hereafter referred to as the "rarity index". The figure thus arrived at had a potential range from 0 to over 100, but the highest value recorded was 39 (Site 221, Longparish, Hampshire).

A soil sample of approximately 0.5kg. was collected by trowel from each site. pH was analysed using an electrical pH meter. Soil texture was determined using a standard method: a small sample of soil was moistened, and kneaded between the thumb and forefinger, and the texture assessed semi-subjectively on a 14 point scale (Appendix 1) with 1 = loamy coarse sand, and 14 = clay (Holloway & Sneesby, 1981). Calcium carbonate content was determined using the Soil Survey standard field technique (Avery & Bascomb 1974).

Three drops of 1M hydrochloric acid were dropped onto each of three portions of soil in a Petri dish. The amount of effervescent carbon dioxide was recorded on a five point scale:-

1 = No visible or audible reaction. Non-calcareous, Ca^{2+} = 0
2 = Audible but no visible reaction. Very slightly calcareous, Ca^{2+} = 0.5% - 1%
3 = Slight visible effervescence. Slightly calcareous, Ca^{2+} = 1% - 5%.
4 = Moderate effervescence, small bubbles. Calcareous, Ca^{2+} = 5% - 10%
5 = Strong effervescence, large bubbles. Very calcareous, Ca^{2+} > 10%

A subjective estimate of the presence of siliceous or calcareous stones in the soil sample was also made.

Data for mean air temperature between January and

March and April and June, and mean rainfall and duration of bright sunshine between April and June were taken from published sources (White & Smith, 1982).

Cropping data was taken from information returned by farmers. It was recorded as the numbers of years between 1980 and the year of survey in which a particular crop was grown. The crop grown in the year of survey was also recorded separately. A "crop index" was also calculated by assigning values to crop types according to their normal sowing date as follows:

winter barley and rape -2

winter wheat -1

spring barley and linseed +1

root crops, maize and vegetables +2.

The numbers of crops of each type grown between 1980 and 1987, weighted as described above, were summed for each field, giving a scale from -14 to +14. This was then rescaled to run from 1 to 29, so that a field with a value above 15 was mainly cultivated in the spring, and a field with a value below 15 was mainly autumn cultivated.

In many cases, the agricultural status of fields at points in the past can be determined from historical records. The earliest reliable land use survey that covered large areas of the country was carried out in the middle of the $19^{th.}$ century, in response to the Tithe Commutation Act of 1836, for the purpose of assessing the taxable value of property. This survey coincided with an expansion in area of arable farmed land, in response to high grain prices (Tansley, 1949; Stamp, 1962; Wells *et al*; 1976). Tithe Commutation maps and documents referring to parishes in Hampshire, Wiltshire and East Suffolk were consulted, in order to determine the land use of surveyed fields in the mid-19th century.

Information on a wider area of the country was available from the land utilisation survey carried out during the 1930s (Stamp, 1962). This survey is however of limited value, as ley grassland of four or more years in length was included in the same category as permanent grassland, when in fact it comprised part of an arable rotation. During the 1930s, long-term ley grassland and "tumbled-down" grassland on abandoned arable land was at a maximum, after 90 years of decline of arable farming subsequent to the repeal of the Corn Laws in 1846 (Stamp, 1948). The only reliable data that can be gained from these maps are therefore positive indications of arable cultivation. In addition to analysis of the data from the two land use surveys separately, data from both of these historical sources was amalgamated to give an indication of whether the surveyed fields had been in arable cultivation at all by the middle of the 1930s.

Data analysis.

Ordination of the floristic data was carried out by detrended correspondance analysis (DECORANA) (Hill, 1979a), and classification by two-way indicator species analysis (TWINSPAN) (Hill, 1979b). DECORANA is a technique for the detection of gradients in vegetation data, and ordinating species along these gradients. Vegetation samples are then ordinated by calculation of mean species scores. TWINSPAN progressively divides both the species and samples in a dichotomous fashion on the basis of the presence or absence of indicator species, thereby classifying the data into groups. The details, shortcomings and advantages of these techniques have been extensively discussed (Hill & Gauch, 1980; Kershaw & Looney, 1985; Peet et al, 1987; Wartenberg et al, 1987), and they have now been widely adopted for handling data sets that include large numbers of species and samples. The National Vegetation Classification (N.V.C) project is based on the use of these two programmes for the classification of the vegetation of the British Isles (Malloch, 1987). Arable weed communities have been studied using these programmes (Brayshay & Kelly, 1988; Post, 1986), and one of their advantages in the study of segetal communities is that they do not require precise measurements of the abundance of individual species, and can also operate on simple presence and absence data.

DECORANA ordinations can be analysed using appropriate statistical methods. In this case, the first three DECORANA axis ordinations were analysed with respect to all environmental and historical variables by stepwise multiple regression, and Pearson correlation coefficients were calculated for the entire data set.

Further analysis of the TWINSPAN output was not carried out.

The association of environmental and historic variables with the presence of individual rare weed species were analysed by stepwise multiple logistic regression (Nelder & Wedderburn, 1972), a technique which allows the fitting of a linear regression model to binomially distributed presence/absence data (Nicholls, 1989). This is a particularly valuable method for the statistical assessment of very simple data, especially where the vegetation being sampled is liable to great fluctuations in abundance from year to year.

RESULTS

301 vegetation samples were recorded during the survey, although five of these were subsequently dropped from the analysis as they were not strictly arable sites.

The sites were distributed over the Southern half of England, from the Lizard in Cornwall, to the North York Moors in Yorkshire (Figure 2), an area which covers the known range for all of the studied species apart from Chrysanthemum segetum, which extends to the Shetland Isles (Perring & Walters, 1976).

The numbers of samples in which the eight selected study species were found, are listed in Table 8.

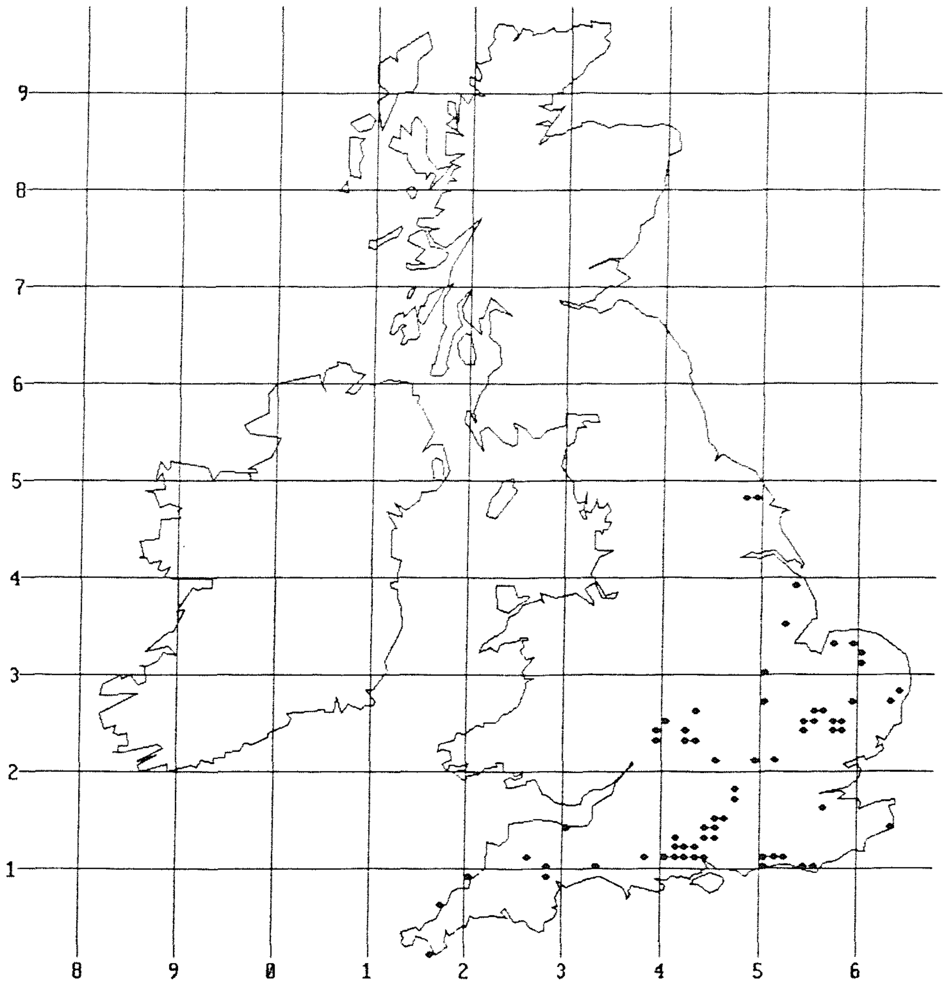


Figure 2. 10km squares containing localities visited between 1987 and 1989 as part of the survey of rare weed sites. (Created by "DMAP", a computer programme for distribution and Coincidence map plotting, written by A. Morton).

Table 8. Numbers of samples in which the eight selected species were surveyed between 1987 to 1989.

Adonis annua	11
Chrysanthemum segetum	41
Buglossoides arvensis	28
Misopates orontium	21
Papaver hybridum	75
Ranunculus arvensis	15
Scandix pecten-veneris	22
Silene noctiflora	29

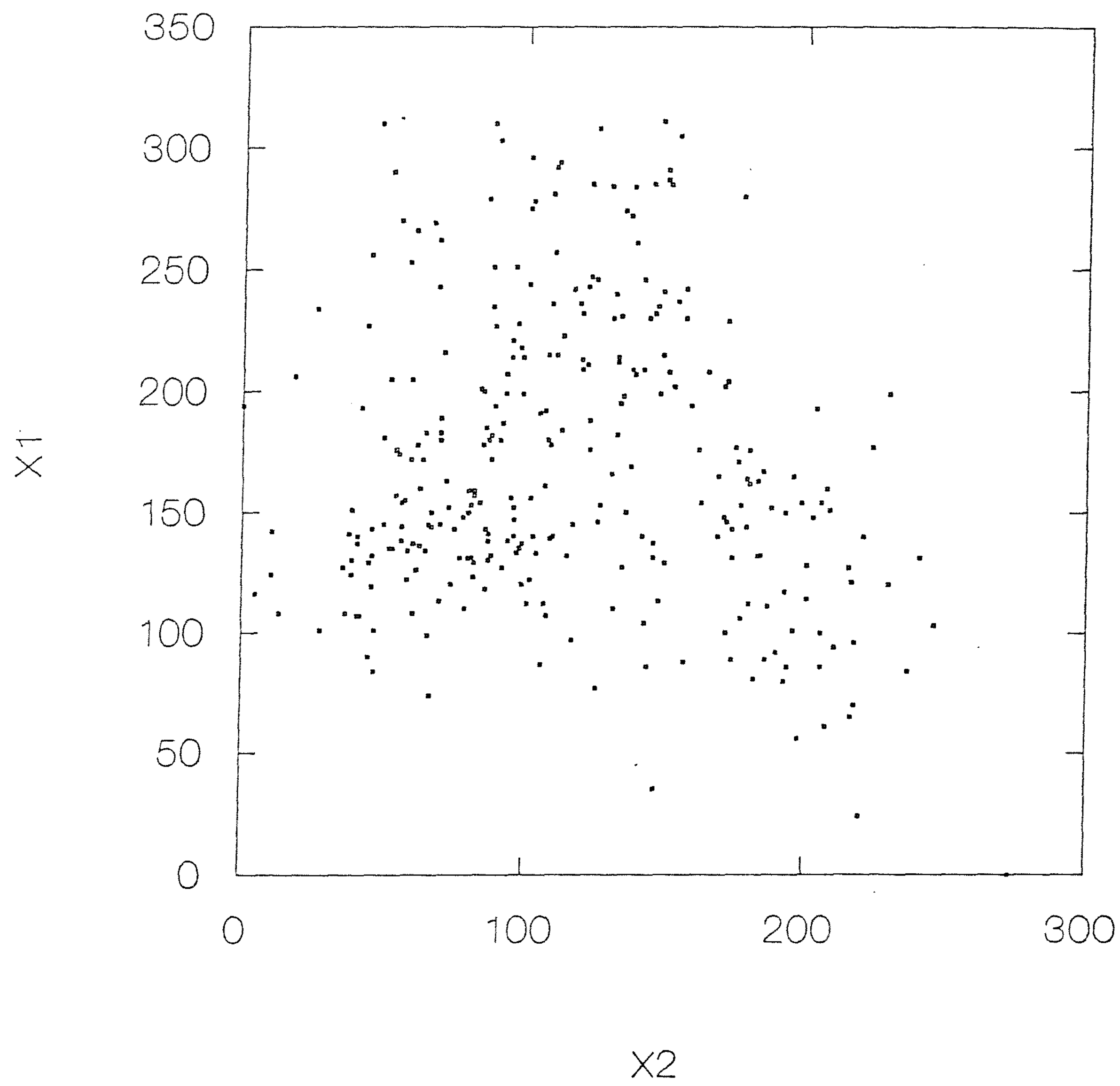
A list of sites is included as Appendix 1 , with the results of the first three axes of the DECORANA ordination, and the recorded environmental variables against which the DECORANA axes and individual species data were compared. The samples were plotted on the first two DECORANA axes (Figure 3), with overlays of samples grouped by levels of environmental data, and samples containing particular weed species (Figure 3 overlays in back-cover pocket).

Correlations between DECORANA axes and environmental variables.

Significant correlations between DECORANA axes and environmental variables are presented in Table 9, and significant correlations between environmental variables in Table 10.

There were highly significant correlations between DECORANA axes and a number of environmental factors. The first axis represented the greatest variation within the vegetation samples, and very significant ($P<0.001$) negative or positive correlations were observed with all soil variables ; pH(-ve), $CaCO_3$ content(-ve), presence of

Figure 3.Ordination of rare weed sites on the first two DECORANA axes (X1 and X2). See overlays a - r , for groupings of sites with respect to environmental variables, TWINSPAN classification, and presence or absence of 8 uncommon weed species.



siliceous (+ve) and calcareous (-ve) stones and texture (-ve), crop index (+ve), winter wheat (-ve) , root crops (+ve) and crop type in the year of survey (+ve). Less significant correlations (P<0.01) were observed with winter air temperature (+ve), summer rainfall (+ve), winter oil-seed rape (-ve), winter barley (-ve), and rarity index (-ve).

Table 9. Significant correlations (P<0.01) between DECORANA axes and environmental variables in a survey of rare weed sites.
Significance levels : positive correlations, ++ = P<0.001, + = P<0.01:
negative correlations, -- = P<0.001, - = P<0.01.

	DECORANA Axes.		
	X1	X2	X3
Soil Variables.			
pH	--		
CaCO	--	-	
Siliceous stones	++		
Calcareous stones	--	-	
Texture	--	++	
Climatic Variables.			
Summer rainfall	++		
Summer sunshine		-	
Winter air temp.			+
Crop data.			
Crop Index	++	--	
Winter rape	-		
Winter wheat	--	++	
Spring barley		--	+
Root vegetables	++	-	
Crop in survey year	++	-	
Winter barley	-		
Rarity Index	-	-	

Axis 2 showed fewer correlations, although these were significant (P<0. 01) for calcareous stones in the soil (-ve) , crop index (-ve) and winter wheat (+ve).

soil pH (-ve), $CaCO_3$ content (-ve) and texture (+ve), summer sunshine (-ve) , spring barley (-ve), root crops (-ve), crop in the year of survey (-ve), and rarity index (-ve).

Axis 3 contained less ecological information, with low positive correlations ($P<0.01$) with winter air temperature, , spring barley and , and a negative correlation with winter wheat. Axis 4 was negatively correlated with spring barley, but positively correlated with root crops and soil texture. These third and fourth axes are frequently regarded as being of limited importance, and dubious value in interpretation of the data (N. Aebischer, pers. comm.). The fourth axis was ignored in the subsequent analysis.

An estimate of the importance of the axes can be gained by examination of their eigenvalues (Table 11). The first axis always accounts for the maximum variation within the floristic data. If the eigenvalues of subsequent axes are much smaller than that of the first, then the amount of meaningful information that they contain can be regarded as proportionately small (Kershaw & Looney, 1985).

Correlations between environmental variables.

Many of the environmental variables were also found to be interrelated (Table 10). Relationships within groups of variables is unsurprising. Soil characteristics for instance are well known to be functionally related

(Etherington, 1975), and pH was found to be strongly correlated with increasing $CaCO_3$ content, presence of calcareous stones, absence of siliceous stones, and medium to heavy soil textures. Climatic conditions were also found to be closely interrelated.

Table 10. Correlations between the environmental variables recorded during the survey of rare weed sites. Significance levels: Positive correlations, ++ P<0.001, + P<0.01. Negative correlations, -- P<0.001% , - P<0.01.

Variables.

Soil	pH	CC	Si	Ca	Tx	Wt	Sr	Ss	Gr	Wr	Wb	Ww	Sb	Rv	Cs	Tm
pH		++		++	++											
$CaCo_3$	++		--	++	++									-		
Silicious stones		--		--		+	+									
Calcareous stones	++	++	--													
Texture	++	++								+		+		--	-	
Climatic																
Winter temp.			+				++	++	++		-	-	+			
Summer rain		+				++		++		-	--	++				
Summer sun						++						-	++			
Crop data																
Grass						++	++									
Winter rape					+							+			--	
Winter barley						-	-						-		-	
Winter wheat					+	-	--	-		+			--	-	--	
Spring barley						+	++	++			-	--				
Root crops		-			--							-			++	
Crop in survey year					-					--	-	--		++		
Historical																
Tithe map																
Amalgamated									+							++
Rarity index	+	+		+												+

The only correlation found with the two historic land use variables, was with the rarity index, which was significantly higher at sites that had been in arable cultivation for long periods. Rarity index was also positively correlated with spring barley, soil pH, $CaCO_3$ and calcareous stone content, and negatively with root crops.

Multiple regression analysis of DECORANA axes in relation to environmental variables.

The first three axes generated by DECORANA were analysed with respect to environmental variables by stepwise multiple regression (Table 11). Data for some environmental variables were not available for some sites, and in order to minimise loss of data due to elimination of cases with missing data from the computer analysis, groups of variables were first analysed separately to detect those that were most likely to have a significant effect on the final model. The final analysis was therefore carried out on a selection of variables.

70% of the variation in the first axis (x1; eigenvalue = 0.273) generated by detrended correspondence analysis, was accounted for by the regression (Table 11, Figure 4). Axis 1 was negatively associated with soil pH and texture, and positively associated with siliceous stones in the soil, summer rainfall, the presence of root crops in the crop rotation, and a spring sown crop in the year of survey. In other words, samples with high x1 values will

Figure 4 . Relationships between a. X1 and b. X2 (the two principle axes of of variation on which the surveyed rare weed sites were ordinated by DECORANA) and the values for X1 and X2 predicted by stepwise multiple regression from a range of environmental variables. See Table 11 for regressions.

a. X1. r^2_{128} = 0.7, P<0.001 b. X2. r^2_{159} = P<0.001

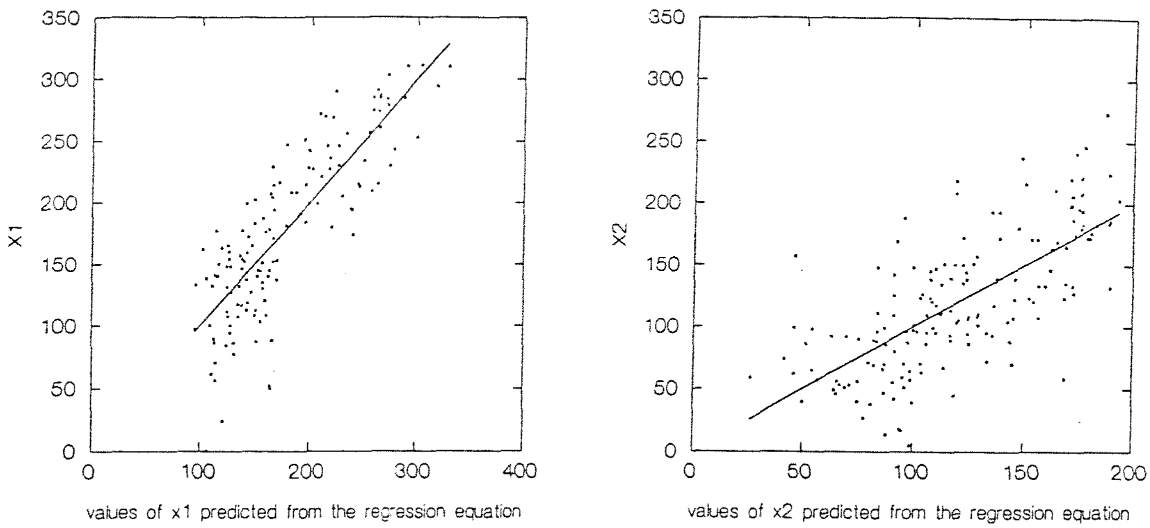
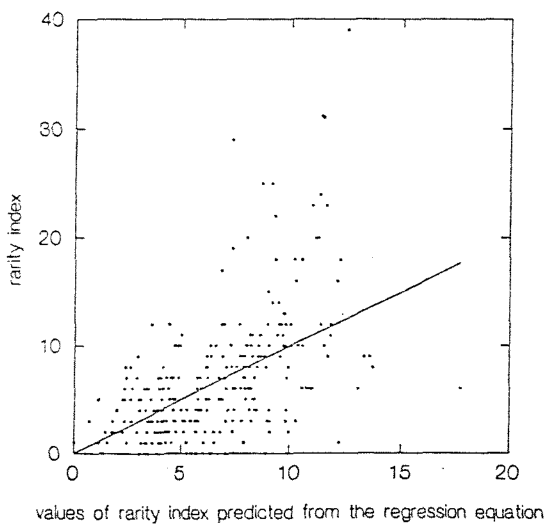


Figure 4c. Relationship between the "Rarity Index", and values for the "Rarity Index" predicted by stepwise multiple regression from a range of environmental variables. See Table 11 for regressions. r^2_{268} = 0.27, P <0.001.



tend to have low pH, a "light" soil, high summer rainfall, will support root crops, and will probably have had a spring sown crop in the survey year. The opposite situation will hold for sites with low x1 values. A tendency was observed for crop rotations to include grass leys, although this did not account for a significant amount of variation.

Table 11. Survey of rare weed sites between 1987 and 1989. Regression coefficients from stepwise multiple regression analysis of DECORANA axes (x1,x2,x3) and rarity index (RI), in relation to environmental variables (See Appendix 1 and text for full explanation of variables). Significance levels: $P < 0.001$, ***; $P < 0.01$, **; $P < 0.05$, *; +, variable significantly associated with axis, but not included in final regression; -, variable not significantly associated with axis; NS, not significant.

	Axis 1	Axis 2	Axis 3	RI
Eigenvalue	0.27	0.21	0.14	-
r^2	0.70	0.49	0.06	0.27
Degrees of freedom	128	159	294	268
Regression probability	***	***	***	***
Constant	374.2***	184.3***	111.8***	3.1NS
Soil pH	-34.5***	+***	+*	-
$CaCO_3$ content	-	-	-	-
Siliceous stones	31.5***	+***	+*	-
Calcareous stones	-	-49.4***	-	5.5***
Soil texture	-7.0***	6.4***	+*	-
Mean air } Jan.-March	-	+*	14.7***	-
temperature} Apr.-June	-	-	+*	-
Mean daily rain Apr.-June	17.5**	-	+**	-
Mean daily sun Apr.-June	-	+***	-	1.6*
Years from 1980 to 1987				
in : Grass	+	-	-	-
Winter rape	-	+*	-	-
Winter barley	-	-8.8**	-	-
Winter wheat	-	-	-	-
spring barley	-	-	-	-
peas/maize	-	-	-	-
root crops	9.9***	-	-	-
Crop in year of survey.	7.7**	+***	-	-
Crop index (see text).	-	-4.1***	-	-
Tithe map data	-	-	-	+***

49% of the variation in the second DECORANA axis (x2: eigenvalue=0.210), was accounted for by the regression (Table 11). x2 was positively associated with soil texture, and negatively associated with the presence of chalk or limestone stones in the soil, and spring crops or winter barley in the crop rotation. Samples with high values of x2 therefore tended to occur on heavy, stone-free soils, on which winter wheat was the major crop. Additional significant negative associations were found between x2 and soil pH, presence of siliceous stones in the soil, summer sunshine, winter rape in the crop rotation, and winter crops in the year of survey, and positive association with winter air temperature, but these were not included in the final equation.

The regression for the third axis (x3: eigenvalue = 0.141) accounted for only 6% of the variation, and the only variable term was mean winter air temperature, with which it was positively associated. x3 was also positively associated with the presence of siliceous stones in the soil, soil texture, summer air temperature, and summer rainfall, and negatively with soil pH.

The rarity index was significantly associated with the presence of calcareous stones in the soil, and high mean summer sunshine, although the model accounted for only 27% of the variation in the data (Figure 4c). Association with continuity of arable use of the sites was also present, but was not included in the regression. Significant associations were also found between the rarity index and the three DECORANA axes.

Relationships between the presence of rare weed species and environmental variables.

Presence and absence of individual species were compared with edaphic, climatic and agricultural variables using stepwise logistic regression (Nelder & Wedderburn, 1972). A model of the form $P = 1/1+e^{-y'}$, where P = the probability of occurrence of the species, and y' is the linear predictor $y' = a + bx$, was fitted to the data for each species. Results are presented in Table 12.

Soil texture was the variable most frequently associated with the individual weed species examined. *Chrysanthemum segetum*, *Misopates orontium*, and *Silene noctiflora* were all highly significantly associated with lighter soils, whereas *Buglossoides arvensis*, *Ranunculus arvensis*, and *Scandix pecten-veneris* were all significantly more frequent on heavier soils. The presence of calcium carbonate in the soil was also of importance, *Adonis annua* and *Papaver hybridum* both showing a significant association with soils rich in calcium carbonate, while *C. segetum* was found more often on calcium carbonate poor soils. *M. orontium* showed a significant association with soils containing siliceous stones, but pH seemed to have no significant effects.

Table 12. The relationships between the occurrence of rare weed species and environmental parameters. Analysis carried out by stepwise logistic regression. The probability of the occurrence of a species is given by substitution of the linear predictor y', into $1/1+e^{-y'}$, (where y'= constant + coefficient x variable). See text for details of variables; only those that were found to be significant in the final regression equation are included below. Significance levels: < 0.001 ***, < 0.01 **, < 0.05 *. P^1 is the probability for the whole regression for each species; P^2 is the probability for each term within each regression.

Species	d.f	P^1	Variables	Coeff.	S.E.	t	P^2
Adonis annua	5, 126	***	Soil $CaCO_3$	1.44	0.71	2.04	**
			Grass	0.45	0.21	2.10	*
			Constant	-9.71	3.42	-2.84	*
Chrysanthemum segetum	3, 129	***	Soil texture	-0.59	0.15	-3.87	***
			rain Apr-June	1.90	0.85	2.25	*
			spring barley	0.45	0.14	3.13	**
			Soil $CaCO_3$	-0.58	0.24	-2.44	*
			Constant	2.30	not significant		
Buglossoides arvensis	1, 163	***	Soil texture	0.33	0.15	2.18	*
			Constant	-5.31	1.76	-3.02	**
Misopates orontium	4, 159	***	Siliceous stones	3.88	1.05	3.71	***
			Soil texture	-0.56	0.14	-3.96	***
			Sun Apr-June	1.90	0.61	3.10	**
			Constant	-10.21	2.76	-3.71	***
Papaver hybridum	5, 127	***	Spring barley	0.73	0.20	3.72	***
			Soil $CaCO_3$	1.47	0.37	4.02	***
			Sun Apr-June	1.37	0.47	2.92	**
			Constant	-35.6	13.0	-2.74	*
Ranunculus arvensis	3, 129	***	Soil texture	1.41	0.64	2.21	*
			Temp. Apr-June	-2.10	0.79	-2.66	*
			Constant	-16.34	8.06	-2.03	*
Scandix pecten-veneris	3, 161	***	Soil texture	1.36	0.49	2.81	**
			Temp. Jan-March	-1.58	0.80	1.98	*
			Constant	-16.67	6.17	-2.70	*
Silene noctiflora	1, 130	***	Soil texture	-0.021	0.006	-3.74	***
			Constant	1.28	not significant		

Table 13. Regression coefficients from stepwise logistic regression of the presence of rare weed species in relation to the first three DECORANA axes (x1, x2, x3). The probability of the occurence of a species is given by substitution of the linear predictor y', into $1/1+e^{-y}$, (where y' = constant + coefficient x variable). Significance levels: < 0.001 ***; < 0.01 **; < 0.05 *; -- = not significant. P^1 is the probability for the whole regression for each species; other asterisks are the probability for each term within each regression.

	d.f	P^1	Constant	x1	x2	x3
Adonis annua	2, 293	***	1.3	-0.022**	-0.014*	--
Chrysanthemum segetum	3, 292	***	-11.3***	0.030***	--	0.024**
Buglossoides arvensis	1, 294	***	0.4	-0.010**	--	--
Misopates orontium	2, 293	***	-10.9***	0.021***	--	0.025**
Papaver hybridum	3, 292	***	2.2*	-0.013***	-0.028***	0.014*
Ranunculus arvensis	1, 294	***	-7.5***	--	0.030***	--
Scandix pecten-veneris	3, 292	***	-6.9***	-0.027***	0.018***	0.039***
Silene noctiflora	3, 292	***	-1.0	0.008*	-0.040***	--

The crops grown in recent years appeared to have few effects, although *C. segetum* and *P. hybridum* were both favoured by rotations including spring barley. *A. annua* was more frequent where grass formed a part of the recent cropping.

The effects of the climatic variables tested were varied. *C. segetum* was significantly more frequent in areas of high mean summer rainfall, and *M. orontium* and *P.*

hybridum were more frequent where the mean amount of summer sunshine was higher. Conversely, *R. arvensis* was more frequent where mean summer air temperature was lower, and *S. pecten-veneris*, where mean winter air temperatures were lower. It must however be remembered when considering the climatic data presented here, that the survey only covered the warmer areas of the southern half of England, and excluded the whole of Scotland and Wales, and the greater part of northern England.

The effectiveness of the regression equations for the prediction of the presence or absence of a species was tested by calculation of the probability of the occurrence of each species at each site, but were found to be rather poor predictors of the presence or absence of a species at a site.

The individual species were also found to be associated in different ways with the three major DECORANA axes described earlier (Table 13). Samples which included these species are highlighted in overlays for Figure 3. These three axes represented successively decreasing gradients of change within the floristic data, and were each associated with a different complex of environmental variables (Table 11). The significant association of an individual species with one of these axes therefore represented its association with a particular region of the vegetation community continuum, and also with one or more of the complex of environmental variables.

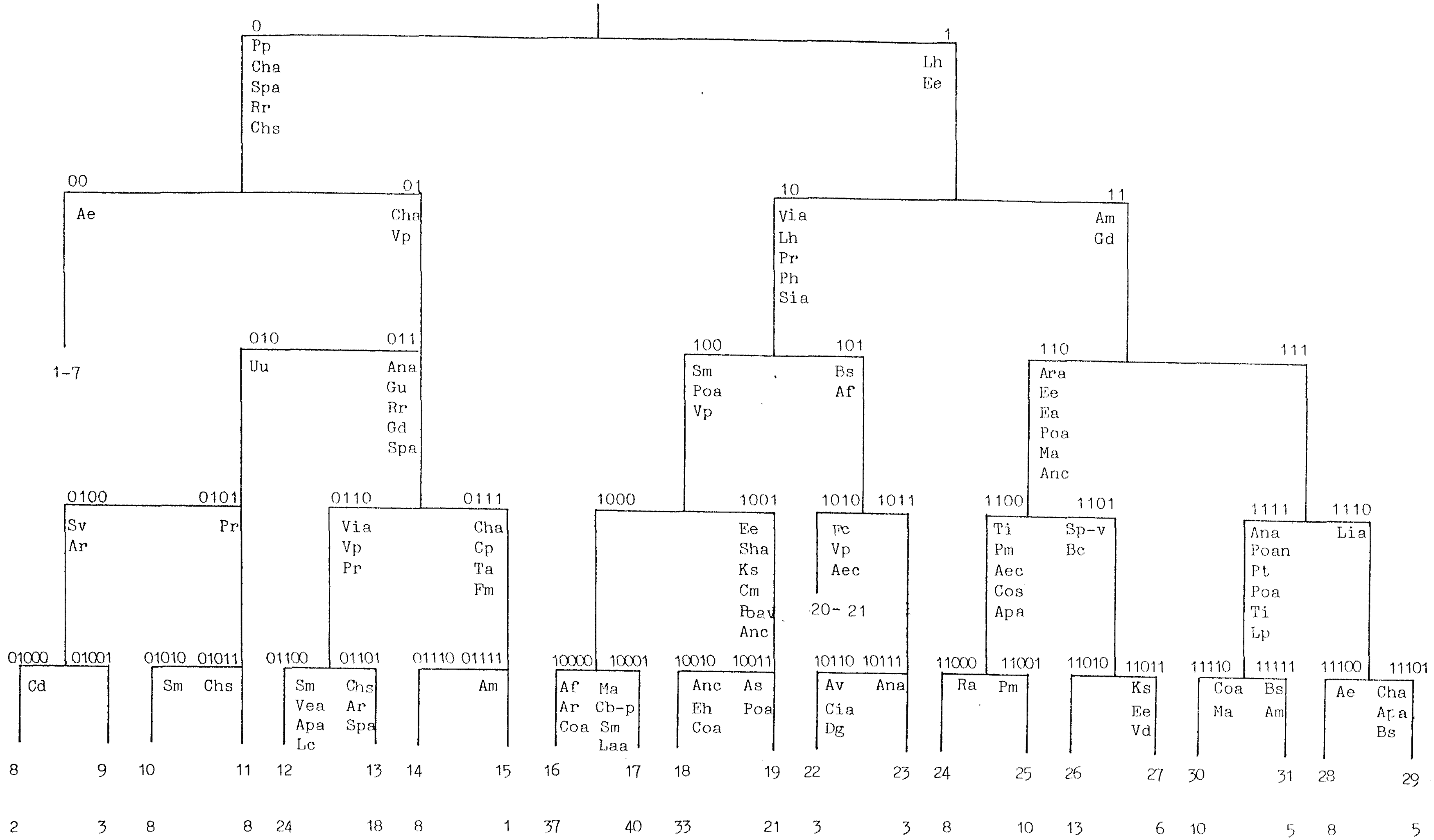
Positive significant associations with DECORANA axis 1 were recorded for C. segetum, M. orontium, and S. noctiflora, but negative associations for A. annua, B. arvensis, P. hybridum, and S. pecten-veneris. Positive associations with axis 2 were observed for R. arvensis and S. pecten-veneris, and negative associations for A. annua, P. hybridum and S. noctiflora. Positive associations were found between axis 3 and C. segetum, M. orontium, P. hybridum and S. pecten-veneris.

Classification of weed communities using TWINSPAN.

A diagram illustrating the first five levels of division detected within the data by TWINSPAN, is presented in Figure 5, and the groups of samples detected are displayed on overlays q. and r. for Figure 3.

Some well defined groups of sites and species were present. Appendix 2 lists the sites (referred to by code number: see Appendix 1) included in each final group (Figure 5), and the presence in the final groups of any of the eight species for which sites were visited, are listed in Table 14.

The first dichotomy separated the sites with relatively calcium carbonate-poor, acidic soils supporting mainly spring crops (Group 0), from the rest, mainly more calcareous and less acidic soils with a variety of cropping systems (Group 1). The second division of Group 1 was less distinct than the first, but seemed to split this group of sites into those on relatively lighter soils with chalk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Pp
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Spa
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Chs
1
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1-7
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Ana
Gu
Rr
Gd
Spa
0100
Sv
Ar
0101
Pr
0110
Via
Vp
Pr
0111
Cha
Cp
Ta
Fm
01000
Cd
01001
01010
Sm
01011
Chs
01100
Sm
Vea
Apa
Lc
01101
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Ar
Spa
01110
01111
Am
10
Via
Lh
Pr
Ph
Sia
11
Am
Gd
100
Sm
Poa
Vp
101
Bs
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1001
Ee
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Cb-p
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Laa
10010
Anc
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Coa
10011
As
Poa
10110
Av
Cia
Dg
10111
Ana
110
Ara
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Ana
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1110
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Pm
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11011
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Ee
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Coa
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11111
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8 9 10 11 12 13 14 15 16 17 18 19 22 23 24 25 26 27 30 31 28 29
2 3 8 8 24 18 8 1 37 40 33 21 3 3 8 10 13 6 10 5 8 5

Figure 5. Classification by "Twinspan" of sites included in the survey of rare weed sites. Divisions of the sites are carried out on the basis of the presence or absence of indicator species, marked on the diagram by their initial letters (below). Sites included in each final group are listed in Table .

SPECIES	ABBREVIATION	SPECIES	ABBREVIATION
Aethusa cynapium	Aec	*Lamium amplexicaule*	Laa
Elymus repens	Ar	*Lapsana communis*	Lc
Alopecurus myosuroides	Am	*Legousia hybrida*	Lh
Anagallis arvensis	Ana	*Buglossoides arvensis*	Lia
Anthemis cotula	Anc	*Lolium perenne*	Lp
Aphanes arvensis	Apa	*Myosotis arvensis*	Ma
Arenaria serpyllifolia	As	*Papaver argemone*	Paa
Arrhenatherum elatius	Ae	*Papaver hybridum*	Ph
Artemisia vulgaris	Av	*Papaver rhoeas*	Pr
Atriplex patula	Ap	*Plantago major*	Pm
Avena fatua	Af	*Poa annua*	Poan
Bromus commutatus	Bc	*Poa trivialis*	Pt
Bromus sterilis	Bs	*Polygonum aviculare*	Poav
Capsella bursa-pastoris	Cb-p	*Fallopia convolvulus*	Pc
Chaenorhinum minus	Cm	*Polygonum persicaria*	Pp
Chenopodium album	Cha	*Ranunculus arvensis*	Ra
Chenopodium polyspermum	Cp	*Raphanus raphanistrum*	Rr
Chrysanthemum segetum	Chs	*Scandix pecten-veneris*	Sp-v
Cirsium arvense	Cia	*Senecio vulgaris*	Sv
Convolvulus arvensis	Coa	*Sherardia arvensis*	Sha
Coronopus didymus	Cd	*Silene latifolia*	Sia
Coronopus squamatus	Cos	*Spergula arvensis*	Spa
Dactylis glomerata	Dg	*Stellaria media*	Sm
Equisetum arvense	Ea	*Thlaspi arvense*	Ta
Euphorbia exigua	Ee	*Tripleurospermum inodorum*	Ti
Euphorbia helioscopa	Eh	*Urtica urens*	Uu
Fumaria muralis	Fm	*Valerianella dentata*	Vd
Geranium dissectum	Gd	*Veronica arvensis*	Vea
Gnaphalium uliginosum	Gu	*Veronica persica*	Vp
Kickxia spuria	Ks	*Viola arvensis*	Via

Table 14. Rare species in each of the final groups detected by TWINSPAN classification of surveyed rare weed sites. (Figure 5). *C.s.* *Chrysanthemum segetum*; *M.o.* *Misopates orontium*; *S.n.* *Silene noctiflora*; *P.h.* *Papaver hybridum*; *A.a.* *Adonis annua*; *B.a.* *Buglossoides arvensis*; *S.p.* *Scandix pecten-veneris*; *R.a.* *Ranunculus arvensis*.

		Presence of rare species; no. of sites.							
Final group.	No. of sites.	*C.s.*	*M.o.*	*S.n.*	*P.h.*	*A.a.*	*B.a.*	*S.p.*	*R.a.*
0 - 7.	3	3							
8.	2								
9.	3	3			1				
10.	8			4					
11.	8	4		2					
12.	24	6	8	2	1				
13.	18	12	5		2				
14.	8	2	4						
15.	1			1					
	First dichotomy.			-----	-----	-----	-----	-----	
16.	38	4	1	6	19	3			1
17.	40	1		6	18		2		
18.	33			2	18	7	6	1	
19.	21			6	12		6	3	1
20-21.	3				1				
22.	3				1				
23.	3				2				
24.	8							1	8
25.	9			1			1	2	1
26.	13						2	6	1
27.	6							6	3
28 & 29	13								
30.	10						4	3	
31.	5						1		

present (Group 10; final groups 16-23), and those with relatively heavier soils without chalk, and supporting predominantly winter crops (Group 11; final groups 24-31). Group 10 included most of the sites for *P. hybridum*, and all sites for *A. annua*. Group 11 includes the majority of sites for *S. pecten-veneris* and *R. arvensis*. The third dichotomy seemed to split both Groups 10 and 11 into relatively species-rich sites (Groups 100 and 110; final groups 16-19 and 24-27) and species-poor sites (Groups 101 and 111; final groups 20-23 and 28-31). The divisions of Group 0 were less clear, possibly due to the smaller number of sites included in this group. There appeared to be a connection with area of the country, and maybe therefore with climate. Group 010 (final groups 8-11) included mainly sites in the eastern half of the country, and group 011 (final groups 12-15) included mainly sites in the west. Most of the sites for *M. orontium* were found in Group 011.

DISCUSSION.

Environmental variation within arable habitats.

It is evident from the results of this survey, that both "natural" environmental factors and agricultural practices have had a profound influence over the nature of weed vegetation. Before considering the effects of these variables on weed communities and species, it is necessary first to look at the relationships between variables, as many were found to be correlated.

As mentioned above, many soil characteristics are closely linked. In Britain, Calcium is the chief soil cation, and as such is largely responsible for the soil pH. In general, a soil with a high calcium carbonate content will tend to have a high pH, and vice versa, although the relationship is not simple (Tansley, 1949; Etherington, 1975). Soils with a high calcium carbonate content will be expected in association with a chalk or limestone geology, and the strong correlation of calcium carbonate with the presence of large quantities of calcareous stones in the soil confirms this, even though the quantification of stone content was very crude and subjective. Soils derived from calcareous glacial drift deposits (boulder clay) can also be very calcium-rich, as can those receiving inputs of aeolian shell sand. Many of the localities surveyed in Hertfordshire, Cambridgeshire and Suffolk had soils derived from boulder clay, but although generally very calcareous, the soils are very different in their texture to those derived directly fom the chalk. Sites 139-147, at Porth Joke, on the coast of north Cornwall, were situated on a headland to the north-east of the highest sand dune system in Britain, and are ideally placed to receive substantial quantities of both shell sand and salt-rich sea spray. In all but two of the fields examined at this site, the pH was greater than 7.6, and the calcium carbonate content greater than 3%, despite being many miles from the nearest calcareous rock, and not having received any agricultural lime for at least seven years. The weed flora is thought to be the richest in Cornwall, containing such disparate elements as *C. segetum*, normally associated with acidic soils (Table 12) and *P. hybridum*, normally associated with basic soils, and here in its only known Cornish site.

The relationship between soil pH and calcium carbonate content may be considerably modified by the differing properties of the types of clay particles in the soil, and by their proportions (Etherington, 1975; Townsend, 1973).

Soil texture will therefore also be expected to be correlated with soil pH, both by virtue of the properties of the clay particles, and because the leaching of soil cations is much faster from a "light" soil with little clay, than from a soil with a large clay fraction (Tansley, 1949). A correlation was found in this survey, but, as noted above, substantial areas of the country are covered in glacial clay deposits largely derived from chalky substrata, and for this reason alone a correlation between "heavier" soils and high pH was to be expected.

Although non-calcareous stones in the soil have no direct effect on pH, they tend to improve soil drainage, and affect soil texture. They were here associated with clay with flint deposits superficial to the chalk, with Tertiary gravels in the Hampshire and London basins, and with the harder geological strata of the south-west of England (Jarvis et al. 1984), and were correlated negatively with the presence of calcareous stones, pH and soil calcium carbonate content.

The climatic factors used were also strongly intercorrelated (Table 10). High winter air temperatures were significantly correlated with high summer rainfall and sunshine, high summer air temperature significantly correlated with low summer rainfall, and high summer rainfall with high summer sunshine (White & Smith, 1982). This reflects the general trend from an "Atlantic" type of climate in the south-west of the country, characterised by mild winters, warm summers and much rain, to a more "continental" climatic type in the midlands and the east, with colder winters, and drier summers.

Some of the climatic and edaphic variables were correlated. The presence of siliceous stones was positively correlated with high winter air temperature and summer rainfall. Both high pH and soil calcium content were correlated with low summer rainfall. These correlations however, imply no causal relationship, as the underlying pattern to both sets of variables is geographical (Coppock, 1964). In addition to the west-east trend from "Atlantic" to "Contentinental" climate, there is also a geological trend. The south-west of the country is characterised by a much older geology, with few calcareous rocks and without any overlying drift deposits, while soils in the south-east are predominantly derived from calcareous rocks or calcareous drift deposits apart from areas such as the London and Hampshire basins and the Weald, where the soils are predominantly acidic (Jarvis et al., 1984).

Cropping data were also strongly correlated with a number of environmental variables. Heavier soils tended to support significantly more winter wheat and rape, and fewer root crops. Root crops were also less frequent on soils with a high calcium content. The presence of siliceous stones correlated positively with spring barley crops, but negatively with winter barley. Grass crops were more frequent on soils with low pH. Crop types were also correlated with climatic variables. Winter wheat and barley were grown more in areas of lower summer rainfall, colder winters, and less sunny summers. Winter rape was also found more in areas of lower summer rainfall. Spring barley on the other hand was recorded more from areas with warm winters, and sunny, wet summers.

The correlations between crop types grown in fields over the past 10 years reflected patterns of crop rotations in modern farming. Grass leys were negatively correlated with winter rape and barley, winter oil-seed rape was positively correlated with winter wheat, but not with spring barley or root crops, both winter wheat and winter barley were negatively correlated with spring barley, and winter wheat was also negatively correlated with vegetable crops. The implications were that not only were there relationships between climatic and edaphic factors and individual crops, but also that these factors were related to crop rotations.

The regional variation in cropping patterns is well known (Coppock, 1964; Jarvis et al, 1984). Intensive arable farms growing largely winter cereals and rape are concentrated in the East Midlands and East Anglia. Mixed farming, incorporating grass leys, vegetables and spring barley becomes more common towards the west of the country. Even at the end of the 1980s it is evident that climatic and edaphic factors still exert much influence over agriculture, as they have done in the past (Overton, 1989), and will probably have a similar effect on weed floras, although the relationships may be difficult to disentangle.

Factors affecting the composition of arable weed communities.

When considering the relationships between weed communities, the distributions of individual species, and environmental factors, the intercorrelations described above must be remembered. Stepwise multiple regression produces a model equation including the selection of environmental variables that best accounts for the data. Variables that are significantly correlated with the data may be eliminated from the equation if the variation that they are responsible for, has already been explained by another, more important factor. This occurs mainly if variables are closely intercorrelated (Snedecor & Cochran, 1967) as they were here. For this reason, variables that were found to be significant in preliminary stages of the analysis, but were not included in the final regression, are also included in Table 11.

The major factors that were found to account for the variation detected by DECORANA in weed populations included in this survey, were found to be soil pH and texture, the presence of calcareous or siliceous stones in the soil, the types of crops grown in the field during the last 10 years, especially roots and winter barley, summer rainfall, and winter air temperature (Table 11).

Soil pH has been suggested as a major factor affecting floristic diversity in temperate regions (Grime, 1979) and in general, floristic diversity in most habitats tends to be greater on more base-rich soils. Most plant species show a restriction to a range of soil pH values, and it was therefore unsurprising that a strong association was observed between DECORANA axis 1 and soil pH. As described above however, soil pH is related to a complex of other variables, some of which were also found to be significantly related to the DECORANA axes. The differences in weed communities between heavy and light soils have been noted previously (Brenchley, 1920; Brenchley & Warington, 1930; Salisbury, 1961), and several species are known to be closely associated with particular soil texture types. Soil texture and the influence that it has over the water retention capacity of the soil, was found to be the most important soil characteristic affecting the diversity and conservation value of weed floras in one area of Germany (Steinrucken & Harrach, 1988). Again as described above, the crops that were grown on a particular soil type, were strongly correlated with soil texture, and it may be that the effect of soil texture on the weed flora is mediated via the effects of the crop rotations. The connection between weed performance and crops sown at different times of the year, as a consequence of their restricted periods of germination, is demonstrated and discussed in Chapter 7 .

Although the models proposed to explain the first two DECORANA axes were found to account for a large part of the variation in the data, other variables were also probably of importance, although it was not practicable to investigate them during this survey. These may include the nitrogen status of soils and the inputs of nitrogen supplied to the crop (Hafliger & Brun-Hool, 1971; Mahn, 1988, Goldberg & Miller, 1990, Chapter 6), the nature and efficiency of herbicide application (Ubriszy, 1968; Rademacher, Koch & Hurle, 1970; Thurston, 1968; Chapter 4), and the types of cultivations practised (Froud-Williams, et al, 1981; Chancellor & Froud-Williams, 1986).

TWINSPAN classification is derived from a DECORANA ordination, and so would be expected to give similar conclusions. It was considered therefore that thorough analysis of the TWINSPAN output was unneccessary. The general results of the classification are described above, and this technique provides a valuable alternative method of viewing the data, where discrete noda on a continuum of change in vegetation can be detected.

Other workers have classified arable weed vegetation using the Zurich-Montpellier system (Braun-Blanquet, 1932; Hafliger & Brun-Hool, 1971; Silverside, 1977). There are many similarities between the TWINSPAN classification outlined here and the classification of European communities proposed by Hafliger and Brun-Hool (1971), and Silverside (1977) considered that weed communities in

Britain could be classified as outlined in Table 15.

Table 15. Phytosociological classification of British arable weed communities by the Zurich-Montpellier system (Silverside, 1977), compared with results from Two-way indicator species analysis of 290 fields in southern England (Fig. 5)

Zurich-Montpellier classification	TWINSPAN group
Order: *Polygono-Chenopodietalia.*	
Alliance: *Fumario-Euphorbion.*	Possibly Fields 42 & 43 01011
Alliance: *Spergulo-Oxalidion.*	
Association: *Spergulo-Chrysanthemetum segeti*	01000,01001,01011,01100, 01101,01110,00
Association: *Descurainio-Lycopsietum arvensis*	Fields 196-201; 01001
Order: *Eragrostietalia.*	
Alliance: *Panico-Setarietalion.*	Not found.
Order: *Centauretalia cyani.*	
Alliance: *Arnoseridion.*	Not found.
Alliance: *Aphanion.*	11
Alliance: *Caucalidion.*	10

Factors affecting the distribution of selected weed species.

The multiple logistic regression models proposed for the eight selected weed species were poor at predicting their occurrence when a retrospective check was carried out. This did not invalidate the models, but suggested that there were a number of other variables affecting weeds that were not measured during this survey. These variables probably cover a number of aspects of farming practice such as the efficiency and nature of herbicide use, fertiliser usage, microclimate, cultivation practice etc.. Because of the intercorrelation of variables described above, the relationships of the individual species to environmental data must be interpreted with the same degree of caution with which the DECORANA axes were treated. The results for the species examined are discussed below, and further discussion may be found in Chapter 9.

Adonis annua was found to be significantly associated with soil calcium carbonate content and the presence of grass leys in the crop rotation. In this survey, this species was recorded exclusively from loamy soils overlying chalk, although it is still known from two other sites on Jurassic limestones in the south-west of England. Salisbury (1961) and Silverside (1977) referred to this species as characteristic of chalky soils. The connection with grass leys is harder to understand. Examination of the data shows that of the 7 fields for which cropping data was obtained, 6 had had more than two crops of grass since 1980. It is possible that the inclusion of grass in crop rotations is a feature of a "less-intensively" managed farm, more conducive to the survival of this very rare species, although the farms on which it is still found appeared to be farmed in a typical modern way. A closer study of site microclimate may reveal additional important factors about this species.

Significant relationships were detected between the presence of *A. annua* and the first two DECORANA axes.

These implied an association with high pH, the absence of siliceous stones but the presence of chalk in the soil, relatively low summer rainfall, few root crops or winter barley grown in recent years, but a general predominance of winter crops. The only site that did not fit totally into these parameters, was Field 248 (Sonning, Berkshire), where alternating crops of winter barley and winter rape was grown. Experimental evidence indicated that this species grows best in November sown winter wheat crops (Chapter 7). The TWINSPAN classification separated all of the sites for A.annua into two groups, 10000, and 10010.

Chrysanthemum segetum has long been known to be associated with well-drained base-poor soils supporting mainly spring sown crops (Brenchley, 1920; Long, 1910; Salisbury, 1961; Howarth & Williams, 1972). The proposed regression model supported that view, with the additional association with high summer rainfall. Examination of the DECORANA axes emphasised the connection with soil characteristics, spring cropping, and "Atlantic" climate.

Several sites in Norfolk had very low rainfall levels, and the association with rainfall may be a case of inter-variable correlation, as base-poor soils are less frequent in the low rainfall areas of Eastern England. This species was capable of growing on calcareous soils with high pH, providing that they were relatively light in texture. Fields 139,140,141,144,145 (Porth Joke, Cornwall), were described above, and owe their calcareousness to aeolian sand deposition. Field 306 (Ringstead, Norfolk) was also on calcareous sand, although here of glacial origin, and Fields 276 and 278 (Collyweston, Northamptonshire) were on oolitic limestone, and although they had a high pH, were relatively poor in calcium carbonate. Field 127 (Fontmell, Dorset) was the only site for C. segetum which had an extremely chalky soil, calcium carbonate rich, and with a pH of 7.8. The high pH of field 191 (Romsey, Hampshire) was probably due to recent liming.

Crop rotations at most of the sites for this species included many spring crops, although there were some important exceptions. Fields 119 and 123-126 (Romsey, Hampshire) had been exclusively under winter cereals since 1980, and C.segetum was infrequent there. Fields 36-41 (Hockering, Norfolk) were mainly cropped with winter cereals, but with one year in four of sugar beet. These field observations were all consistent with the results described in Chapters 5 & 7, in which C.segetum was found to germinate mainly in the spring and very early autumn, and to survive only in plots of spring barley and in winter barley sown in September.

At a number of sites, specific efforts had been made to control C. segetum with herbicides. In the herbicide trials described in Chapter 4, resistance was shown to two of the chemicals most commonly used in spring cereals. Recently developed compounds have been shown to be very effective at controlling this species (Flint, 1987).

C. segetum was an indicator species for the first TWINSPAN dichotomy, implying that this may mainly be on the basis of soil and crop type. The only sites for *C. segetum* in group 1, were those described above, from rather unusual soil types in Cornwall, Northamptonshire, and Norfolk, implying the presence of a difference in the weed communities present at these sites.

Buglossoides arvensis was found to be significantly associated with soil texture only, and at no site was the soil lighter than a silty loam. *B. arvensis* was associated with low values of DECORANA axis 1, confirming the effect of soil texture, but also suggesting that it might be associated with high soil pH, the absence of siliceous stones, low summer rainfall, and a predominance of winter crops. Long (1910) and Salisbury (1961), stated that this species was more frequent in chalky fields.

This species appeared to occur in two distinct situations. Fields 70 to 73 (Warwickshire), 90 (Wickhambrook, Suffolk), 114 (North Thoresby, Lincolnshire), and 280 and 281 (Raunds, Northamptonshire), were all on clay loam soils, supporting mainly winter crops, and with very species-poor weed floras. Fields 92 (Wickhambrook), 247 (Pirton, Hertfordshire) and 253 (Ivinghoe Aston, Buckinghamshire) were intermediate between the species-poor stands, and the other 17 samples, which were all on lighter chalky soils, with a more species rich flora, and, where evidence was present, a more varied crop rotation. TWINSPAN classified the species-poor sites into group 110 and 111, while species-rich sites were classified into group 100. It may be that a genetic difference existed between the populations in the two different situations, or it may be that the species-poor sites represented a degraded remnant of a richer flora.

This species still causes problems to farmers on heavy soils in some areas of the south midlands (G.Cussans, pers comm.; G.Collini, pers comm.). This species is relatively "versatile". It was capable of standing a high degree of crop competition (Chapter 6) and survived in crops sown on a wide range of dates, although it performed best in wheat crops sown in mid-October (Chapter 7). It is also resistant to a number of herbicides (Chapter 4 ; Flint, 1987), and it is therefore difficult to understand why it has become rare in recent years.

Misopates orontium was found most frequently on "light" soils containing siliceous stones in areas experiencing high levels of summer sunshine. Associations with DECORANA axes resembled those for C. segetum, although axis 3 was rather more important, which implied a greater restriction to areas of "Atlantic" climate, as reflected by the predominantly south-western distribution of this species in Britain. The importance of soil type was emphasised by the association with axis 1.

This species was found on some rather heavier soils in

Devon, (50-52, 135; Sandford) and Cornwall (152, Lizard), although these were all stony, and relatively calcium poor. These sites were the only ones visited at which C. segetum was not also present. C. segetum was however present in a number of sites at which M. orontium was not, and it may be that the difference between the distributions of areas of high summer rainfall and high summer sunshine may account for the differences between the distribution of these two species. The B.S.B.I. survey recorded only three sites outside the south-west of Britain for this species, one of which was included in this survey (Site 62, Bix, Buckinghamshire).

No correlation was found with cropping variables, although in all of the sites but one for this species where crop information was available, the predominant crops were spring sown. It is possible that correlations with crop variables were obscured by the effects of the other variables included in the regression. The highly significant association with DECORANA axis 1 implied some relationship with crop rotation, although the interrelationships of the variables make interpretation difficult. In the experiment described in Chapter 7, M. orontium was found only in spring barley crops sown in March, and in an experimental study of germination periodicity (Chapter 5), it was found to germinate only between February and August.

TWINSPAN classified most sites for M. orontium into group 011, the exception being Field 141 (Porth Joke, Cornwall).

Papaver hybridum was associated with soils with high calcium carbonate content, spring barley in the crop rotation, and areas with high levels of summer sunshine. Although it was found in greatest quantity on the chalk from Wiltshire to Kent, and was present at most of the sites for other rare weed species visited in these counties, this species was not entirely confined to chalky soils, being found also on calcareous sand in Cornwall (Fields 139-147) and Norfolk (Fields 34 & 306, Ringstead), and oolite in Northamptonshire (Field 279)(See C. segetum above).

Significant associations with the DECORANA axes confirm the importance to this species of a calcareous soil containing chalk or limestone. They also suggest a preference for spring crops, although not root crops, and for sunny, dry summers. These indications are all consistent with the distribution of this species in the cereal growing regions of south and particularly south-east England. P. hybridum grew best in plots of wheat sown in late November in the experiment described in Chapter 7, although it was also found to perform reasonably well in spring barley plots.

P. hybridum was confined by TWINSPAN to group 1 at the first dichotomy, exceptions being Fields 140, 142 & 146 (Porth Joke). It acts as an indicator species at the second dichotomy, and most localities were to be found in group 10.

Ranunculus arvensis, was regarded by Salisbury (1961) as a common and troublesome species. This contrasts with the situation now, and most of the few sites recorded for this species within the last three years were visited during this survey. R. arvensis was associated mainly with heavy soils, in areas with relatively low summer air temperatures. Long (1910) believed this species to be mainly found on heavy soils. The association with air temperature may be coincidental, as this species is now mainly restricted to a small area to the north of the Cotswolds in the south-west midlands. It is surprising that no correlation was found between this species and winter crops, as a predominance of winter cereals was recorded at all sites for which cropping data was available. This species was not found in any fields which had a spring-sown crop in the year of survey. In the experiment described in Chapter 7 , this species was found almost entirely in autumn drilled crops.

The positive relationship with DECORANA axis 2 was further support for the preference of R. arvensis for heavier soils. It also implied a preference for sites that grew mainly winter wheat or oil-seed rape, but not winter barley. The majority of sites from which this species was recorded were cropped with either wheat or rape in the year of survey, although this might again be a coincidental relationship, as the relatively heavy soils tend to be better for these two crops (Coppock, 1964).

In many of the sites, the flora was species-poor, with R. arvensis represented by few individuals, and may represent an impoverished version of the type of community found at Fields 17 & 18 (Fivehead, Somerset) and Field 307 (Broadbalk, Hertfordshire), which are among the most important in the country for the conservation of the arable flora.

The TWINSPAN classification showed no distinction between the species-rich and species-poor sites for R. arvensis. All sites apart from Broadbalk (307) were separated into group 110.

Scandix pecten-veneris shows many similarities to R. arvensis. It has undergone a decline of similar magnitude in recent years, it is mainly found now on heavy soils, and its distribution was connected with a climatic factor, in this case with low winter air temperatures. This climatic association may also be coincidental, as this species now has a distinct centre of distribution in East Suffolk, an area which has relatively cold winters (Coppock, 1963). The association with clay soils contradicts both Long's (1910) and Salisbury's (1961) assertion that this species was more abundant on chalky soils than elsewhere. Brenchley (1920) noted that it seemed to show different soil preferences in different parts of the country, and stated in unpublished notes that it was found on all soils except chalk in Norfolk! This may simply reflect the lack of chalky soils in this county. One of Brenchley's survey sites in Nottinghamshire held S. pecten-veneris, R. arvensis, and C. segetum. Such associations are not known to exist in this country today, and neither S. pecten-veneris or R. arvensis are now found in Nottinghamshire.

Most populations of this species are now known from impoverished communities of weeds in East Anglia, often with large amounts of Alopecurus myosuroides. It was surprising (c.f. R. arvensis) that no correlation was found with the amount of winter cereals in recent crop rotations as in the experiment described in Chapter 7, S. pecten-veneris was found mainly in autumn-sown crops. In this survey, S. pecten-veneris was recorded from spring cereals at four sites, although at all of these, numbers were small, and the plants performed poorly.

Associations with the DECORANA axes emphasised the connection with clay soils, and implied an association with higher pH levels. They also suggested an association with winter rape and wheat, and a negative association with root crops.

This species is still known from a few species-rich sites including two on calcareous silty clay loams in Hampshire (Field 240, Worting, and 221, Longparish). The Longparish farm has what may be the richest weed flora in the country, including Adonis annua and Torilis arvensis. Broadbalk (Field 307), Fields 17-19 (Fivehead), and Field 14 (Burmington, Warwickshire) all have S. pecten-veneris in association with R. arvensis, and may be relics of the type of weed flora that once existed over wider areas of the country in the past.

The majority of sites for S. pecten-veneris were classified, with those for R. arvensis, into TWINSPAN group 11, successive divisions separating the species-poor sites into groups 11001, 11010 and 11110. These groups also contain all of the more degraded sites for Buglossoides arvensis.

Silene noctiflora was associated only with soil texture, preferring lighter soils. Although recorded mainly from sandy loams in East Anglia, it was also present in a number of sites on calcareous loams in the south of England. Salisbury (1961) recorded similar edaphic and regional trends for this species, and Brenchley's notes only mention it from sandy and chalky soils in Norfolk. There was a tendency for S. noctiflora to be found in association with rotations including substantial proportions of spring crops, in particular sugar beet in East Anglia. The connection with cropping was not detected by the analysis of environmental variables, but correlations with the first two DECORANA axes suggest a positive connection with root crops and spring crops in general. Experiment showed that this species only survived to produce fruit in spring barley crops sown in March (Chapter 7).

Silene noctiflora was found with *C. segetum* at a few sites in the north of its range (Fields 109 and 111, Thornton Dale, and 113, Hackness, North Yorkshire; 278, Collyweston, Northampton; 306, Ringstead, Norfolk)(See also *P. hybridum* above). TWINSPAN classification divided the sites fairly evenly between Groups 01 and 10, and only one site was classified into the "heavy soil" group (11).

Factors affecting the "rarity index" of weed communities.

In addition to establishing the connection between whole weed floras and individual species with environmental and agricultural factors, it was also possible to make a connection between these same factors and the conservation value of the sites.

The conservation value of each site was calculated in terms of a "rarity index", using a weighting system similar to that proposed by the N.C.C. (A.Smith, pers.comm.). The regression suggested a connection between increasing rarity index and the presence of calcareous stones in the soil and relatively high levels of summer sunshine. Negative associations with DECORANA axis 1 and 2, suggested further connections between rarity index and high pH, low summer rainfall, few root crops, but a general tendency towards rotations including spring crops and winter barley. Considering all of these factors together, the impression given was that the richest arable weed sites tended to be found on calcareous soils in the south-east of England. This however is a very generalised picture, and several exceptionally rich sites were found in other parts of the country.

The length of time for which the survey fields had been in arable cultivation was not found to have any significant effect on the quality of the weed flora of a field as determined by DECORANA, or on the presence or absence of individual rare species. The connection with the rarity index however, was found to be highly significant, and this is to be expected if the processes of colonisation of new habitats by plants are considered.

The first plants to colonise newly ploughed ground will be the few that are already present in the soil seed-bank, and those which produce large quantities of seed that is dispersed efficiently for relatively long distances (Grime, 1979; Jefferson & Usher, 1985). Secondary colonisation will include the invasion by field-margin ruderals such as Galium aparine and Bromus sterilis, and by the much more gradual spread by other means, of those species that are still abundant in arable land.

The effectiveness of seed dispersal by arable weeds will vary according to arable farming practices. In the past, colonisation by a wide range of species, including many that are now rare, was facilitated by inefficient grain cleaning, and the sowing of grain that was heavily contaminated by weed seed (Wellington, 1959). The decline of a number of species, such as Agrostemma githago, Bromus secalinus and the linicoles have been linked to improvements in seed cleaning (Broad, 1952; Salisbury, 1961; Kornas, 1988). The very spiny seeds of some species such as Torilis arvensis, Ranunculus arvensis and Scandix pecten-veneris, may have been dispersed in large quantity by the armies of labourers who worked at harvest time (Salisbury, 1961), or by the sheep which grazed the stubbles. The practice of taking the harvested crop off the field for threshing in farmyards may also have assisted in the dissemination of weed seed. The greater abundance of many species in the past, and the consequent greater abundance of their seed, will have helped in their colonisation of newly ploughed fields. Cleaner grain since the earlier years of the century has prevented the colonisation of fields in this way by most species, and efforts are also made to prevent transport of weed seed in farm machinery. The increasing rarity of some species has meant that fewer sources of their seed are available.

The majority of the less common species of arable farmland have seeds that are very heavy in relation to their surface area, are not carried by the wind for any appreciable distance, and are thus poor colonists (Salisbury, 1961). They also require a succession of seasons of favourable conditions to enable them to accumulate the soil seed-bank that is neccessary for their long-term survival. It may therefore be expected that rarer species will be more frequent in fields which have had a longer history of arable cultivation. The recently ploughed sites in which rare species were recorded (e.g. 156, Damerham; 119, Romsey), were surrounded by other fields in which the rare species were present in large quantity.

The connection between richness in species with poor dispersal mechanisms, and continuity of habitat through time, has been demonstrated for vascular plants in woodlands (Peterken, 1974), lichens in woodlands (Rose & James, 1974), and grasslands (Wells et al; 1976). Peterken (1977) based some of his case for woodland conservation in Europe on the particular value that attaches to "ancient woodland", and the length of time that successional processes require before a woodland of conservation value is formed. He also suggested that similar principles may apply to other habitats that are now isolated in a matrix of intensively managed farmland. On this basis, a similar case can be made for the conservation of those arable sites that still retain a conservation interest, and which can be demonstrated to have a long history of arable cultivation.

In many ways, this attempt to demonstrate a link between the conservation value of a field and its history was rather unsatisfactory. In the time available, it was only possible to examine the Tithe Commutation Act records for three counties, Hampshire, Wiltshire and East Suffolk, and it would have been desirable to complete this information for all sites surveyed. The species on which the rarity index was based, were selected on the basis of their rarity over the whole country, and bore no relation to their occurence in long-established arable sites, or to their seed dispersal ability. It may be however that their rarity is connected with the ease with which they colonise new sites. A retrospective examination of the species is therefore required, in order to assess their faithfulness to sites of long arable history, and to study the mechanisms by which their seed is spread.

It would also be desirable to calculate rarity weightings for each species on the basis of its abundance in the local flora. For instance, Legousia hybrida is reasonably common on the chalk of south-east England, whereas it is present in only three known localities in Cornwall. This species might reasonably be given a much higher weighting in Cornwall than in Hampshire or Sussex. Peterken (1974) recommended calculating a list of "ancient woodland indicator species" for each 10km. grid square of the country in order to allow for the ecological differences in regional floras.

No attempt was made to pre-select survey sites known to be of recent first cultivation, and the inclusion of such sites in the survey was entirely by chance. This was especially so, as the three counties for which full historical data were collected have had long histories of large scale arable farming, especially in the areas in which the survey fields were located (Stamp, 1962).

This survey also presents some evidence for the degradation of Britain's weed floras in recent years. As described above, a number of species, particularly those associated with winter cereals on heavier soils, such as B. arvensis, R. arvensis and S. pecten-veneris, are now to be found not only in remnants of species-rich communities, but also as relic populations in highly impoverished ones. The impoverished communities also frequently contain such species as Bromus sterilis, B. commutatus, Alopecurus myosuroides, and Galium aparine, that are known to have increased in recent years (Chancellor & Froud-Williams, 1986) in connection with changes in farming practice (Chapter 1).

Although the results discussed above have allowed some important conclusions to be made about the ecology and distribution of rare arable weed species and communities, it is not yet possible to say with precision why a rare species is present in one field, but is absent from the superficially similar field adjacent to it. It is obvious that much further work on both community and species dynamics is essential if greater understanding is to be acheived.

CHAPTER 3.

THE DISTRIBUTION OF WEED SEED BANKS IN RELATION TO DISTANCE FROM THE FIELD EDGE.

INTRODUCTION.

Casual observations have indicated that the edges and corners of arable fields tend to be the areas of greatest botanical interest, and surveys have supported this view (Marshall 1985 & 1989; Hald *et al*; 1988). Although much of the evidence refers to relatively common species, it is possible that rarer species also share this type of distribution.

The first areas of fields to be considered for alternative uses are often field margins, and a range of possible alternative uses and managements have been proposed in recent years. If populations of rare species are restricted to the edges and corners of fields, the effects of such management practices may prove detrimental to their survival.

The aim of this survey was to examine the relationship between the size and composition of arable weed seed-banks in fields known to contain uncommon species, and distance from the field margin, as a basis for the assessment of the impact of field margin management on populations of rare and uncommon weed species.

A number of problems are inherent in the estimation of the true population size of an arable weed with an annual life-cycle. In a normal farming situation, most weed seedlings will be eliminated by applications of herbicide, leaving only plants of those species resistant to the herbicide used, those which miss herbicide application by chance, and those which germinate after spraying. Any survey must therefore be conducted in the short time available between the germination of weed seedlings after the drilling of the crop and herbicide application. As a substantial proportion of the seed production each year is buried by ploughing, and because the seeds of most species can survive for considerable periods without germination, a large resource of dormant seed can build up in the soil seed-bank (Roberts, 1981). An assessment of seedling emergence in any one year, is consequently a sample of only one cross-section of this seed-bank, and will be strongly influenced by the interaction of cultivation time with the germination periodicity of the individual species present, weather conditions, type and efficiency of cultivation, and seed production in previous years (Roberts & Ricketts, 1979; Froud-Williams, Chancellor & Drennan, 1984). In order to obtain an accurate picture of annual weed populations in cultivated land, it is therefore necessary to assess the soil seed-bank, in addition to counting the emergence of seedlings (Roberts & Ricketts, 1979; Debaeke, 1988).

The theory and methodology of seed-bank sampling and estimation has been extensively researched (Brenchley & Warington, 1930; Roberts, 1981), and estimates have been made of the number of soil cores required to give a satisfactory estimate of the seed-bank size and composition (Barralis et al; 1986). The number of seeds in soil samples can be determined in two ways: by physical methods of sorting and visual examination (Roberts & Ricketts, 1979; Warwick, 1984; Debaeke, 1988; Chauvel et al; 1989), or by allowing viable seed to germinate from the collected soil (Brenchley & Warington, 1930; Roberts, 1962; Thompson & Grime, 1979; Bigwood & Inouye, 1988). These methods were compared by Roberts (1981) and by Ball and Miller (1989).

In addition to determining the distribution of weed with relation to the distance from the crop edge, this survey was also intended to provide information about the relationship between the buried seed-bank and the seedlings that emerge from it.

METHODS.

In early April 1988, seven fields that had been drilled with a spring barley crop, but which had not yet received an application of herbicide were chosen. These fields were located on four farms in Hampshire, and were all known to contain populations of relatively uncommon weed species. The soils at all sites were chalky, with textures ranging from silty loams to silty clay loams. The recent cropping history of these fields is presented in Table 16.

Table 16. Crops grown in fields included in the survey of weed distribution in relation to distance from the field edge.

Year.	1988	1987	1986	1985	1984	1983
Longparish a.	sb	wb	sb	ww	not known.	
Longparish b.	sb	sb	ww	rg	rg	sb
Micheldever a.	sb	sb	sb	ww	ww	osr
Micheldever b.	sb	sb	sb	ww	ww	osr
Battledown N.	sb	sb	sb	sb	ww	rg
Battledown S.	sb	sb	sb	ww	rg	rg
S.Allenford.	sb	wb	ww	ww	rg	rg

sb = spring barley, wb = winter barley, ww = winter wheat, rg = rye-grass, osr = winter oil-seed rape.

A corner of each field was chosen, attempting to ensure that there were no obvious localised effects due to shading and aspect that might exert an influence over the distribution of the weed seed-bank. A grid of transects was laid out, with sampling points on each transect at the following distances from the crop edge (in metres); -0.5, 0, 1, 2, 4, 8, 16, 32, 64, and 128. (Figure 6). At each sampling point, all weed seedlings in a $0.25m^2$ quadrat were identified and counted. In addition, a soil core was taken, using a cylindrical steel tube of radius 3.5 cm (giving a cross-sectional area of 3.85×10^{-3} m^2), to a depth of 20cm., the approximate depth of ploughing. At each sampling distance, a total of 56 cores were taken. The number of cores and the cross-sectional area of the soil core compare with 12 cores of cross-sectional area of

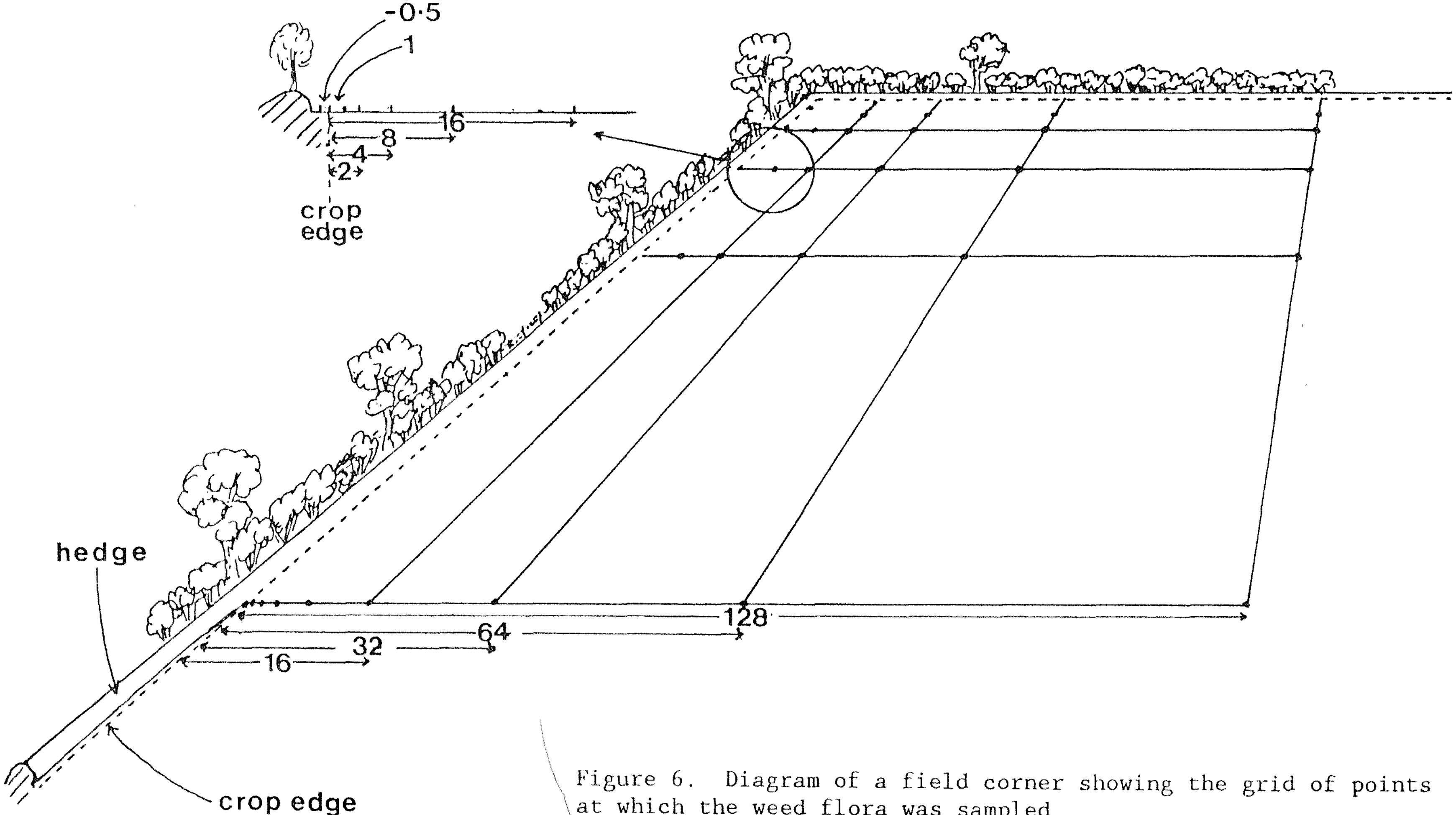


Figure 6. Diagram of a field corner showing the grid of points at which the weed flora was sampled.

$7.74 \times 10^{-3}\ m^2$ per plot sampled by Brenchley and Warington (1930), 200 cores of $4.9 \times 10^{-4}\ m^2$ by Marshall (1989), and an optimum number of 100 cores of $1.66 \times 10^{-3} m^2$ which was proposed by Barralis et al (1986).

The direction of crop drilling in the main part of the field was recorded, and an attempt was made to obtain information on the direction of ploughing and other farming operations, but these proved to be too complex and variable from year to year to be interpreted. In the analysis, the X - axis was defined as being parallel to the drilling direction, and the Y - axis as being perpendicular to it (Figure 7)

Each soil core was broken down, and placed in a separate tray. The trays were kept in an unheated greenhouse, and were watered as necessary. Each tray was stirred at approximately four month intervals, and emerging seedlings counted. The trays were moved around the greenhouse occasionally, in order to minimise any effects of non-uniform conditions. Seedling emergence was monitored for two years (Roberts, 1958).

RESULTS.

74 species were recorded during the field survey, and 65 from the seed-bank soil samples. Due to difficulties in identification of very small seedlings of some species, (Veronica polita, V. arvensis and V. persica; Anthemis cotula and Tripleurospermum inodorum; Papaver hybridum and P. argemone) these were considered as aggregates. The weed

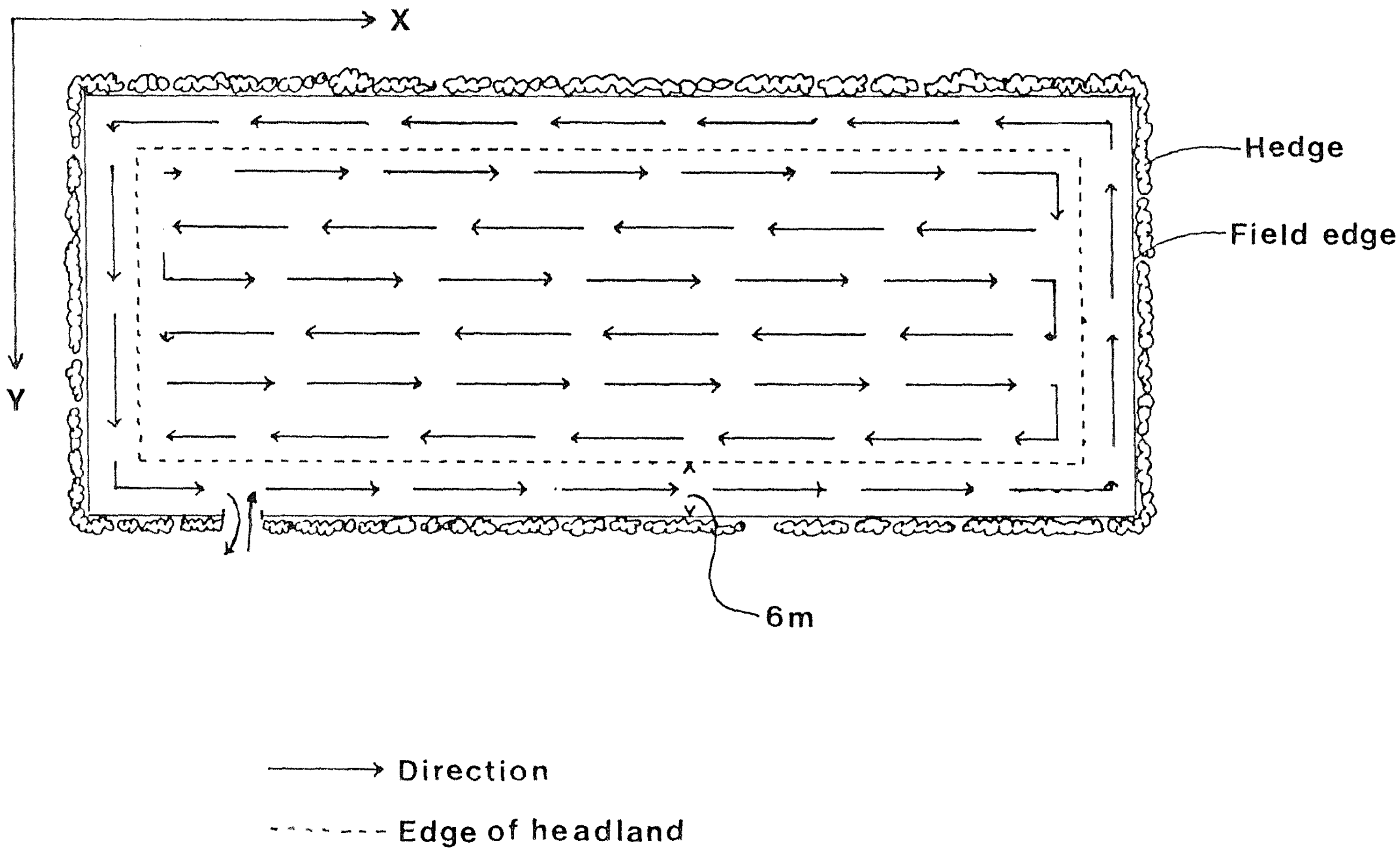


Figure 7. Diagram showing the typical pattern of operations carried out by farm machinery during cultivations, drilling and harvest. X and Y are axes along which the distances were measured at which the weed flora was sampled.

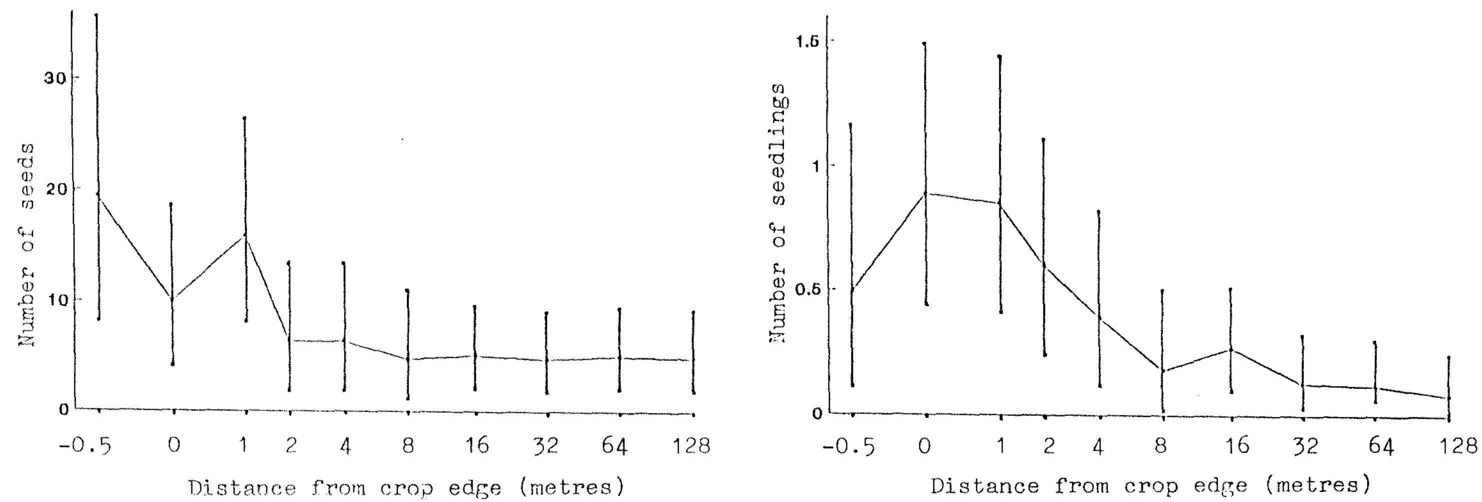
communities in the different fields showed considerable similarities to each other, and were characteristic of sites with a long history of cultivation for cereals on chalky soils in central southern England (Silverside, 1977).

The total number of seedlings and species recorded in both the field survey of seedlings and the soil seed-bank survey, were analysed with respect to distance from the crop edge along the X and Y axes of the field corner using analysis of variance by multiple regression. The patterns of distribution shown by individual species were also investigated. Nine species, *P. hybridum* (including *P. argemone*), *Viola arvensis*, *P. rhoeas*, *A. cotula* (including *T. inodorum*), *Legousia hybrida*, *Lapsana communis*, *Aethusa cynapium*, *Polygonum aviculare*, and *Valerianella dentata*, were chosen to represent the species recorded in the field survey of seedlings, and five, *P. hybridum*, *V. arvensis*, *P. rhoeas*, *A. cotula* and *L. hybrida* from the species recorded from the seed-bank (Figure 8). *V. arvensis*, *P. rhoeas*, *A. cotula*/*T. inodorum*, *L. hybrida*, and *P. aviculare* were selected because of their presence in fairly large numbers in each of the fields. *P. hybridum* and *V. dentata* were the most frequent of the uncommon species recorded, and *L. communis* and *A. cynapium* were chosen as common species that were not ubiquitous, but were still present in numbers that permitted analysis. It was hoped that these species would demonstrate a representative range of

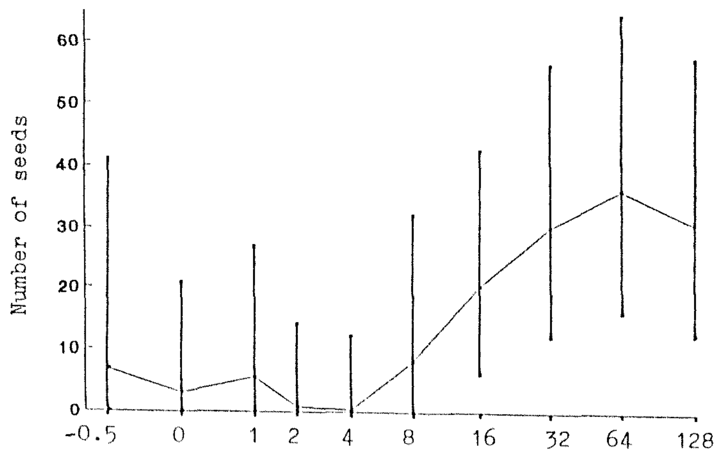
Figure 8 . Distribution patterns of arable weeds in relation to distance from the crop edge. Mean numbers of seed from the seed-bank survey and mean numbers of seedlings from the field survey are presented with 95% confidence limits, and apply to a soil surface area of $0.25m^2$.

a. Papaver hybridum. Seed-bank

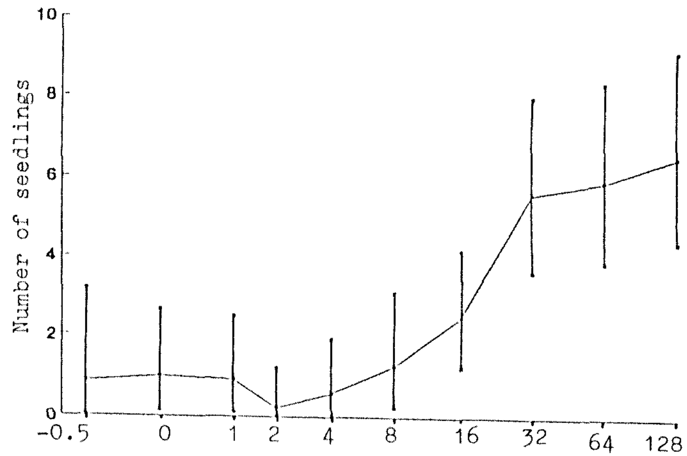
b. Papaver hybridum. Field survey



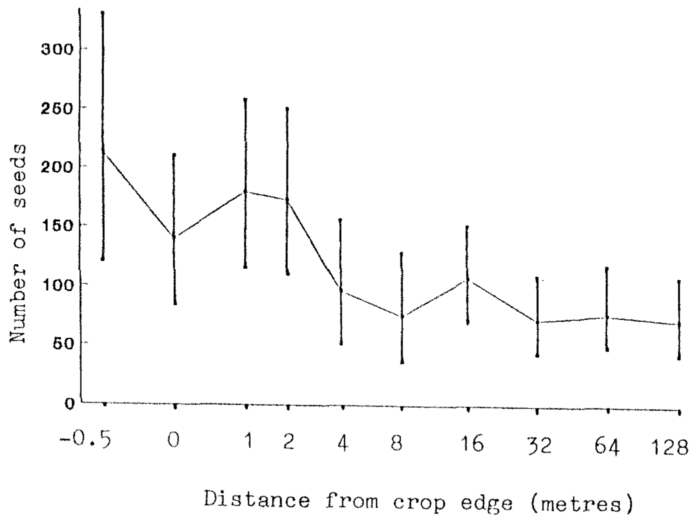
c. *Viola arvensis*. Seed bank



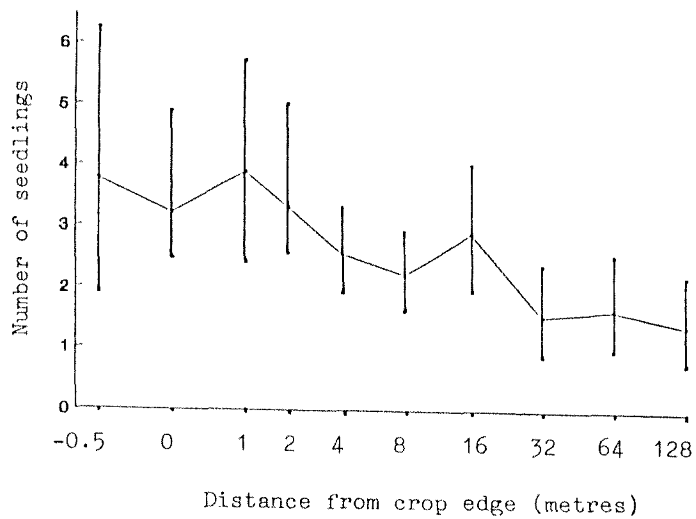
d. *Viola arvensis*. Field survey



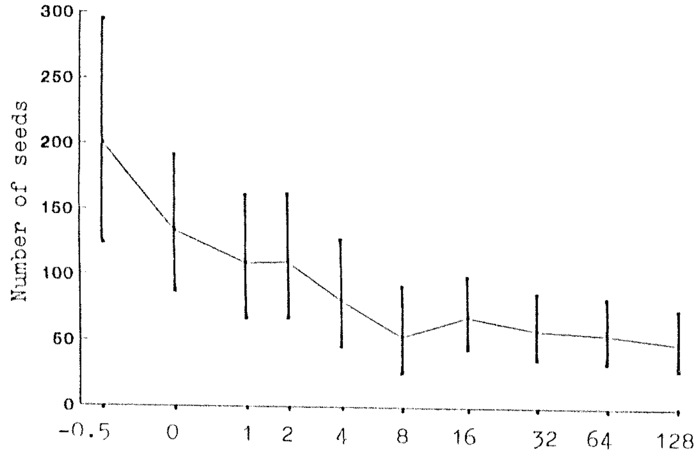
e. *Papaver rhoeas*. Seed bank



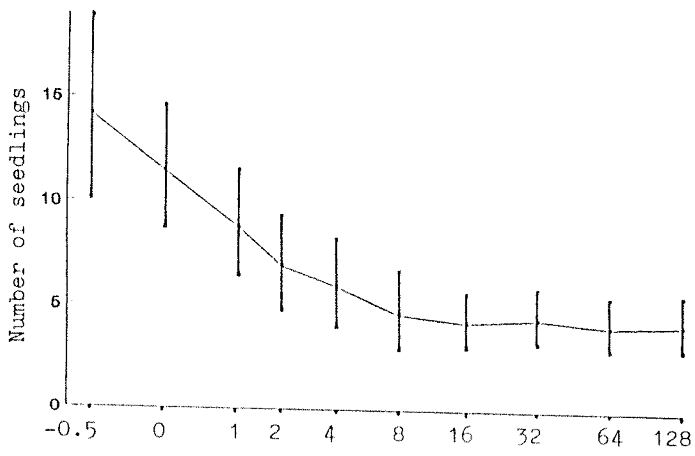
f. *Papaver rhoeas*. Field survey



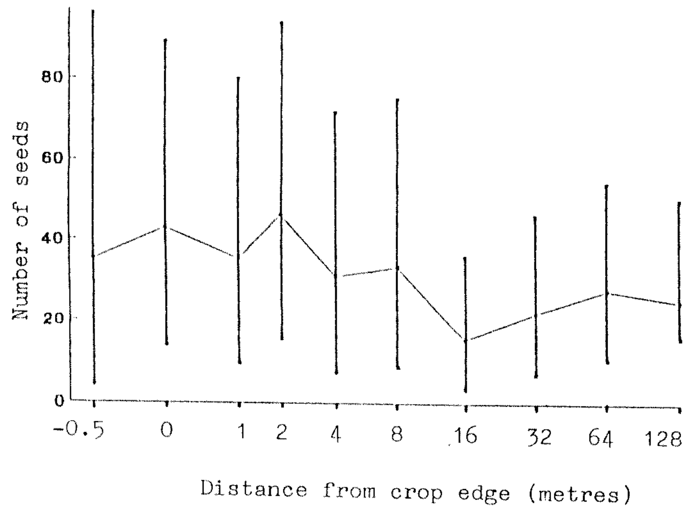
g. Anthemis cotula/Tripleurospermum inodorum. Seed bank



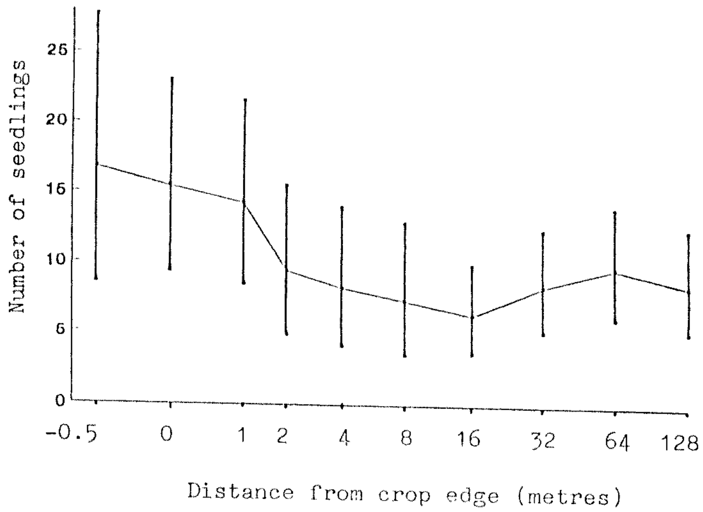
h. Anthemis cotula/Tripleurospermum inodorum Field survey



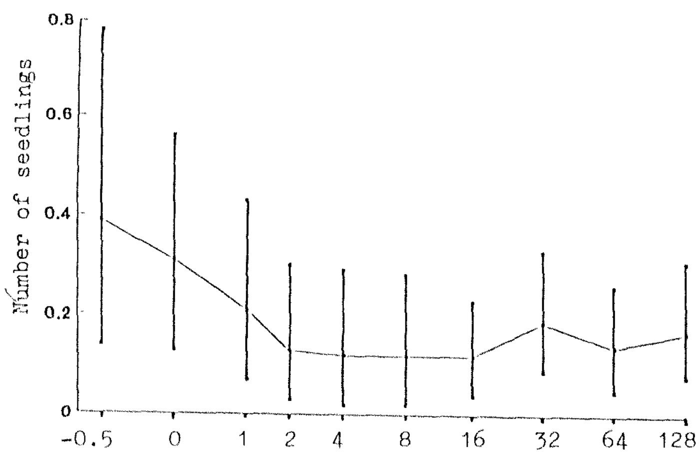
i. Legousia hybrida. Seed bank



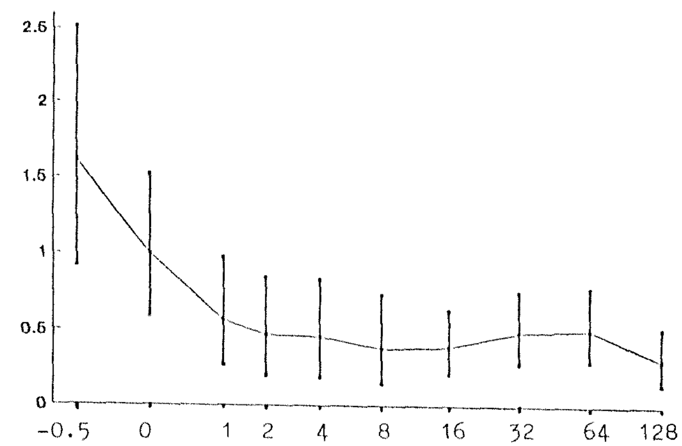
j. Legousia hybrida. Field survey



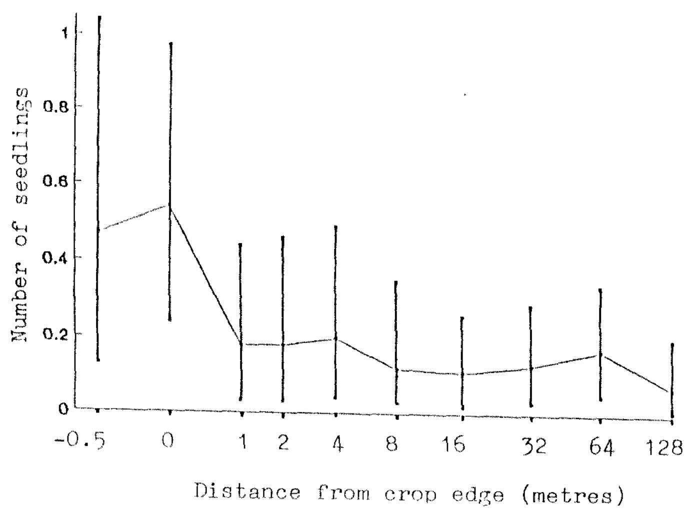
k. Aethusa cynapium. Field survey



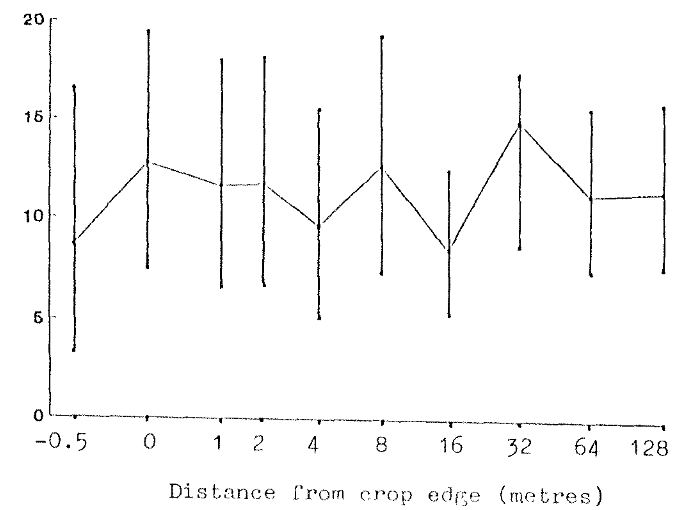
l. Lapsana communis. Field survey



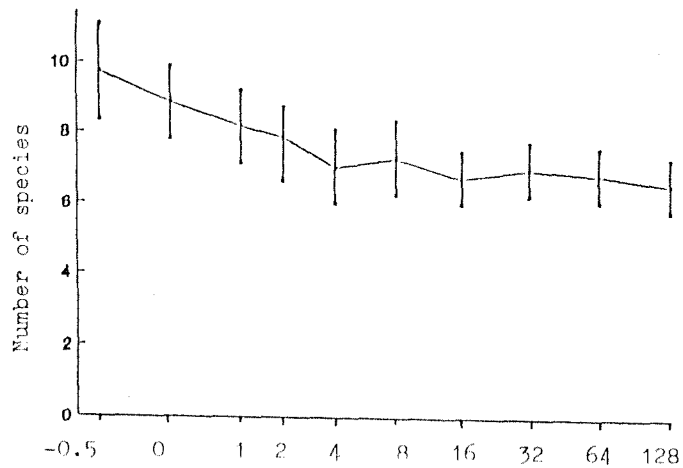
m. Valerianella dentata. Field survey



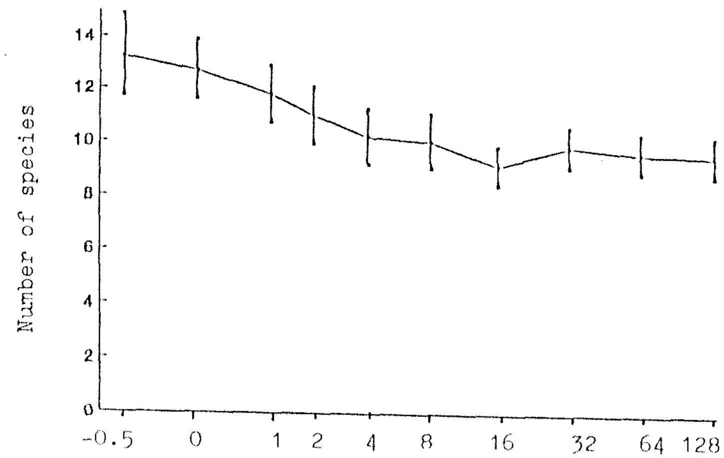
n. Polygonum aviculare. Field survey



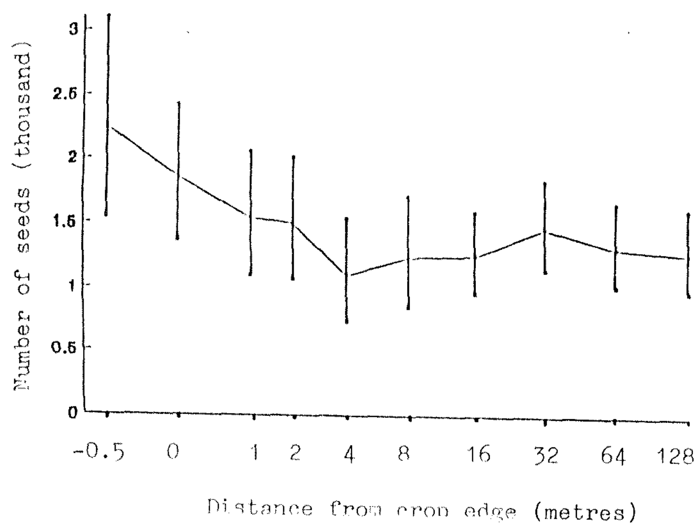
o. Species richness. Seed bank



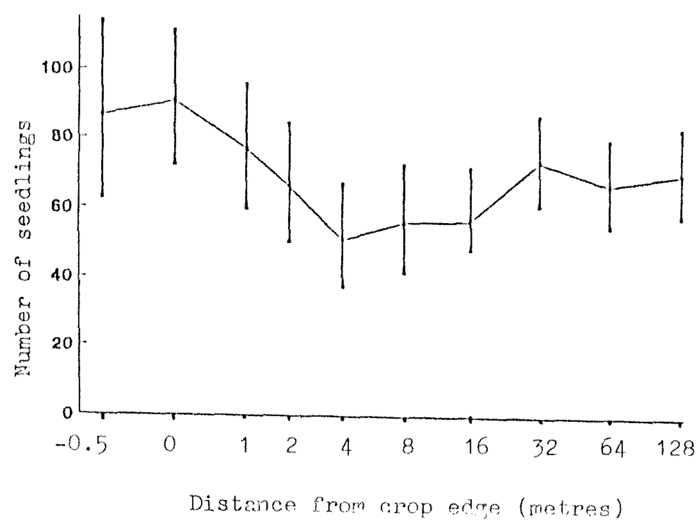
p. Species richness. Field survey



q. Total number of seedlings. Seed bank



r. Total number of seedlings. Field survey



distributions with respect to distance from the crop edge.

Grass species were omitted from the analysis due to difficulties with their identification as seedlings in the field. Species with wind disseminated seed and those which regenerate from underground perennating organs do not form seed-banks which can be sampled using the methods described. These were also omitted from the analysis.

The different effects of each axis on the weed frequencies were compared for the field survey of seedlings, but were only found to be significantly different from each other in the case of *P. aviculare*, a species for which there was no significant change in numbers with respect to distance from the crop edge. For simplicity therefore, the weed populations were assumed to behave in a similar way in relation to both X and Y axes.

The numbers of seedlings and species recorded in the seven fields were also compared. In the cases of all species, the variation between populations in different fields was highly significant ($p<0.001$).

All of the individual species from the field survey for which results were analysed apart from *V. arvensis* and *P. aviculare* were significantly more abundant within four metres of the crop edge. Maximum numbers of *A. cotula*, *L. hybrida*, *L. communis*, and *A. cynapium* were recorded outside the crop itself (sampling point, -0.5m). Numbers of *P. hybridum*, *L. communis* and *V. dentata* all declined to less than 20% of their crop edge maximum, at the 128m sampling point (Figure 8).

Four other rare species, *Buglossoides arvensis*, *Scandix pecten-veneris*, *Adonis annua* and *Galeopsis angustifolia*, were also recorded during the survey, although not present in sufficient numbers for analysis. All records for the first three of these species were all made within two metres of the crop edge. *G. angustifolia* however, was only found in the 32m and 128m samples.

The two species which did not decline significantly with increasing distance from the crop edge were *V. arvensis* and *P. aviculare*. *V. arvensis* behaved in a strikingly different way to most of the other species examined, reaching a maximum at 128 metres from the crop edge of almost 30 times that of the minimum number recorded at 2 metres from the crop edge (Figure 8).

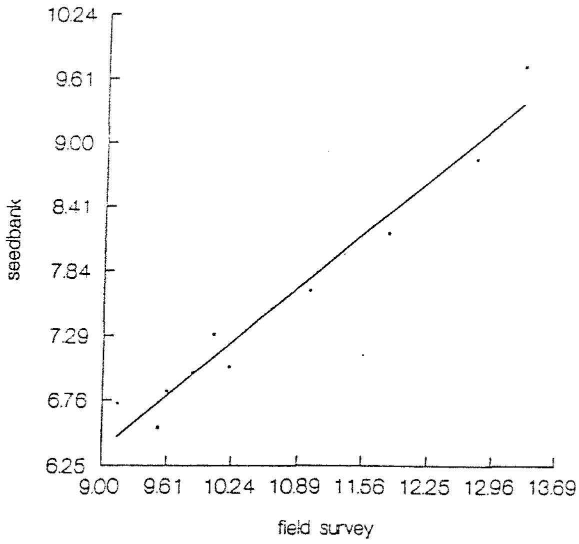
P.aviculare showed no significant trend (Figure 8).

The total number of seedlings of all species recorded was greatest between -0.5 and one metre from the crop edge, with a minimum number occurring at between four and sixteen metres, increasing slightly again to a secondary maximum, as such abundant species as *V. arvensis* became more frequent towards the field middle. The species richness of the weed flora also decreased significantly with increasing distance from the crop edge, but did not become significantly less after a distance of four metres.

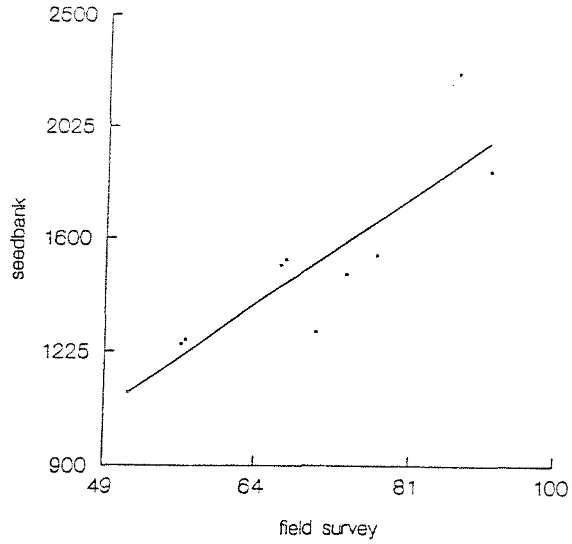
The results from the field survey of seedlings were compared by regression analysis with results from the soil

Figure 9 . Relationships between the numbers of seed present in the seed-bank, and the numbers of seedlings recorded in the field survey. Mean results at each sampling distance averaged over seven fields. Results apply to numbers of seeds and seedlings per $0.25m^2$ of soil surface area. Analysis performed on square-root transformed data.

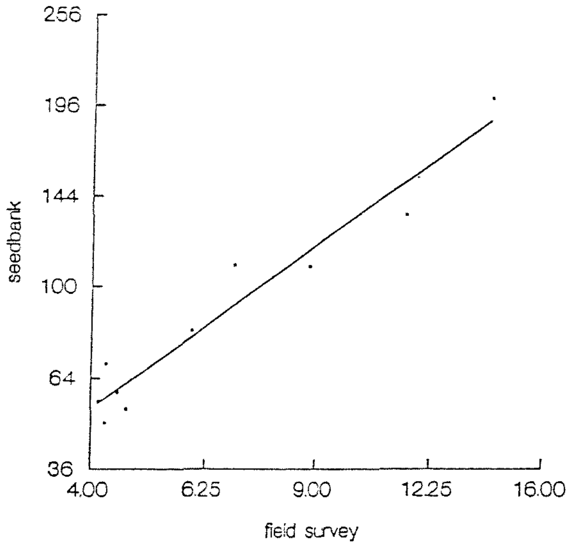
a. Number of species
Seed-bank = 0.0046 + 0.51 x field survey - 0.098 x field survey $^{0.5}$
$r_8^2 = 0.96$, $P<0.001$



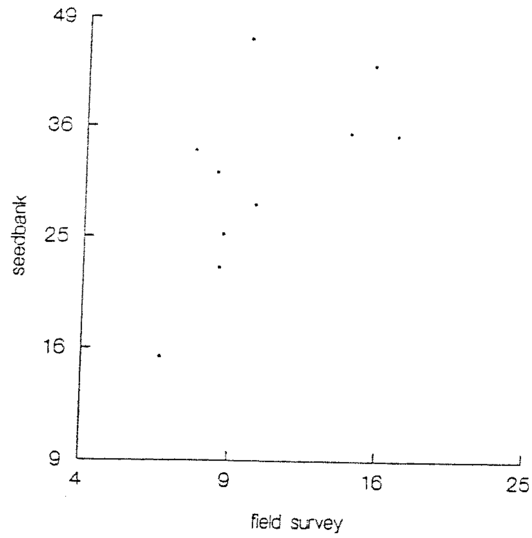
b. Number of seedlings
Seed-bank = 2.62 + 17.5 x field survey + 13.55x field survey $^{0.5}$
$r_8^2 = 0.75$, $P<0.001$



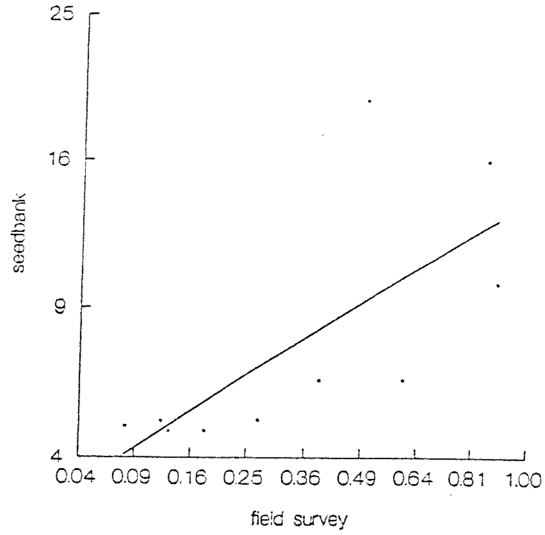
c. <u>*Anthemis cotula/Tripleurospermum inodorum*</u>
Seed-bank = 0.02 + 12.91 x field survey + 1.08 x field survey $^{0.5}$
$r_8^2 = 0.93$, $P<0.001$



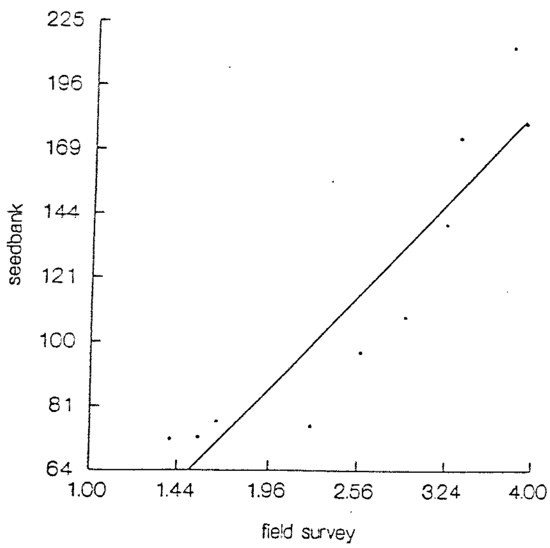
d. Legousia hybrida
Regression not significant



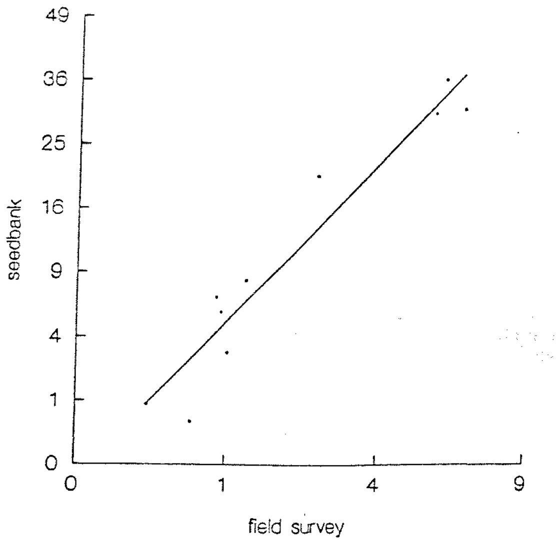
e. Papaver hybridum
Seed-bank = 1.85 + 6.47 x field survey + 5.66 x field survey $^{0.5}$
$r_8^2 = 0.43$, $P<0.025$



f. Papaver rhoeas
Seed-bank = 0.98 + 59.73 x field survey - 14.48 field survey $^{0.5}$
$r_8^2 = 0.83$, $P<0.001$



g. Viola arvensis
Seed-bank = 0.063 + 6.2 x field survey - 1.25 x field survey $^{0.5}$
$r_8^2 = 0.91$, $P<0.001$



cores for five individual species, the total number of seedlings and the number of species. Two regression analyses were carried out, the first using both the actual numbers of seedlings and seed recorded from each sample, and the second using the mean numbers of seed and seedlings recorded at each sampling point.

Results from the seed-bank survey were very similar to those from the field survey. Patterns of distribution shown by individual species are presented in Figure 9, as is the distribution of the total number of seedlings and the number of species. The only noticable differences between the two surveys were noted for L. hybrida, for which no significant decrease with increasing distance from the crop edge was observed in the seed-bank survey. The species-richness also decreased significantly with increasing distance from the crop edge, although there tended to be about three species fewer in the seed-bank at each survey point than were recorded in the field survey.

The number of seedlings recorded in each $0.25m^2$ quadrat was compared with the numbers of seedlings emerging from its corresponding soil core (Table 17a). For the total number of seedlings recorded, the species richness of each sample, and all five individual species, the results from the field survey were found to be closely related to those from the soil samples. In only one case however (A. cotula/T. inodorum, $r^2 = 0.59$), did the regression account for more than half of the variation in the data (Table 17a).

Table 17. Regression of results from the field survey of seedlings against results from the seed-bank determination.
SB = No. of seed in seed-bank.
SL = No. of seedlings per quadrat.
Probabilities of significance of regression: P<0.001 ***
P<0.05 *; N.S. not significant.

a. Numbers per individual sample.

Papaver hybridum.	$SB = 0.17 + 0.83\ SL^{0.5} + 1.07\ SL$ *** $r^2_{398} = 0.059$; Std. error = 2.63
Viola arvensis.	$SB = 1.29 + 4.01\ SL^{0.5} + 3.12\ SL$ *** $r^2_{478} = 0.338$; Std. error = 6.18
Papaver rhoeas.	$SB = 5.35 + 16.06\ SL^{0.5} + 12.04\ SL$ *** $r^2_{478} = 0.358$; Std. error = 6.80
Anthemis cotula/ Tripleurospermum inodorum	$SB = 4.97 + 25.2\ SL^{0.5} + 31.9\ SL$ *** $r^2_{478} = 0.59$; Std.error = 1.02
Legousia hybrida.	$SB = 2.75 + 5.93\ SL^{0.5} + 3.2\ SL$ *** $r^2_{318} = 0.2$; Std.error = 7.17
Total seedlings.	$SB = 181.44 + 81.9\ SL^{0.5} + 3.24\ SL$ *** $r^2_{478} = 0.21$; Std error = 15.25
Number of species.	$SB = 3.54 + 1.41\ SL^{0.5} + 0.14\ SL$ *** $r^2_{478} = 0.11$; Std error = 2.74

b. Mean numbers per sampling point.

Papaver hybridum	$SB = 1.85 + 6.47\ SL^{0.5} + 5.66\ SL$ * $r^2_8 = 0.43$; Std. error = 0.62
Viola arvensis	$SB = 0.063 + 6.2\ SL - 1.25\ SL^{0.5}$ *** $r^2_8 = 0.91$; Std. error = 0.59
Papaver rhoeas	$SB = 0.98 + 53.7\ SL - 14.49\ SL^{0.5}$ *** $r^2_8 = 0.83$; Std. error = 0.95
Anthemis cotula/ Tripleurospermum inodorum	$SB = 0.02 + 12.91\ SL + 1.08\ SL^{0.5}$ *** $r^2_8 = 0.93$; Std. error = 0.60
Legousia hybrida	Not significant.
Total seedlings.	$SB = 2.62 + 17.5\ SL - 13.55^{0.5}$ *** $r^2_8 = 0.75$; Std. error = 2.13
Number of species.	$SB = 0.0046 + 0.51\ SL - 0.098\ SL^{0.5}$ *** $r^2_8 = 0.96$; Std. error = 0.22

When the mean results from each sampling point were compared however, the proposed models fitted the data much better in all cases apart from Legousia hybrida for which the regression was not significant. The regressions for V. arvensis, P. rhoeas, A. cotula/T. inodorum, total seedling number and number of species, accounted for at least 75% of the variation in the data (Table 17b).

DISCUSSION.

This survey demonstrated that the observed concentration of weed vegetation at the margin of arable fields is not merely an illusion created by the effects of differential herbicide applications and crop competition in the year of observation, but at least in the fields surveyed, is an accurate reflection of the composition and size of the weed seed-bank. Not only did the numbers of seven out of the nine individual species studied decline in relation to increasing distance from the field edge, but so did the species richness of the vegetation. Despite the increase of at least one common species (Viola arvensis), the total number of seedlings was also found to decrease.

A similar survey was carried out during April 1984, during which plant numbers were counted at distances of 2.5, 5, 10, 15, 20 and 50 metres into the crop (Marshall, 1989). Results for Lapsana communis, Tripleurospermum inodorum, Polygonum aviculare, Papaver rhoeas and V. arvensis corresponded very closely with those from the survey described here. Results obtained for the distributions of *T. inodorum*, *V. arvensis* and *P. rhoeas* from set-aside arable fields also showed patterns similar to those recorded here (C.Bealey, unpublished data).

It would appear that not only are some species of arable weed becoming restricted in terms of the numbers of fields in which they occur, but also in terms of their distributions within those fields.

Comparisons of results from seed-bank determination and field surveys of seedlings are of considerable interest in relation to understanding the relationships between the seed-bank and the flora that develops from it. The results from both methods of survey were very similar. The differences between the numbers of species recorded in the field survey and the seed-bank survey may be due largely to the different surface areas of soil to which the two surveys apply. The relationship between sample area and species richness is well known (Kershaw & Looney, 1988). It was also possible that some of the species recorded in the field did not derive from the seed-bank, and may have come from wind dispersed seed (e.g. *Senecio vulgaris*, *Sonchus oleraceus*) or from underground perennating organs (e.g. *Elymus repens*, *Tussilago farfara*), and would therefore not have been recorded with accuracy in the seed-bank survey.

A study of the two regression analyses supported the hypothesis that very close relationships exist between seed-bank and germinated vegetation at least in the fields surveyed. The data for individual seedling counts were much less well correlated with their corresponding individual estimates of the seed-bank than were the mean numbers of seedlings with the mean estimated numbers of seeds in the seed-bank at each sampling distance. The differences between the two regressions illustrate the patchiness of the seed-bank distribution in the soil, both vertically and horizontally (Soriano et al; 1967; Bigwood & Inouye, 1988; Chauvel et al; 1989). Although the overall trends in the distributions of seed-banks were well demonstrated by the surveys described here, it is probable that the pattern of variation of seed-banks may show considerable fluctuations over small distances, as a consequence of the non-uniform distribution of seeding plants in previous seasons. It has been shown that the estimation of seed-bank size and composition becomes more accurate as the number of soil samples increases (Roberts, 1981; Barralis et al; 1986). It has become generally accepted that when attempting to estimate the size and composition of the seed-bank, it is better to take a large number of small samples than a small number of large ones, and such methods have been followed in many previous surveys (Brenchley & Warington, 1930; Roberts & Ricketts, 1979; Bigwood & Inouye, 1988; Debaeke, 1988; Marshall, 1989). Barralis et al (1986) calculated that 100 soil cores are necessary in order to achieve a precision of between 20% and 70%.

The number of seedlings recorded in the field was found to be a suitable and fairly accurate predictor of the size of the seed-bank given sufficient replicates, at least for the more abundant species. If the amount of time and labour involved in the collection of soil samples are considered, the ability to predict the content of the seed-bank from the above-ground weed flora would be an extremely useful point to remember when considering further surveys. Additional work is required to determine the relationships between the seed-bank and the seedling flora of fields subject to more varied crop rotation and with different weed floras. Some other attempts have been made to correlate the numbers of germinating seedlings in the field with the content of the seed-bank. Debaeke (1988) calculated this relationship for V. arvensis (Seedbank = 1.7 + 7.246 Number of seedlings), and P. rhoeas (Seedbank = 0.9 + 32.258 Number of seedlings), among other species. These results are extremely close to those obtained in the survey described here.

No attempt was made here to measure any environmental variable with respect to distance from the field edge, and so any attempt to account for the observed distributional trends must be rather conjectural.

Evidence indicates that crop yields are frequently lower near field edges (Boatman & Sotherton, 1988; Tucker et al; 1988), and it is probable that farming practices such as herbicide and fertiliser application are less efficient in these areas. Farming operations on the field headland differ considerably from those practiced on the rest of the field (Fielder, 1987), and typical directions of cultivations, drilling and spraying are illustrated in Figure 7. In addition to being less efficient, these operations involve considerable turning of farm machinery on the headland, causing soil compaction and damage to the growing crop. As an additional consequence of the use of the headland area for turning farm machinery, the inner strip of the headland, and the outer strip of the main part of the field may frequently receive a double application of herbicide, fertiliser, and cereal seed.

The field headland is also treated differently at harvest time. Similar patterns to those illustrated in Figure 7 are followed by the combine harvester. The combine will harvest a strip of the field on each run, but will deposit the straw and weeds in a narrow band behind it in the middle of each swathe. This will tend to have a concentrating effect on the distribution of weed seed, and may result in the formation of "bands" of weeds corresponding to the direction followed by the combine at the previous harvest. It is unlikely however that this will have much effect on the weed distributions detectable by the rather coarse-scale survey methods used here.

Stubble burning, where practiced, would have an additional effect on weed distributions. Burning is known to have a considerable impact on weed populations (Froud-

Williams, 1987), but has usually only been carried out on the central parts of fields, the headlands being cleared of straw and ploughed as firebreaks. As far as is known, stubble burning has not been carried out on the surveyed fields in recent years.

It is possible that the effects of crop competition may thus increase across the field headland, creating opportunities for species present in the seed-bank to flower and seed well in proximity to the field edge, and progressively less well with increasing distance. An area of poorest weed performance could be created at the inner edge of the headland, as a result of double applications of crop seed and chemicals as described above. The accumulated effect over many years would be to create a gradient of seed abundance in the soil in relation to distance from the less-intensively farmed field edge.

If as suggested above, the distribution patterns of weeds in relation to distance from the field edge are connected with crop competitiveness and the efficiency of herbicide application, then it may be predicted that those species which are less competitive in relation to the crop, and more susceptible to herbicides will show a more sharply decreasing gradient of abundance, and vice-versa. The two species which were not shown to decrease with distance (*P. aviculare* and *V. arvensis*) are among the most abundant dicotyledonous weeds of spring cereals in modern farming (Boatman & Wilson, 1988). These species are both relatively resistant to many of the herbicides most commonly used in spring cereals, and observations have indicated that both of these species can take advantage of the reduced competition from associated weed species after herbicides have been applied (N.D. Boatman, pers. comm.). P. hybridum was found to be very poorly competitive in relation to cereal crops grown at fertiliser levels normally used in modern farming (Chapter 6), and both P. rhoeas and T. inodorum were found at reduced numbers at high fertiliser levels, although results were not significant. Papaver spp., and "mayweed" species are relatively susceptible to many commonly used herbicides (Flint, 1987; Chapter 5).

The lower abundance of some species at the -0.5m sampling point, may be due to the relatively irregular cultivation of this extreme edge of the field, thereby creating an intermediate zone where the soil is disturbed only occasionally. In some of the fields surveyed, this area is also sprayed with a residual broad-spectrum herbicide to prevent the possible ingress of hedgerow weed species into the field. This effectively prevents the growth of weeds in this area. In some cases, this zone can be of immense importance for pauciennial species, and non-competitive annuals of atypical periodicity such as Ajuga chamaepitys and Teucrium botrys.

As many aspects of farming practice have increased considerably in their intensity in recent decades, it is possible that the restriction of species to field-edge refugia is an accelerating process that will have the most pronounced effect on those species least well adapted to modern methods. The continued existence of rare species in the fields surveyed may indicate less intensive management regimes than those commonly practised in modern farming. It is possible that the rarer species will show an even more marked restriction to field edges at sites where more intensive agricultural management is practised.

Several proposals have been recently made for the alternative use of arable field margins, either for environmental benefits, or to reduce cereal overproduction. These include the Game Conservancy's "Conservation Headland", and some of the prescriptions included as "set-aside" and "environmentally sensitive area" options. All of these practices will have an effect on populations of annual species in field margins, although their impact requires assessment in the field.

CHAPTER 4.

THE EFFECTS OF HERBICIDES ON POPULATIONS OF ANNUAL WEEDS.

INTRODUCTION.

Until the 1950s, the control of weeds involved a mixture of techniques such as seed cleaning, mechanical cultivation, crop rotation and hand weeding (Evans, 1963; Lockhart *et al*; 1990). With the development of effective chemical agents, some of these methods have become less important, although organic farming continues to rely on non-chemical techniques for weed-control (Widdowson, 1987).

The first chemical agent used for weed control in cereals was copper sulphate, which was developed in France in 1896, for control of *Sinapis arvensis* (Lockhart *et al*; 1990). Since then, the number of chemicals used in agriculture has increased dramatically. Inorganic molecules such as sulphuric acid, ferrous sulphate and sodium chlorate were the next to be introduced, and the first organic herbicide, DNOC, was patented in 1932. DNOC is no longer marketed in Britain due to its high toxicity to non-target organisms. Other early herbicides such as MCPA and mecoprop (Table 18) have maintained their popularity to the present day. In 1956, eight compounds were approved for use as herbicides, by 1979, this had increased to 85 (Makepeace, 1980), and currently the total stands at 93 (Lockhart *et al*; 1990).

Economics have dictated that most herbicide testing has been carried out on common species, or those that have

Table 18. Dates of introduction of herbicides used in the herbicide screening experiment. Data from Lockhart, Samuel & Greaves (1990).

Chemical.	Date of introduction.
MCPA	1945
Mecoprop	1957
Chlortoluron	1971
Ioxynil + Bromoxynil.	1970/1971

posed agronomic problems, and consequently, little is known about the toxicity of herbicides to the majority of the less common weed species. Of the species considered for detailed study in this project, only Chrysanthemum segetum and to a lesser extent Buglossoides arvensis, can still be locally regarded as problems to the cereal grower, although Scandix pecten-veneris and Ranunculus arvensis were still common until the late 1950s. Some information about these four species is available, but data on other rare species are very limited (Flint, 1987). Table 19 summarises the known information for the species included in this study.

Since the introduction of "modern" herbicides in 1943, the areas of crops sprayed have increased dramatically (Table 20). Some crops receive an average of more than two herbicidal compounds each year, and it is probable that almost all arable land in Britain has received at least one application of herbicide in its history. The types of herbicides used have changed as compounds have been developed. The percentage of cereal area sprayed with the herbicides tested in this experiment is shown in Table 21.

Table 19. Responses of weed species to some commonly used herbicides. Data from Flint (1987), except for * from Woodford & Evans (1963), ** from Boatman, Freeman & Green (1988).
R Resistant, S Susceptible, MR Moderately resistant, MS Moderately susceptible; figures refer to number of expanded true leaves per plant up to which the plant is susceptible; heights refer to maximum height of plants that are susceptible.
Species: Chrys.seg. *Chrysanthemum segetum*; Bugl.arve. *Buglossoides arvense*; Ran.arve. *Ranunculus arvensis*; Scan.p-v. *Scandix pecten-veneris*; Sil.noct. *Silene noctiflora*; Pap.rho. *Papaver rhoeas*; Viola arv. *Viola arvensis*.

Species. / Herbicide.	Chrys. seg.	Bugl. arve.	Ran. arve.	Scan. p-v.	Sil. noct.	Pap. rho.	Viola arve.
MCPA	R	MR	S	S	R*	S	MR
Mecoprop	R	MR	S	MR	-	2-3	R
Chlortoluron	S	-	-	-	-	S	-
Ioxynil+ bromoxynil	2-4	6	6	-	-	6	R
Isoproturon	S	S	-	-	-	5-10cm	R
Pendimethalin	S	-	S	-	-	S	S
Fluroxypyr	R	-	-	-	-	R	R**
Trifluralin	MS	-	-	R	-	MS	-
Clopyralid	10cm	-	-	-	-	-	-
Metsulfuron-methyl	8cm	-	-	-	-	-	3cm
2-4-D	R	MS	S	MR	R*	S	R
Atrazine	S	S	R	S	-	S	MS

Table 20. Percentage of crop area sprayed per year with herbicides. Data from Sly, 1974; Steed & Sly, 1977, and Sly, 1984.

Year	Winter wheat	Winter barley	Spring barley
1943	0	0	0
1974	158	141	130
1977	168	120	130
1982	251	208	154

Table 21. Percentage of cereal area sprayed with four individual herbicides between 1974 and 1982. Data from Sly, 1975; Steed & Sly, 1979, and Sly, 1984.

Year	MCPA	Mecoprop	Ioxynil/ bromoxynil	Chlor- -toluron
1974	26.4	23.3	7.6	-
1977	15.7	16.6	10.2	1.8
1982	13.6	36.1	14.0	17.3

The apparent changes in the modern weed flora have frequently been associated with the escalation in herbicide usage (Chancellor, 1977; Fryer & Chancellor, 1970; Heydemann, 1983), although the establishment of a causal connection between the two phenomena is difficult. Surveys have been carried out, which have enabled the comparison of weed frequencies under different conditions of herbicide usage, and with the results of earlier surveys. Mijatovic & Lozanovski (1984) associated the decline of many species, including Agrostemma githago, Centaurea cyanus, Sinapis arvensis and Papaver rhoeas in Yugoslavia with the introduction of herbicides such as 2,4-D and MCPA. Ervio & Salonen (1987) considered herbicides to have been of importance in the decline of some species in spring barley in Finland, although they believed the changes in weed communities to have been due to a complex of factors. Whitehead & Wright (1989) concluded that no changes had occurred in Britain's weed flora in recent years. Their results are however open to other interpretations.

Long-term changes in the size and composition of some seed-banks under different herbicide treatments have been demonstrated experimentally. In Hungary, Ubrizsy (1968), observed the effects of eight years of MCPA, 2-4-D, and atrazine application on the weed floras of wheat and maize fields. Among those species that decreased in herbicide treated plots during his experiments were A. githago, Ranunculus arvensis, Buglossoides arvensis, Ajuga chamaepitys, Misopates orontium and C. cyanus, all of which have become rarer in Britain in recent years. He also observed the increase in importance of perennial species, and species that were resistant to those herbicides used.

Roberts and Neilson (1981a) showed by determination of the seed content of the soil, how the numbers of seed of several species including Chrysanthemum segetum, Papaver rhoeas and Viola arvensis, had declined after 16 years of application of tri-allate, MCPA, simazine or linuron in spring barley, maize or carrot crops, although the effects of the different herbicides were not compared. Hume (1987) demonstrated the long-term decline of Chenopodium album and Thlaspi arvense in response to 2-4,D in Canada, and Dvorak and Krejcir (1980) demonstrated decreases under herbicide treatments (largely MCPA) in the seed-banks of a number of species, including Silene noctiflora, in Czechoslovakia. Yearly experimental treatments of MCPA, 2-4,D, DNOC, calcium cyanamide, or mechanical cultivation, and a rotation of all treatments over a period of 14 years, were observed by Rademacher, Koch and Hurle (1970) in Germany, to have a considerable effect on the weed flora. Most species were observed to decrease under all herbicide treatments, although MCPA, 2-4,D and DNOC were found to be most effective.

An additional feature recorded in all of the experiments and surveys described above, was the increase in abundance and frequency of species resistant to the herbicides examined. Some of the species most often mentioned were *Galium aparine*, *Stellaria media*, *Lamium purpureum*, *Fallopia convolvulus*, *Polygonum aviculare*, *Elymus repens* and *Alopecurus myosuroides*.

Some of the most interesting observations relevant to the effects of herbicide use on weed floras, have been made on the long-term winter-wheat experiment on Broadbalk field at the Rothamsted experimental station. The field contains an extremely rich traditional weed flora, including such species as *Galium tricornutum*, *Torilis arvensis*, *Scandix pecten-veneris* and *Ranunculus arvensis*. It is of particular importance in the study of the cereal ecosystem, because of the long history and continuity of the experimental regime. The experiment was set up in 1843, with the aim of investigating the nutritional requirements of wheat, and although the treatments have varied to reflect changes in common agricultural practice, the experiment remains essentially the same in 1990. Fallowing was practised from 1925 onwards, in an attempt to control weeds, in particular *Alopecurus myosuroides*, and herbicide treatments were introduced in 1957, initially with MCPA, but with other compounds as they became available (Bawden, 1968; Thurston, 1968). One plot of the experiment has remained free of any herbicide, and is one of very few such areas of arable farmland in Britain. This experiment represents a unique opportunity to investigate the effects of long-term herbicide use on populations of arable weeds. Seed-bank composition and size were determined at intervals from 1925 until 1976, in order to study the effects of changes in agricultural practice (Thurston, 1968). The relationship between weed flora and nutrients was described by Brenchley and Warington (1930), and preliminary observations on the impact of chemical weed control were described by Thurston (1964 and 1968).

In all of these experiments and surveys, declines of susceptible species were observed, but in none were any species driven to total extinction. This contrasts with the results of wider-scale surveys (A.Smith, pers. comm.; Oesau, 1979; Eggers, 1984a) in which the local and national extinctions of some species have been observed (Chapter 1). It is possible that herbicides work alongside other factors to affect populations of weed species, although it is evident that much more information is required on the specific phytotoxicity of herbicides to rare species, and on their long-term effects on weed populations.

In order to establish the susceptibility of rare weed species to a range of commonly used herbicides, a herbicide screening experiment was carried out. The herbicides used, were selected on the basis of their popularity with farmers (Table 21), their relatively long history (Table 18), and the known differences in their spectra of activity (Table 19).

To provide some further data on the long-term effects of herbicides on weed populations, a series of soil samples was taken from the Broadbalk experiment at Rothamsted, and the soil seed-bank compared with that recorded by other workers in previous years.

MATERIALS AND METHODS.

Herbicide testing.

Seeds of the following species, Chrysanthemum segetum, Buglossoides arvensis, Misopates orontium, Papaver hybridum, Papaver rhoeas, Ranunculus arvensis, Scandix pecten-veneris, Silene noctiflora and Viola arvensis, were sown into a sand and loam compost in six-inch clay flowerpots. P. rhoeas and V. arvensis were chosen as comparison species asP. rhoeas is known to be susceptible, and V. arvensis is known to be resistant to many herbicides (Flint, 1987). The pots were sunk to a depth of 12 cm. in soil, and surrounded by black polythene in order to conserve soil water and to suppress weed growth. The pots were watered regularly.

When the seedlings had acquired between four and six expanded true leaves, numbers were reduced to between three and five per pot, ensuring that the individuals were well spaced from each other. The plants were allowed to recover from any possible damage incurred during the thinning process for one week before herbicide application.

Four herbicides in common use were tested. These were applied at the recommended concentration for cereal crops, and also at 0.25 of the recommended concentration,(see Table 22) as it has been suggested that the effects of herbicides on pot grown plants may be greater than effects when grown in the field (Marshall, 1987; Makepeace et al; 1989). Herbicides were applied using a Cooper-Pegler "Falcon 10" knapsack sprayer, at a pressure of 2.5 bar. Testing was carried out on two dates, mecoprop and chlortoluron being sprayed on the 25th of May, and MCPA and ioxynil/bromoxynil mixture on the 30th of October. Mecoprop was also applied to pots containing P. rhoeas, M. orontium, and S. pecten-veneris on the second date, to act as a standard. Treatments were replicated four times on the first date, and three times on the second.

Table 22. Amount of active ingredient (a.i.) of herbicide applied to pot-grown weed plants.

Herbicide.	active ingredient (kg a.i./ha). Full rate	0.25 rate
Mecoprop	1.28	0.33
Chlortoluron	1.38	0.34
MCPA	1.40	0.26
Ioxynil/bromoxyil	0.38/0.38	0.10/0.10

Plant vigour was assessed in relation to control plants sprayed with water, on a seven point scale as follows (After Richardson & Dean, 1974):

0 - completely dead.
1 - moribund, but not all tissue dead.
2 - alive, with some green tissue but unlikely to make further growth.
3 - very stunted, but apparently still making some growth.
4 - considerable inhibition of growth.
5 - readily distinguishable inhibition of growth.
6 - detectable adverse effect compared to the control, e.g. colour difference, morphological abnormality, epinasty or slight reduction in growth.
7 - indistinguishable from control.

Vigour assessments were carried out at two and five weeks after spraying, and at four weeks after spraying, production of flowers by the earlier sown plants was counted. All plants were harvested at five weeks post-spraying, and dried at 100°c for dry matter determination.

Broadbalk seed-bank sampling.

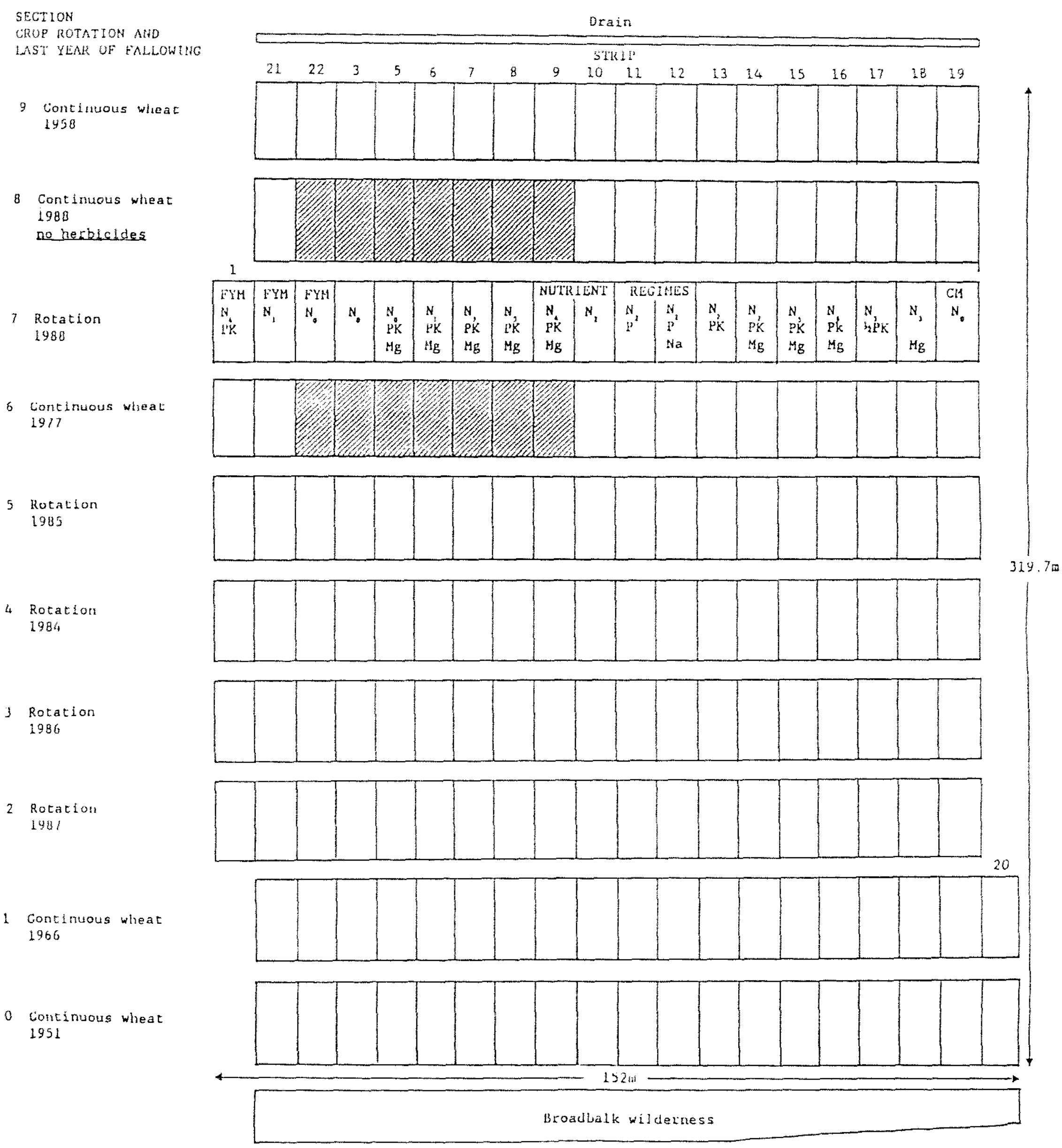
Seed-bank sampling on Broadbalk started in 1925, with samples being taken from "plots" 2,5,7,10,12,16 and 18 (Figure 10) from each of the original five "sections" of the experiment (Brenchley & Warington, 1930). Samples were again taken from these plots between 1926 and 1930, and from plots 2,7 and 18 between 1931 and 1940, and again in 1945. In 1955, two years before the introduction of herbicides, samples were taken from plots 2,5,7,9 and 18, and these samples were repeated from 1956 until 1967 (Thurston, 1968). Further samples were taken in 1974 and 1975 (J.Thurston, pers.comm.).

The sampling methods carried out until 1975 were

Figure 10. Diagrammatic plan of the broadbalk winter wheat experiment. Rothamsted Experimental Station (after Johnston & Garner, 1968 and J. McEwan, pers. comm.). Plots from which soil samples were taken for seed bank determination are marked by cross-hatching.

Nutrient regimes: FYM = farmyard manure (224kg nitrogen/ha); CM = castor oil meal; P = Phosphorus; K = potassium; Mg = Magnesium; Na = sodium. N = nitrogen (as ammonium sulphate); N_0 = 0, N_1 = 48, N_2 = 96, N_3 = 145, N_4 = 193, N_5 = 241, N_6 = 289kg nitrogen/ha. Each nutrient regime is repeated in each section of the experiment.

Crop rotation: fallow, potatoes, winter wheat, winter wheat, winter wheat.



described by Brenchley and Warington (1930), and are summarised here. All sampling was carried out in the stubbles in autumn, immediately before ploughing. 12 soil samples were taken from each plot-section, using a corer of cross-sectional area 77.4cm^2, to a depth of 14.4cm. These samples were bulked to form four larger samples per plot section, washed to remove stones and some of the soil, and spread out in pans in a greenhouse. Emerging seedlings were identified, counted and removed, and the soil stirred at intervals of 6-7 weeks.

The seed-bank was sampled again in January 1988 as part of this project. Samples were taken from the herbicide-free section (section 8, Figure 10), and from the nearest section of the field that grew continuous crops of winter wheat, and which was the most similar in terms of length of time since the last year of fallow (section 6). This was an attempt to minimise the effects of fallowing on the samples. Previous work has shown how weed seed populations recover very rapidly from fallowing (Brenchley & Warington, 1936), and it was considered that any differences between sections due to previous fallowing would be minimal. Section 8 was being fallowed during the year of sampling (1987-88), with the previous fallow having been in 1981. The last fallow year for section 6 was 1977. Most differences between the two sections could therefore be ascribed either to the long-term effects of herbicides, or environmental effects unconnected with experimental variables, and which would have probably been in operation before the adoption of herbicide use.

Soil samples were taken using a cylindrical corer of 38.5cm^2 cross-sectional area, to a depth of 14.4cm (the same depth as earlier samples). Twelve samples were taken from each of the five plots 2,3,5,6,and 7 from the herbicide-free section (section 8). Ten samples were taken from two additional plots (8 & 9) of section 8, and also from plots 2,3,5,6,7,8 and 9 from the herbicide treated section 6 (Figure 10). Each sample was spread out in an individual plastic tray in a greenhouse, and watered regularly. Emerging seedlings were identified, counted and removed, and the soil disturbed at approximately four-month intervals.

In the years between 1925 and 1975, visual weed surveys were carried out in May of each year. This was not possible during the 1987-88 cropping season, as the herbicide-free section was undergoing one of its periodic fallows, which entails regular cultivation for weed seedling destruction.

RESULTS.

Herbicide testing.

Results for dry matter and flower production were analysed by analysis of variance for each species and each herbicide with respect to water sprayed plants (Tables 24, 25, 26 & 27). Vigour scores at five weeks were analysed using the non-parametric Kruskal-Wallis analysis of variance (Table 24, 25, 26 & 27).

a. Mecoprop. (Table 24).

At 0.33 kg ai./ha (0.25 field rate), mecoprop had a significant effect on Silene noctiflora, Papaver hybridum, B.arvensis, Misopates orontium, Ranunculus arvensis and the common species Papaver rhoeas (Table 24). Flower production and dry matter production per plant were significantly reduced in all of these cases, although the vigour scores recorded suggested that the plants might be capable of recovery.

At 1.28 kg a.i./ha (full concentration), mean vigour scores of less than four were recorded for S. noctiflora, P. hybridum, R. arvensis, S. pecten-veneris, and P. rhoeas. Despite having a vigour score significantly less than the control plants and those treated with low rate herbicide, B. arvense was still considered capable of recovery. M. orontium was treated with mecoprop at full concentration in October, as insufficient seedlings were present in May. It was significantly affected, with a mean vigour score of 2.

Dry matter and flower production per plant were significantly reduced for all of the seven species listed above apart from C. segetum (Table 24), when treated with the full concentration of mecoprop.

V. arvensis and C. segetum seem to show some resistance to this herbicide. Effects on P. rhoeas and S. pecten-veneris appeared to be less at the later application

Table 24. Responses of weed species to mecoprop application. Significance levels (F-test) calculated with respect to water sprayed plants for all species; * P<0.05; ** P<0.01; *** P<0.001. N.S. = not significant.

a. Mean plant vigour five weeks after application of mecoprop, with 95% confidence limits. Scored on a 7 point scale (see text), with respect to water sprayed control plants (7 = indistinguishable from control, 0 = dead). Kruskal-Wallis analysis of variance.

	Application Date				
	25 May	25 May		30 Oct	
	Concentration (kg. a.i./ha)				
	1.28	0.33	control	1.28	P
Silene noctiflora.	3.5 2.3 1.1	5.7 4.5 3.3	7	-	*
Viola arvensis.	6.8 6.3 5.9	7.0 6.5 6.0	7	-	ns.
Papaver hybridum.	4.1 3.0 1.9	5.4 4.3 3.2	7	-	***
Chrysanthemum segetum.	6.3 6.0 5.7	7.1 6.8 6.5	7	-	ns.
Scandix pecten-veneris.	4.5 3.3 1.1	7.9 6.7 5.5	7	5.5 4.3 3.1	***
Buglossoides arvensis.	5.6 5.0 4.4	6.6 6.0 5.4	7	-	*
Misopates orontium.	-	4.4 4.3 4.2	7	2.2 2.0 1.9	***
Papaver rhoeas.	3.0 1.3 0	7.0 5.3 3.6	7	7.0 5.3 3.6	**
Ranunculus arvensis.	2.5 0.8 0	7.5 5.8 4.1	7	-	**

b. Geometric mean dry weight per plant five weeks after application of mecoprop. Analysis of variance performed on $Log_{10}(n+1)$ transformed data (in brackets). Standard errors of difference apply to transformed data.

Application date: 25th May.

	Concentration (kg a.i./ha).				
	Control	0.33	1.28	s.e.d.	P
Silene noctiflora	1.02	0.46	0.28	0.03	**
	(0.31	0.17	0.11)		
Viola arvensis	1.26	0.97	0.57	0.10	N.S.
	(0.35	0.30	0.20)		
Papaver hybridum	1.29	0.39	0.37	0.07	*
	(0.36	0.14	0.14)		
Chrysanthemum segetum	20.38	15.60	3.57	0.34	N.S.
	(1.33	1.22	0.66)		
Scandix pecten-veneris	0.85	1.36	0.61	0.10	N.S.
	(0.27	0.37	0.21)		
Buglossoides arvensis	3.08	1.96	0.91	0.08	*
	(0.61	0.47	0.28)		
Misopates orontium	12.27	3.53	-	0.06	**
	(1.12	0.66	-)		
Papaver rhoeas	2.54	1.99	0.08	0.08	**
	(0.55	0.48	0.04)		
Ranunculus arvensis	5.04	1.47	0.05	0.11	**
	(0.78	0.39	0.02)		

Application date 30th. October.

Scandix pecten-veneris	0.79	-	0.61	0.03	N.S.
	(0.25		0.21)		
Misopates orontium	0.04	-	0.04	0.004	N.S.
	(0.02		0.02)		
Papaver rhoeas	0.08	-	0.06	0.002	N.S.
	(0.035		0.025)		

c. Geometric mean number of flowers produced per plant with 95% confidence limits, by a number of rare weed species, four weeks after treatment with mecoprop. Analysis of variance carried out on $\log_{10}(n+1)$ transformed data.

	Concentration (kg ai.\ha)			
	Control	0.33	1.28	p
	(3.08	2.17	0.18)	
Silene noctiflora.	2.46	0.84	0.00	***
	(1.94	0.56	0)	
	(5.99	2.46	2.65)	
Viola arvensis.	3.4	2.19	1.31	N.S.
	(1.78	0.38	0.46)	
	(4.13	2.12	0.87)	
Papaver hybridum.	2.75	1.28	0.37	***
	(1.74	0.67	0	
	(3.74	4.60	1.70)	
Chrysanthemum segetum.	2.2	2.78	0.82	N.S.
	(1.16	1.56	0.23)	
	(4.88	7.48	1.54)	
Scandix pecten-veneris.	3.35	5.27	0.87	***
	(2.21	3.63	0.39)	
	(17.71	4.98	5.60)	
Buglossoides arvensis.	11.13	3.09	3.52	***
	(7.31	1.80	2.09)	
	(2.81	1.96	0.78)	
Papaver rhoeas.	1.68	1.08	0.26	N.S.
	(0.89	0.47	0)	
	(35.39	12.12	0.64)	
Ranunculus arvensis.	21.13	6.98	0.00	***
	(12.46	3.85	0)	

date. The vigour score was still reduced, but no effect was observed on dry matter production.

b. Chlortoluron. (Table 25).

Mean vigour scores of only two species, P. hybridum and P. rhoeas, were significantly reduced by applications of chlortoluron at 0.34 kg ai./ha, and in both cases the plants were considered capable of recovery (Table 25). Dry matter production per plant of R. arvensis, B. arvensis, and P. hybridum was lower at this rate. Flower production of P. hybridum and R. arvensis was also reduced.

The full concentration of herbicide had a significant effect with a mean vigour score of less than 3 for all species tested, except for V. arvensis, and even this had a significantly reduced vigour score (Table 25).

Dry matter and flower production was significantly reduced for all species other than V. arvensis and P. rhoeas. (Table 25).

In terms of dry matter production, chlortoluron at full concentration had significantly greater effect on B. arvense, S. pecten-veneris, and C. segetum, but lesser effect on P. rhoeas and P. hybridum, than the standard, mecoprop (Table 25).

Effects on flower production however, were different. Chlortoluron suppressed flower production by P. hybridum, C. segetum and B. arvense to a significantly greater extent than mecoprop. Mecoprop on the other hand caused a greater

Table 25. Responses of weed species to chlortoluron application. Significance levels (F-test) calculated with respect to water sprayed plants and mecoprop sprayed plants for all species; * P<0.05; ** P<0.01; *** P<0.001.; N.S. = not significant.

a. Mean plant vigour five weeks after spraying with chlortoluron, with 95% confidence limits. Scored on a 7 point scale (see text), with respect to water sprayed control plants (7 = indistinguishable from control, 0 = dead). Kruskal-Wallis test. Application date; 25th May.

	Concentration (kg. a.i./ha)				
	Chlortoluron			Mecoprop	
	1.38	0.34	Control	1.28	P
	2.5	7.7		4.0	
Silene	0.8	6.0	7	2.3	*
noctiflora.	0	4.3		0.6	
	6.0	7.7		7.0	
Viola	5.3	7.0	7	6.3	*
arvensis.	4.6	6.3		5.6	
	1.8	7.1		4.8	
Papaver	0.03	5.3	7	3.0	**
hybridum.	0	3.5		1.2	
	3.3	8.6		7.8	
Chrysanthemum	1.5	6.8	7	6.0	*
segetum.	0	5.0		4.2	
	3.4	7.9		4.9	
Scandix	1.8	6.3	7	3.3	**
pecten-veneris.	0.2	4.7		1.7	
	3.9	7.7		6.4	
Buglossoides	2.5	6.3	7	5.0	*
arvensis.	1.1	4.9		3.6	
	2.1	7.1		3.1	
Papaver	0.3	5.3	7	1.3	**
rhoeas.	0	3.5		0	
	3.5	8.6		2.6	
Ranunculus	1.3	6.8	7	0.8	*
arvensis.	0	5.0		0	

b. Geometric mean dry weight per plant five weeks after spraying. Analysis of variance performed on $\log_{10}+1$ transformed data (in brackets). Standard errors of differences apply to transformed means.

		Concentration (kg a.i.\ ha)				
		Chlortoluron		Mecoprop		
	Control	0.34	1.38	1.28	s.e.d.	p
Silene noctiflora	0.91	1.48	0.18	0.28	0.09	*
	(0.28	0.39	0.07	0.11)		
Viola arvensis	1.26	1.86	0.57	0.57	0.11	N.S.
	(0.35	0.46	0.2	0.20)		
Papaver hybridum	1.29	0.83	0.04	0.37	0.07	**
	(0.36	0.26	0.02	0.14)		
Chrysanthemum segetum	20.38	15.98	1.09	4.89	0.36	N.S.
	(1.33	1.23	0.32	0.77)		
Scandix pecten-veneris	0.79	0.96	0.19	0.61	0.07	N.S.
	(0.25	0.29	0.08	0.21)		
Buglossoides arvensis	3.08	1.71	0.16	0.91	0.11	**
	(0.61	0.43	0.07	0.28)		
Papaver rhoeas	2.54	2.39	4.07	0.08	0.10	***
	(0.55	0.53	0.71	0.04)		
Ranunculus arvensis	5.04	3.30	0.00	0.05	0.09	***
	(0.78	0.63	0.00	0.02)		

c. Geometric mean number of flowers produced per plant, four weeks after application of chlortoluron. Analysis of variance carried out on $\log_{10}(n+1)$ transformed data.

	Concentration (kg ai.\ha)			
		Chlortoluron		
	Control	0.34	1.38	P
	(3.08	2.87	1.30)	
Silene noctiflora.	2.46	2.28	0.11	***
	(1.94	1.78	0)	
	(5.99	2.92	2.04)	
Viola arvensis.	3.4	1.48	0.92	N.S.
	(1.78	0.56	0.21)	
	(4.13	2.33	1.37)	
Papaver hybridum.	2.75	1.44	0.00	***
	(1.74	0.78	0)	
	(3.74	3.01	0.91)	
Chrysanthemum segetum.	2.2	1.71	0.29	*
	(1.16	0.83	0)	
	(4.88	4.38	2.19)	
Scandix pecten-veneris.	3.35	2.97	1.36	*
	(2.21	1.93	0.74)	
	(16.71	12.71	1.07)	
Buglossoides arvensis.	11.13	8.42	0.42	***
	(7.31	5.45	0)	
	(2.81	2.41	2.24)	
Papaver rhoeas.	1.68	1.4	1.28	N.S.
	(0.89	0.69	0.61)	
	(35.39	23.15	1.61)	
Ranunculus arvensis.	21.13	13.69	0.58	***
	(12.46	7.93	0)	

Table 26. Responses of weed species to MCPA application. Significance levels (F-test) calculated with respect to water sprayed plants and mecoprop sprayed plants; * P<0.05; ** P<0.01; *** P<0.001. N.S. = not significant.

a. Mean plant vigour 5 weeks after application of MCPA with 95% confidence limits. Scored on a 7 point scale (see text), with respect to water sprayed control plants (7 = indistinguishable from control, 0 = dead). Kruskal-Wallis test
Application date: 30th October.

	Concentration (kg. a.i./ha)				
	MCPA			Mecoprop	
	1.4	0.26	Control	1.28	P
Silene noctiflora.	5.7 5.0 4.3	7.1 6.3 5.4	7	-	N.S.
Viola arvensis.	7.4 6.3 5.2	7.1 6.0 4.9	7	-	N.S.
Papaver hybridum.	5.7 5.0 4.3	7.4 6.7 6.0	7	-	*
Chrysanthemum segetum.	6.7 6.3 5.9	6.7 6.3 5.9	7	-	N.S.
Scandix pecten-veneris.	5.1 4.3 3.5	6.8 6.0 5.2	7	5.1 4.3 3.5	**
Buglossoides arvensis.	6.1 5.3 4.5	7.8 7.0 6.2	7	-	N.S.
Misopates orontium.	6.3 5.0 4.7	8.0 6.7 5.4	7	3.3 2.0 0.7	*
Papaver rhoeas.	5.0 3.7 2.4	6.6 5.3 4.0	7	6.6 5.3 4.0	*

b. Geometric mean dry weight per plant 5 weeks after application of MCPA. Analysis of variance performed on $\log_{10}(n+1)$ transformed data (in brackets). Standard errors of differences (s.e.d.) apply to transformed means.

	Concentration (kg a.i.\ ha)					
		MCPA		Mecoprop		
	control	1.4	0.26	1.28	s.e.d.	P
Silene noctiflora.	0.09 (0.04	0.10 0.04	0.10 0.04)	-	0.01	N.S.
Viola arvensis.	0.04 (0.02	0.04 0.02	0.04 0.02)	-	0.002	N.S.
Papaver hybridum.	0.05 (0.02	0.07 0.03	0.04 0.02)	-	0.004	N.S.
Chrysanthemum segetum.	0.13 (0.05	0.27 0.10	0.24 0.09)	-	0.03	N.S.
Scandix pecten-veneris.	0.32 (0.12	0.17 0.07	0.21 0.08	0.19 0.08)	0.05	N.S.
Buglossoides arvensis.	0.15 (0.06	0.21 0.08	0.22 0.09)	-	0.01	N.S.
Papaver rhoeas.	0.08 (0.04	0.07 0.03	0.08 0.03	0.06 0.03)	0.007	N.S.
Misopates orontium.	0.04 (0.02	0.05 0.02	0.05 0.02	0.04 0.02)	0.006	N.S.

reduction in flower production by S. pecten-veneris, P. rhoeas and R. arvensis (Table 25).

M. orontium was not screened.

c. MCPA. (Table 26).

Vigour scores for only two species, S. noctiflora and P. rhoeas were significantly affected by the lower application concentration of 0.26 kg ai/ha and in neither case were the plants considered unlikely to recover. The full concentration of 1.4 kg ai/ha. significantly reduced the vigour scores of S. noctiflora, P. hybridum, S. pecten-veneris, M. orontium and P. rhoeas. P. rhoeas (mean vigour score = 3.7), and S. pecten-veneris (mean vigour score = 4.3) were the most affected.

Dry matter production was not significantly reduced for any species at either concentration.

d. Ioxynil/bromoxynil. (Table 27)

This herbicide had the greatest effects of all of those tested. At the full concentration of 0.38+0.38 kg a.i./ha, S. noctiflora, P. hybridum, B. arvense, M. orontium and P. rhoeas were killed, and plants of V. arvensis, C. segetum and S. pecten-veneris were thought unlikely to recover (mean vigour score <3). The low concentration (0.1+0.1 kg a.i./ha) had very little effect on the plants, small reductions in vigour being observed for S. pecten-veneris and B. arvense only (Table 27).

The production of dry matter by V. arvensis, was

Table 27. Responses of weed species to ioxynil/bromoxynil application. Significance levels calculated with respect to water sprayed plants and mecoprop sprayed plants; * P<0.05; ** P<0.01; *** P<0.001. N.S. = not significant. Application date, 30th October.

a. Mean plant vigour 5 weeks after application of ioxynil/bromoxynil with 95% confidence limits. Scored on a 7 point scale (see text), with respect to water sprayed control plants (7 = indistinguishable from control, 0 = dead). Kruskal-Wallis test.

	Concentration (kg. a.i./ha)				
	Ioxynil/bromoxynil			Mecoprop	
	0.38/0.38	0.1/0.1	Control	1.28	P
Silene noctiflora.	2.2 0 0	8.5 6.3 4.1	7	-	***
Viola arvensis.	3.2 1.3 0	7.9 6.0 4.1	7	-	**
Papaver hybridum.	2.3 0 0	8.8 6.5 4.2	7	-	*
Chrysanthemum segetum.	3.2 1.3 0	8.6 6.7 4.8	7	-	*
Scandix pecten-veneris.	3.2 2.0 0.8	7.2 6.0 4.8	7	5.5 4.3 3.1	*
Buglossoides arvensis.	2.1 0 0	6.1 4.0 0.9	7	-	**
Misopates orontium.	1.8 0 0	8.1 6.3 4.5	7	3.8 2.0 0.2	*
Papaver rhoeas.	1.7 0 0	8.5 6.8 5.1	7	7.0 5.3 3.4	*

b. Geometric mean dry weight per plant 5 weeks after application of ioxynil/bromoxynil. Analysis of variance performed on $Log_{10}(n+1)$ transformed data (in brackets). Standard errors of differences (s.e.d.) apply to transformed means.

	Concentration (kg. a.i./ha)					
		Ioxynil/ bromoxynil		Mecoprop		
	Control	0.1/0.1	0.38/0.38	1.28	s.e.d.	P
Silene noctiflora.	1.43 (0.39	1.44 0.39	0.00 0.00)	-	0.007	**
Viola arvensis.	0.04 (0.02	0.03 0.01	0.01 0.004)	-	0.001	***
Papaver hybridum.	0.05 (0.02	0.04 0.02	0.00 0.00)	-	0.006	*
Chrysanthemum segetum.	0.13 (0.05	0.33 0.13	0.12 0.05)	-	0.032	N.S.
Scandix pecten-veneris.	0.27 (0.10	0.19 0.08	0.08 0.04	0.19 0.08)	0.058	N.S.
Buglossoides arvensis.	0.15 (0.06	0.15 0.06	0.02 0.01)	-	0.027	N.S.
Papaver rhoeas.	0.08 (0.04	0.15 0.06	0.00 0.00	0.06 0.03)	0.006	***
Misopates orontium.	0.04 (0.02	0.06 0.02	0.00 0.00	0.04 0.02)	0.006	*

significantly lower at the low application rate than by the control plants. Ioxynil/bromoxynil significantly reduced the vigour scores of *P. rhoeas* and *M. orontium* more than did the standard, mecoprop (Table 27).

Investigation of the seed-bank of the Broadbalk winter wheat experiment.

One of the problems encountered in the analysis of data from Broadbalk, was that when the experiment was set up in 1840, modern statistical methods were unknown, and the experiment was not designed with these methods in mind. The nutrients applied to each strip running the length of the field, and the crop rotations followed on each section of the field running at right angles to the strips are different. Each plot is therefore unique and unreplicated, prohibiting a complete statistical analysis. Numbers of seeds of each species per m^2 of soil area in both of the sampled sections of the field were compared using analysis of variance by multiple regression for four years of sampling; 1925, 1945, 1975 and 1987. Results from 1955 were unfortunately not available. By comparing results from the seed-bank between Section 6 and 8 before the introduction of herbicides, it was hoped that any significant variation between the two sections attributable to factors other than herbicide application could be detected. Any significant variation between the seed-banks of the two strips after 1957 that was not present before this date, and any significant variation between the seed-bank of Section 6 before and after 1957, was therefore attributable to the effects of herbicides.

Numbers of only two species, Odontites verna and Capsella bursa-pastoris, differed significantly between sections before 1957 (Table 28). None of the other species showed significant differences between sections before the introduction of herbicides, although numbers of some varied considerably from year to year (Table 29).

After the introduction of herbicides, significant differences were observed between the two sections for Alopecurus myosuroides, Papaver rhoeas, Aphanes arvensis, Legousia hybrida, C. bursa-pastoris, Scandix pecten-veneris and Veronica hederifolia, which all became less abundant in the herbicide treated section. S. pecten-veneris was not recorded at all in the herbicide treated soil samples taken in 1987 (Table 29), and further declines of A. myosuroides, L. hybrida and C. bursa-pastoris occurred between the surveys of 1975 and 1987, although numbers of seed of A. arvensis and V. hederifolia apparently increased between these two dates (Table 29).

It is possible that variations in the seed-banks of S. media, M. lupulina, M. arvensis and O. verna were due to herbicide application, but were not found to be significant. These may have been obscured by the effects of other fluctuations in the seed-banks, as observed before 1957.

Table 28. Mean numbers of seedlings per m^2 of soil surface area (with 95% confidence limits), germinating from soil cores from plots which have never received herbicides, and from plots which have received herbicides, before and after the year in which herbicides were first applied. Significance levels (F-test) from analysis of variance by multiple regression; *** P<0.001; ** P<0.01; * P<0.05.

	Section 8 No herbicide ever applied	Section 6 pre-1957 -herbicide	 post-1957 +herbicide	P
Alopecurus myosuroides	9638 6834 4511	13698 7535 3200	1478 717 259	Herbicide ***
Stellaria media	1956 786 140	692 253 30	78 25 1	N.S.
Papaver rhoeas	32969 17266 6598	30817 12775 2550	837 501 250	Herbicide *
Tripleurospermum inodorum	1071 500 144	460 80 0	458 285 153	N.S.
Medicago lupulina	1273 554 130	567 196 17	63 24 0	N.S.
Polygonum aviculare	572 297 111	625 117 0	983 250 0	N.S.
Aphanes arvensis	9090 5009 2135	16602 8738 3376	237 131 56	Herbicide ***
Myosotis arvensis	247 93 13	400 59 0	12 4 0	N.S.
Veronica persica	922 493 170	2616 1582 807	1132 387 32	N.S.
Odontites verna	643 408 217	193 86 22	55 29 11	Section *
Legousia hybrida	1256 643 233	3133 949 317	257 85 6	Herbicide *
Capsella bursa-pastoris	154 73 22	1429 621 147	14 4 0	Herbicide *** Section ***
Scandix pecten-veneris	171 83 26	369 87 0	1.6 0.2 0	Herbicide *
Veronica hederifolia	988 691 432	1737 1113 628	13 3 0	Herbicide ***

Table 29. Numbers of seedlings per m² of soil surface area germinating from soil cores collected from 2 strips of the Broadbalk winter wheat experiment. Strip 8 has never received applications of herbicide, whereas strip 6 has received herbicides annually since 1957.

	Section	Year. 1925	1945	1975	1987
Alopecurus	8	5676.0	7869.0	13018.3	5555.6
myosuroides	6	6321.0	11642.3	2193.0	408.5
Stellaria	8	301.0	301.0	21.5	2528.4
media	6	5686.8	505.3	0.0	98.9
Papaver	8	57168.5	6493.0	31332.0	16782.9
rhoeas	6	18075.1	14609.3	490.2	675.1
Tripleurospermum	8	15.1	139.8	344.0	1821.1
inodorum	6	15.1	569.8	505.3	238.7
Medicago	8	350.5	1462.0	333.3	1463.2
lupulina	6	279.5	311.8	62.5	36.6
Polygonum	8	522.5	0.0	139.8	716.0
aviculare	6	509.6	0.0	10.8	1335.2
Aphanes	8	7174.6	11309.0	662.2	9969.6
arvensis	6	8090.5	12835.5	49.5	227.9
Myosotis	8	286.0	139.8	0.0	365.5
arvensis	6	350.5	0.0	10.8	12.9
Veronica	8	2365.0	623.5	103.2	666.5
persica	6	1963.0	1333.0	71.0	1313.7
Odontites	8	157.0	415.0	688.0	610.6
verna	6	150.5	43.0	49.5	34.4
Legousia	8	5654.5	1365.3	193.5	1578.1
hybrida	6	875.1	2644.5	458.0	55.9
Capsella	8	279.5	365.5	75.3	51.6
bursa-pastoris	6	522.5	1182.5	21.5	6.5
Scandix	8	264.5	365.5	17.2	98.9
pecten-veneris	6	101.1	311.8	6.5	0.0
Veronica	8	1382.5	1548.0	602.0	458.0
hederifolia	6	1541.6	645.0	0.0	18.5

DISCUSSION.

The complete elimination of the weed seedlings that germinate in a single year would prevent the return of any seed of that species to the soil. Few herbicides are totally phytotoxic however, especially in the conditions in which they are used within a crop. The selectivity of herbicides towards weed species is therefore an important factor to consider. A further factor that should be borne in mind is the efficiency of application, although this was not studied here. Within the relatively homogeneous conditions of a cereal field, considerable uniformity of herbicide application can be achieved, especially when modern technology is in use. The distribution of weed seed-banks observed in Chapter 3, lends some support to the hypothesis that efficiency may be rather lower towards the edges or corners of arable fields.

The long-term control of a species of plant that forms a bank of dormant seed in the soil is affected by the length of time that the seed can remain dormant, and the proportion of the seed-bank that germinates each year and is subjected to the control measure. Application of a herbicide, no matter how toxic it may be, will therefore not lead to the immediate extinction of a weed population, although it will, if applied regularly and efficiently, cause a decrease in the population, related to the dynamics and original size of the seed bank (Mortimer, 1987), and may eventually reach a position at which the population is no longer viable.

From the observations made on the toxicity of individual herbicides, it is apparant that some very commonly used compounds can achieve a very high degree of control of several of the species studied. Three weed performance parameters were examined; dry weight production, vigour score, and flower production. Dry weight production is of limited value when assessing herbicide efficiency over short periods of time in uncontrolled non-greenhouse conditions. At times when plant growth is relatively slow, herbicide symptoms may be observed, but few differences may be apparent between the dry matter production of treated and untreated plants. This probably explains the lack of significant differences observed between the dry weights of plants treated with different herbicides in October. For this reason, the visual assessment of plant vigour in relation to untreated control plants is probably of greater value, and despite an element of subjectivity, is a rapid, easy, accurate and consistant method, and allows herbicide trials to be conducted within a relatively short time-span (Richardson & Dean, 1974; Marshall, 1987; Makepeace et al; 1989). As with all assessments of annual plant species, the true measure of success is seed production (Grime, 1979), but this is very difficult and time consuming to determine, and is only possible in the context of a more long-term experiment. It is probably only meaningful when the effects of herbicide application are considered in a field situation. In the experiments described here, flower production was recorded for those plants sprayed in May with chlortoluron and mecoprop, as a non-destructive measure of reproductive success. Results for flower production were related to the vigour scores for plants of all species other than C. segetum and B. arvense.

Mecoprop and ioxynil/bromoxynil are among the most widely used non-residual herbicides for dicotyledonous weed control, and their effectiveness against most of the species tested was considerable. Chlortoluron is used mainly for its residual effect against Alopecurus myosuroides, but it also controls a wide range of dicotyledonous species as well, as results here indicated.

MCPA was one of the first herbicides to be developed, mainly for use against P. rhoeas and Sinapis arvensis, although it is also effective in the control of S. pecten-veneris and R. arvensis (Flint, 1987). Both P. rhoeas and S. pecten-veneris were affected by MCPA in this experiment, despite being applied at a non-optimal time of the year. This herbicide acted rather slowly on the plants tested, nastic responses and other morphological changes being produced rapidly, but little overall reduction in growth being observed. It is possible that a more rapid response would be shown to a spring application, and that greater effects of the autumn application would be observed if the plants had been left for longer than the standard five weeks, and if the plants had been tested in the presence of a crop. Response of plants to the related "hormone" herbicide mecoprop, was also less marked than was expected from this autumn application when compared to the spring application.

The resistance of V. arvensis to many herbicides is well known (Flint, 1987), and this may partially account for its continuing abundance in Britain. Of the less common species tested, C. segetum showed the least sensitivity to the four herbicides, and much effort and research has been directed towards its control (Aamisepp, 1973 & 1974; Erskine, 1974; Cortes et al; 1981; Cahill, 1982; Drummond & Ball, 1984). Although recent years have seen the development of a number of herbicidal treatments effective against this species, it still presents problems to arable farmers in some regions. B. arvensis is less frequently cited as a problem, but is resistant to many herbicides (German Plant Protection Service, 1979; Flint, 1987; G.Collini, pers comm.), and is still very locally frequent in some parts of England. For both of these species, greater suppression of flower production by mecoprop and chlortoluron was observed than might have been expected from the vigour scores (Tables 24 & 25).

It is possible that the use of chemicals such as those described in this experiment on populations of susceptible plants, especially of those that produce few, relatively short-lived seed, and which have a restricted gemination period (this volume, Chapters 5 & 7) could cause a rapid decrease. Much of the recent decline of S. pecten-veneris for instance, can be explained in terms of herbicide use. Brenchley and Warington (1930) noted the "relatively short period of natural dormancy" of seeds of this species, and this is supported by other observations (Chapter 5). This species is susceptible to many of the early developed herbicides, including all four of those tested, and, along with R. arvensis, has decreased more rapidly in recent years than has any other species in the British flora (Smith, 1986).

Although it seems obvious that the regular use of herbicides for weed control will have had a long-term effect on populations of arable weeds, relatively little evidence for this has been published. The most recently published survey (Whitehead & White, 1989) concluded that there had in fact been no change in the abundance or composition of Britain's weed flora. This contradicts the views of many other workers (Smith, 1986; Chancellor & Froud-Williams, 1986; Chancellor, 1976), and results from the Broadbalk winter wheat experiment, which provide some valuable evidence of the decline of populations of several species, associated with the adoption of herbicides for weed control.

The numbers of seeds of annual plant species present in the soil seed-bank, are the only reliable and accurate measures of their abundance (Roberts, 1981). Despite the fluctuations recorded in numbers of seed of many species between surveys of Broadbalk, and the apparant overall reduction of weed seed numbers in the field, significantly greater declines of *A. myosuroides*, *P. rhoeas*, *A. arvensis*, *C. bursa-pastoris*, *S. pecten-veneris*, and *V. hederifolia* have been recorded in herbicide treated plots over the last thirty years than in those plots that have remained untreated. It is of particular interest to note that *S. pecten-veneris* is one of those species that has declined most, and was not recorded at all in the herbicide treated strip in the most recent survey. The general decline in weed numbers may be due to the continuing practice of the rotational fallowing of the herbicide free strip, and was noted as early as 1936 (Brenchley & Warington, 1936). Periodic fallowing of some sections may also account for the fluctuations in the size of seed populations. It is also of interest to note that another rare species, *R. arvensis*, which was recorded as frequent in 1955 (Warington, 1958), was considered to be unaffected by fallowing, but only nine seedlings were recorded during the most recent survey.

Results from Broadbalk demonstrated that not only can herbicides eliminate yearly generations of weed seedlings, but that they can, by prevention of seed return to the soil, lead to the depletion of the soil seed-bank of both rare and common species. In the case of one species, *S. pecten-veneris*, this has progressed to a point at which it could not be detected by the soil sampling as carried out on this occasion. Although this survey applies to one site only, it is likely that similar depletions have occurred over the whole of the arable area of Britain, as the recent B.S.B.I./N.C.C rare arable weed survey (A.Smith, pers. comm.) has indicated. In fact, Broadbalk field is farmed rather less intensively than most arable fields. Buffer strips which receive reduced inputs of herbicides and fertilisers, exist around all of the experimental plots, and these can allow those species that are more susceptible to herbicides to persist in parts of the field that are otherwise unsuitable. In a normal farming situation, such areas of low input exist only in the corners and extreme edges of fields (Chapter 3), and in these cases, seed-bank depletion would probably be even greater than on Broadbalk.

There are some additional points to be remembered when considering the response of individual, pot-grown plants to herbicides. It has been suggested that such plants are more susceptible to herbicides than those grown under field conditions (Marshall, 1987; Makepeace et al; 1989). This increased susceptibility has however been noted only in greenhouse conditions, and is partly a consequence of the poor development of protective leaf cuticles (Makepeace et al, 1989). Weed plants within a healthy cereal crop are under considerable competitive pressure. Sub-lethal effects due to herbicides may be sufficient to disadvantage a weed plant with relation to the crop (Easson & Courtney, 1989), and to cause death of the weed, when an isolated pot-grown plant might otherwise recover.

Results for herbicide sensitivity must be considered in the context of other environmental and agricultural factors. It is possible that herbicides may be more effective in more competitive crops (Richards, 1989). Other factors such as the dates of spraying, local climate and soil type may also have a bearing on the effects of herbicides. Further experimentation to study the interactions of herbicides and other factors on rare weed populations in field situations is desirable.

CHAPTER 5

THE GERMINATION PERIODICITY OF ANNUAL WEEDS.

INTRODUCTION.

Most species of annual arable weed spend periods of their life-cycles as dormant seed in the soil (Grime, 1979; Roberts, 1981). The length of time that seeds of different species can remain dormant, and the factors that cause and break this dormancy, are very important to the ecology of weeds.

The nature and mechanisms of seed dormancy have been extensively researched (Warington, 1936; Thurston, 1959; Roberts, 1981: Roberts *et al*; 1987). Among the major factors which have been found to affect germination, are the availability of water, the intensity and quality of light, changes of temperature, changes in concentrations of soil gases, and the presence of nitrate ions in the soil (Baskin & Baskin, 1987; Roberts *et al*, 1987).

Seed dormancy is an extremely important adaptation to life in habitats which experience disturbance or regular periods of conditions inimical to plant growth, and can be considered to be of three types (Harper, 1957). "Innate" dormancy is a property of the seed at the moment it is shed from its parent and "induced" dormancy is a physiological response of the seed to environmental conditions. "Enforced" dormancy is simply an inability of a seed that is otherwise physiologically capable of germination, to germinate in unfavourable conditions. The advantages of such mechanisms to weed species are that they can allow survival through "hard times", and can enable the synchronisation of plant growth with favourable conditions (Harper, 1957; Grime,1979).

These three types of dormancy can be illustrated using the example of the common weed species, Aethusa cynapium. When shed from the parent plant, the seed embryos are unripe and are in a state of "innate" dormancy, and are incapable of germination. The "after-ripening" of the embryo occurs after a period of chilling over the winter, and the seeds will germinate readily in the spring, providing that dormancy is not enforced by adverse environmental conditions, such as low light intensity or lack of moisture. Dormancy of ungerminated seed is then "induced" by increasing temperatures in the early summer, preventing germination until dormancy is again broken by winter chilling (Roberts & Boddrell, 1985).

"Enforced" dormancy can be caused by a number of factors, such as insufficient moisture or light beneath a crop canopy (Grime, 1979). It can also be brought about by burial under the soil by ploughing. This is a property of many weed species, and is an important adaptation to survival through less predictable adverse conditions.

The range of factors responsible for the breaking of dormancy in different species is great (Thurston, 1959; Fenner, 1985). For most seed-bank forming species however, it is probable that there are two major factors other than the availability of sufficient moisture, in the breaking of the "enforced" dormancy of buried seed. The chief of these factors is the presence of light of suitable intensity and quality (Warington, 193 ; Grime, 1979). The effect of even very short periods of light exposure on the germination of seedlings of some common weed species has been demonstrated (Wesson & Wareing, 1969a), and it has also been shown that this light sensitivity is much more important in seeds that have undergone burial (Wesson & Wareing, 1969b). Red light has been shown to have the greatest effect on the stimulation of germination of a number of species (Popay & Roberts, 1969; Grime, 1979). The other major factor that has been shown to break enforced dormancy is the increased fluctuation of soil temperature following soil disturbance (Warington, 1936; Thompson & Grime, 1979; Fenner, 1985), even at depths to which light cannot penetrate.

This sensitivity to light quality and intensity and temperature fluctuation accounts for the flush of seedlings that commonly emerges from the soil after the disturbance caused by ploughing (Brenchley & Warington, 1936).

One of the consequences of seed dormancy that varies according to environmental conditions, is that populations of seeds can persist in the soil, with germination suppressed by darkness and relatively constant temperature for considerable lengths of time (Brenchley & Warington, 1936; Toole & Brown, 1946; Kivilaan & Bandurski, 1981). The other important consequence of seed dormancy is that the seeds of particular species can show a marked periodicity of germination, in response to changes in both induced and enforced dormancy (Mortimer, 1990). Aethusa cynapium germinates almost entirely between March and May (Roberts & Boddrell, 1985).

Brenchley & Warington (1930), studied the germination of weed seedlings from samples of soil that were collected primarily for the study of the effects of different fertiliser and fallowing regimes on weed populations. Their studies included a number of species that are now very uncommon, such as Scandix pecten-veneris, Torilis arvensis, Galium tricornutum, and Ranunculus arvensis. They found that these species germinated mainly during the winter.

H.A. Roberts and his colleagues conducted a number of experiments, in which they determined the periodicity of germination of a number of commonly occurring weed species, using a standard method (Roberts, 1964; Roberts, 1979; Roberts & Dawkins, 1967; Roberts & Feast, 1973; Roberts & Neilson, 1980; Roberts & Neilson, 1981b; Roberts & Boddrell, 1983a, 1983b & 1984). Although they did not study any very uncommon weed species, a valuable picture was given of the range of germination periodicities exhibited by arable weeds, and the experimental method established was simple and easily repeatable.

A useful summary of the germination periodicity profiles of 38 weed species including R. arvensis and Chrysanthemum segetum is given by Mortimer (1990).

If the conservation of rare weed species is to be effective, it is essential to know the periods of the year during which their seeds germinate. If the germination of a species is restricted to a very short period, then it is necessary to ensure that any cultivations of the soil occur before the seeds germinate, otherwise the seedlings will be destroyed. Similarly, if a crop canopy is well established before weed germination occurs, then germination may be inhibited, and competition from the crop will ensure the lack of success of any weed seedlings that do germinate.

An experiment was designed with the aim of determining the germination periodicity of a range of rare weed species, and their responses to soil disturbance. Some common species were also included for comparison.

METHODS.

The experimental method followed that of Roberts and Boddrell (1984). Twenty-four species of annual weed were selected for study, including the eight uncommon species selected for detailed investigation (Table 6), a range of common species, and some other species for which seed was available. The number of seeds used and the sowing date was dictated by supply. The number of seed per species, seed source, and the number of replicates of each species in each soil disturbance treatment, is shown in Table 30. The seed of all species was stored at room temperature in dry conditions before sowing. For the seed planted in November 1987 and October 1988, as short an interval as possible was left between seed harvest and sowing.

Table 30. Species included in the investigation of germination periodicities, and numbers of seeds per pot.

	Number of seed	No. of replicates. Treatment. 1	2	3	Seed source (footnote)
Sown March 1987.					
Alyssum alyssoides	1000	3	3	2	S.T.N.C.
Arnoseris minima	300	3	3	3	"
Bupleurum rotundifolium	300	3	2	3	"
Filago spathulata	1000	3	3	3	"
Myosurus minimus	1000	3	3	3	"
Misopates orontium	1000	3	3	3	"
Papaver argemone	1000	3	3	3	"
Papaver hybridum 1.	1000	3	3	3	"
Papaver lecoquii	1000	2	2	2	"
Silene noctiflora	1000	3	3	3	"
Sown November 1987					
Adonis annua	100	-	-	4	S.T.N.C.*
Chrysanthemum segetum	1000	4	4	4	H
Buglossoides arvensis 1.	300	4	4	4	H
Myosotis arvense	300	4	4	4	H
Papaver dubium	1000	4	4	4	W
Papaver hybridum 2.	1000	4	4	4	W
Papaver rhoeas	1000	4	4	4	H
Ranunculus arvensis	200	4	4	4	J.C.
Silene latifolia	1000	4	4	4	H
Scandix pecten-veneris 1.	300	4	4	4	H
Tripleurospermum inodorum	1000	4	4	4	H
Valerianella rimosa	500	4	4	4	S.T.N.C.*
Buglossoides arvensis 2.	100	-	-	4	W
Sown October 1988					
Scandix pecten-veneris 2.	100	-	-	4	J.C/H.

Seed source: STNC Suffolk Trust for Nature Conservation; H Herbiseed (commercial suppliers); JC John Chambers (commercial suppliers); STNC* from plants grown from Suffolk Trust for Nature Conservation seed; W from wild populations.

15cm. diameter earthenware flowerpots were sunk into the ground until only 3cm. of pot rim remained above the level of the surrounding soil. These were then filled to 8cm below the surrounding soil level with washed "half inch" gravel, in order to prevent the accumulation of stagnant water in the pot. The seed of each species was mixed with approximately 1.75 litres of sterilised John Innes No. 1 compost, and the flower pots were filled to external soil level with this mixture. The pots were surrounded with pea gravel in order to discourage the growth of unwanted weed plants, and to conserve soil moisture. Mollusc control was achieved with metaldehyde pellets.

Three soil disturbance regimes as described below were carried out on all species apart from Adonis annua, Buglossoides arvensis 2, and Scandix pecten-veneris 2, for which insufficient seed was available.

Treatment 1. Disturbance at the beginning of March.
Treatment 2. " " " " " October.
Treatment 3. " " " " " every month.

Emerging seedlings were counted at the beginning of each month. The experiment spanned the entire three years of the project.

RESULTS.

The numbers of seedlings germinating in each month of the experiment (Figure 11), and the numbers of seedlings germinating over the whole period of the experiment in each of the three soil disturbance treatments (Figure 12) were compared by analysis of variance after $\log_e(n+1)$ transformation. The effect of soil disturbance treatment on the germination periodicity of each species is illustrated in Figure 13.

"Initial" germination.

Most species showed an initial burst of germination after sowing (Table 31). This was consistent with the observations of others (Roberts, 1964 etc.), who have ignored this when considering periodicities. Initial germination was considered to have finished when germination resumed after a period of low seedling numbers, implying that the seed had passed through a period of dormancy. This occurred at different points for each species. For those species planted in March 1987, initial germination of Misopates orontium had finished by the end of June, Alyssum alyssoides, Arnoseris minima, Papaver argemone, P. lecoquii and Silene noctiflora by the end of July, and Bupleurum rotundifolium, Filago spathulata, Myosurus minima, and P. hybridum by the end of August. For those species planted in November 1987, little initial germination was recorded for Silene latifolia, that of C. segetum, B. arvense, P. hybridum, and P. rhoeas was over by the end of December, that of P. dubium was finished by the end of January, and Myosotis arvensis, and Ranunculus arvensis and Scandix pecten-veneris by the end of February.

Table 31. The initial and total germination of seeds of annual weed species, expressed as percentages of the initial numbers of seed, and the percentage of total germination accounted for by initial germination (in all cases, initial germination was over had finished within five months of sowing).

	a. Initial germination	b. Total germination	% a/b
Planted March 1987.			
Alyssum alyssoides	12.1	16.6	72.8
Arnoseris minima	5.5	14.0	39.4
Bupleurum rotundifolium	43.7	56.1	77.9
Filago spathulata	1.2	5.8	20.1
Myosurus minimus	4.2	14.0	30.4
Misopates orontium	0.8	6.5	12.5
Papaver argemone	7.7	16.6	46.5
Papaver hybridum	1.6	9.8	16.0
Papaver lecoquii	4.3	10.8	39.6
Silene noctiflora	1.0	3.7	26.6
Planted Nov. 1987			
Adonis annua	42.3	45.0	94.4
Chrysanthemum segetum	2.5	6.7	37.9
Buglossoides arvensis 1.	40.1	43.9	91.3
Myosotis arvense	2.9	20.1	14.5
Papaver dubium	9.1	24.5	37.3
Papaver hybridum	2.1	20.6	10.4
Papaver rhoeas	12.5	23.8	52.7
Ranunculus arvensis	46.3	76.9	60.2
Silene latifolia	0.01	11.5	<0.1
Scandix pecten-veneris 1.	99.4	99.9	99.5
Tripleurospermum inodorum	2.8	22.5	12.6
Valerianella rimosa	20.5	21.0	97.7
Buglossoides arvensis 2.	18.4	23.1	79.9
Planted Oct. 1988			
Scandix pecten-veneris 2	20.7	39.2	52.8

The initial germination (Table 31, a) of A. annua, B. arvensis 1, S. pecten-veneris and V. rimosa accounted for over 90% of the total number of seedlings recorded during the experiment (Table 31, a/b). For A. alyssoides, B. rotundifolium, A. annua, B. arvensis 2, R. arvensis, S. pecten-veneris and V. rimosa, the initial germination accounted for between 60% and 80% of the seedlings recorded

(Table 31, a/b). The two different sowings of *S. pecten-veneris* showed different proportions of initial germination. 95% of the seedlings recorded from the first sowing had germinated within four months of sowing, but only 53% of the seedlings recorded from the second sowing germinated initially (Table 31, a/b).

Monthly germination periodicity.

Germination of all species was significantly different ($p<0.05$) in different months of the year. A peak in seedling numbers was recorded for most species during July 1988, but as it was felt that this was due to unusual weather conditions, it has been left out of the description of the results. Possible reasons for this peak, and variations in periodicity between years, are discussed below.

Too few seedlings of *A. alyssoides*, *B. rotundifolium*, *A. annua*, and *S. pecten-veneris* (first sowing) were recorded after the initial germination flush, to allow detection of any consistent pattern. Few of the other species were restricted entirely to a single period. The chief exceptions were *M. minimus* which germinated mainly between October and January, and *V. rimosa*, recorded mainly between September and December. *M. orontium* showed a more widespread periodicity, germinating predominantly during April and May, but also in smaller numbers during other months. *F. spathulata* germinated in all months between

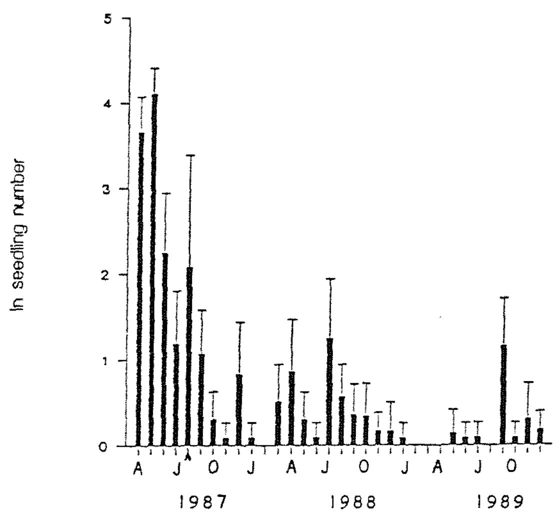
September and May, but mainly between October and January and in March. Few seedlings of R. arvensis were recorded after the initial period, but those that were, seemed to be confined to the months between October and January (Figure 11).

Most species showed a bimodal pattern of germination during the year, (Figure 11), although there were very important significant differences between individual species. In 1988, C. segetum germinated predominantly between March and May, with fewer seedlings appearing in the early autumn, a pattern that was reversed in 1989. Two seed sources of B. arvensis were used, one from a commercial source (B. arvensis 1), and the other collected from single population in Northamptonshire (B. arvensis 2). The germination periodicities of both were similar, with peaks in March and April, and again between October and December. Seed of P. hybridum was also acquired from two sources, P. hybridum 1 from the Suffolk Trust for Nature Conservation, sown in March 1987; P. hybridum 2 from "wild" sources, sown in November 1987. Although these both gave germination peaks betwen February and April and between September and December, the spring peak was larger for P. hybridum 1, whereas the autumn peak was higher for P. hybridum 2.

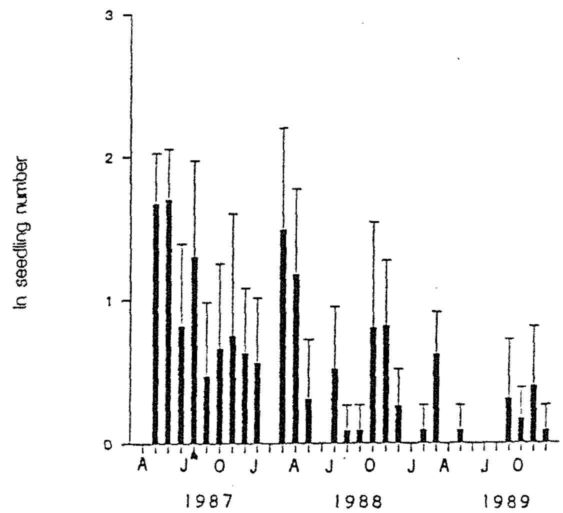
Of the two other uncommon Papaver species, the majority of seedlings of P. lecoquii were recorded during September, with some germinating in the adjacent months, and fewer in the spring. P. argemone showed a similar

Figure 11. Mean numbers of seedlings per pot ($\log_n(x+1)$ with upper 95% confidence limit) germinating in each month of a study of the germination periodicity of seeds of 24 annual weed species. (a - j sown March 1987: k - u, w and x, sown in November 1987. v sown in October 1988. Results averaged over 3 soil disturbance treatments.) Arrow indicates end of "initial" germination.

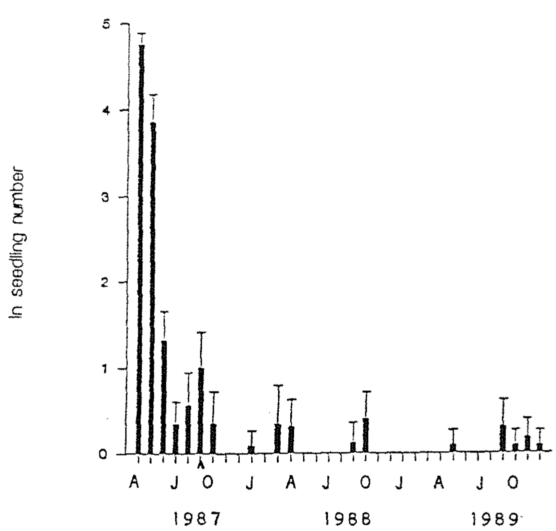
a. Alyssum alyssoides



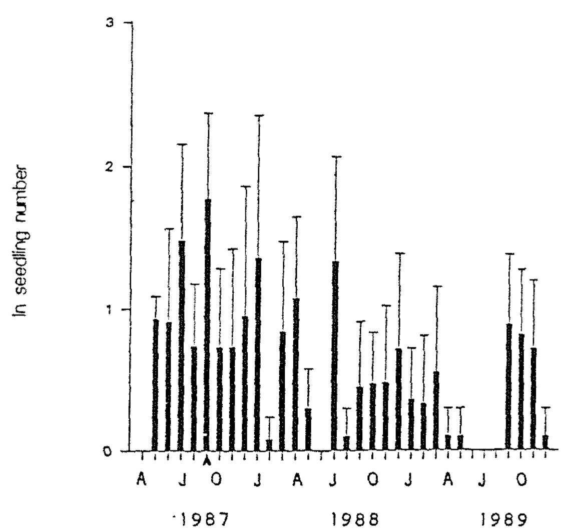
b. Arnoseris minima



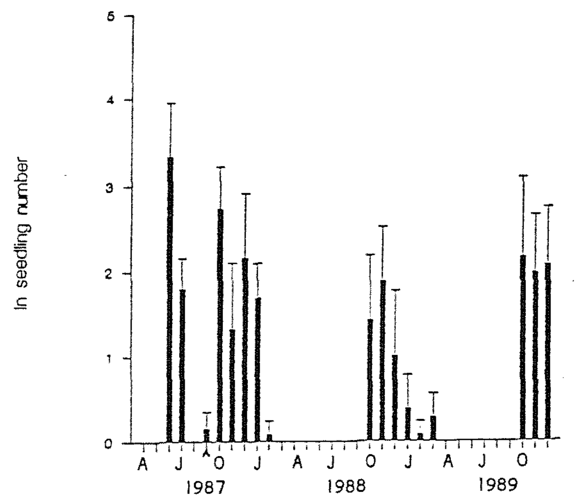
c. Bupleurum rotundifolium



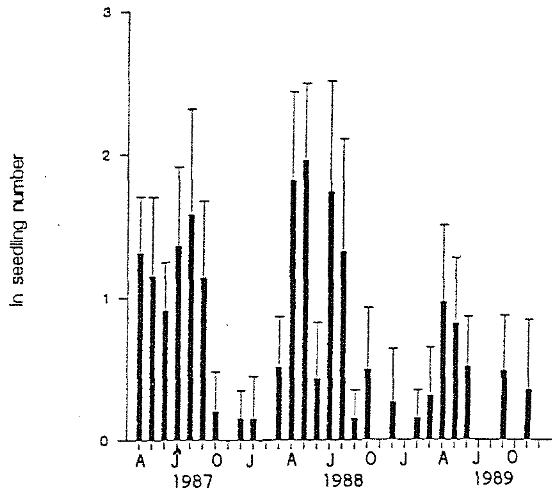
d. Filago spathulata



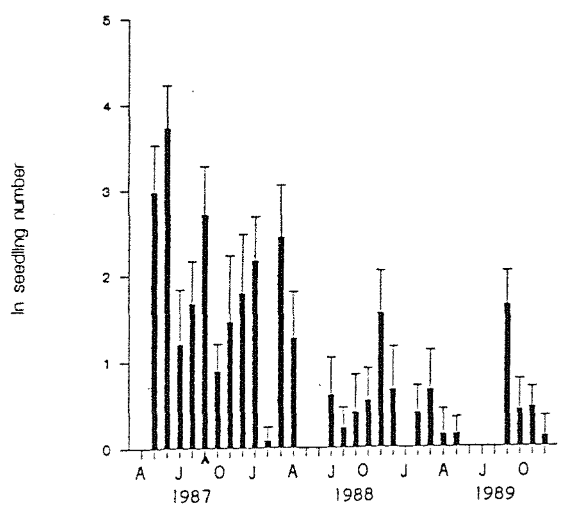
e. Myosurus minimus



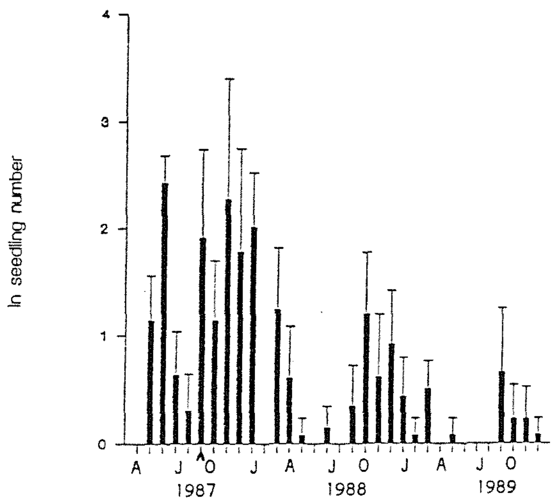
f. Misopates orontium



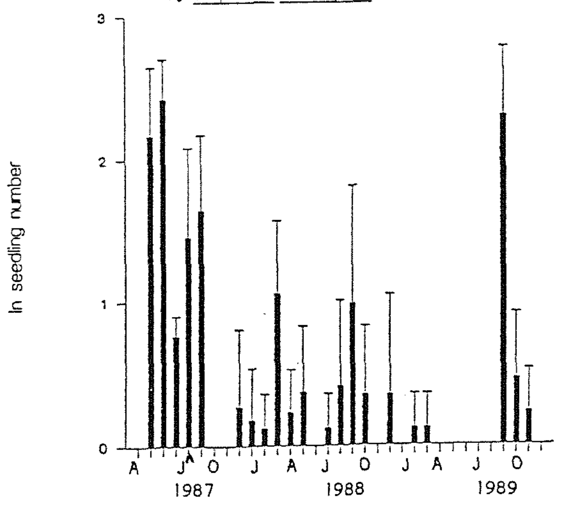
g. Papaver argemone



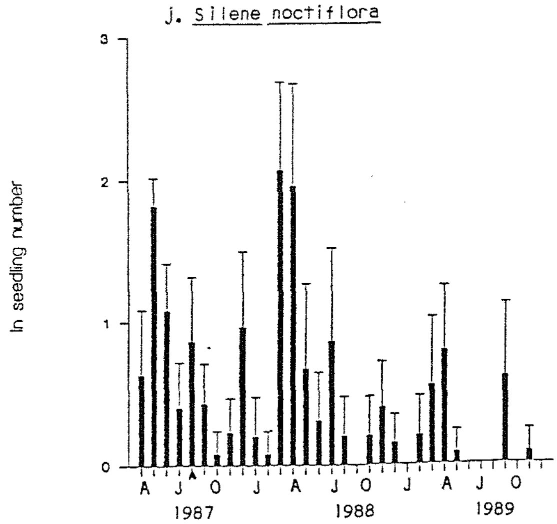
h. Papaver hybridum 1

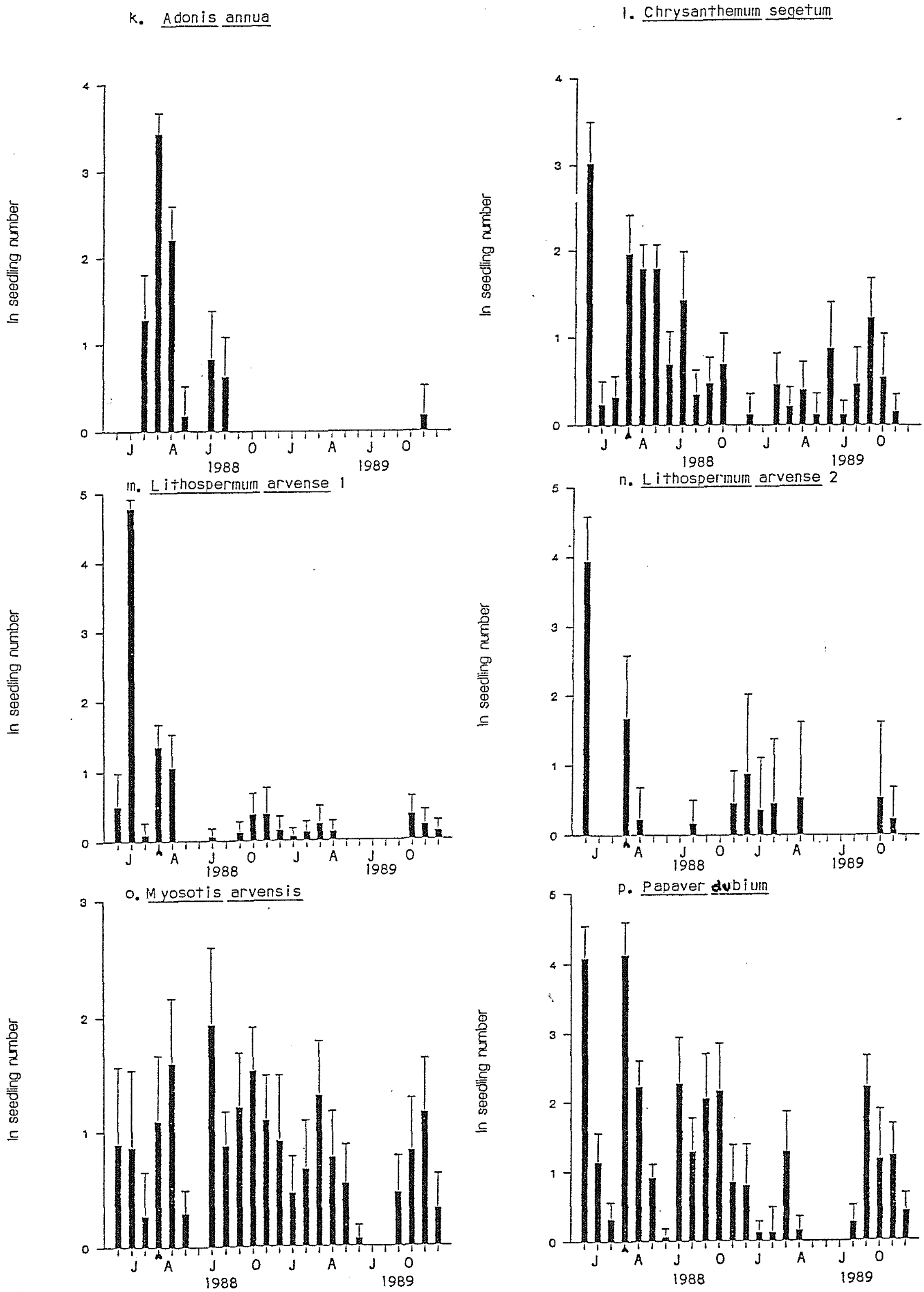


i. Papaver lecoquii

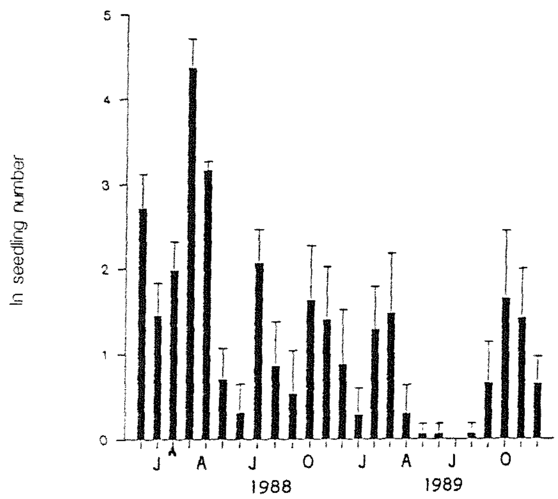


j. Silene noctiflora

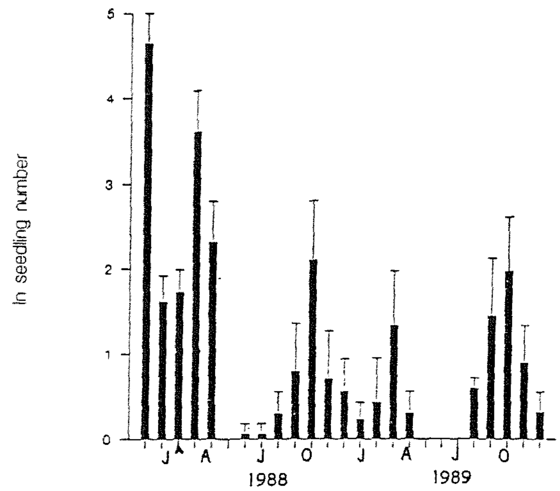



k. Adonis annua
l. Chrysanthemum segetum
m. Lithospermum arvense 1
n. Lithospermum arvense 2
o. Myosotis arvensis
p. Papaver dubium
ln seedling number
J A J O J A J O
1988
1989

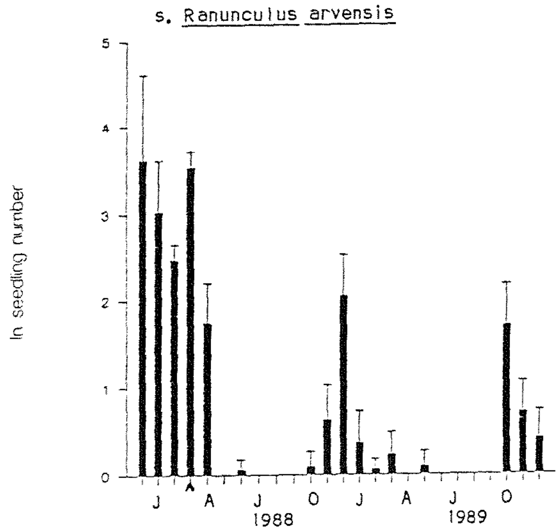
q. Papaver hybridum 2



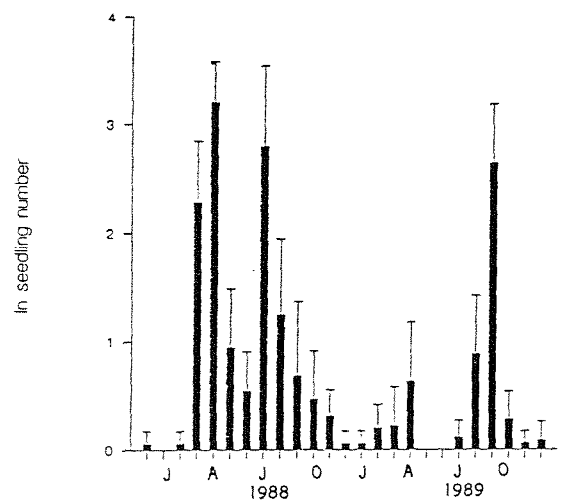
r. Papaver rhoeas



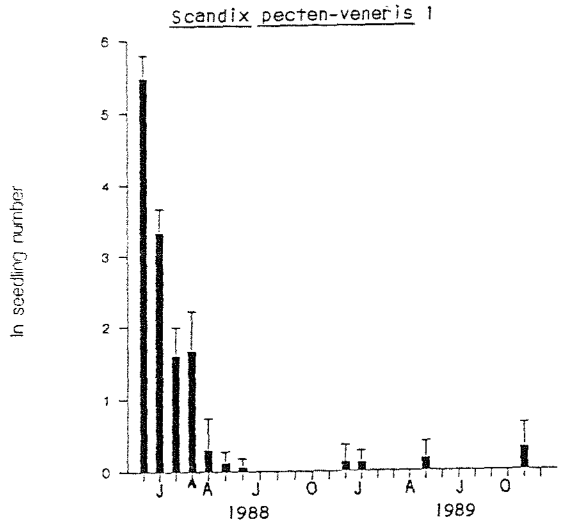
s. Ranunculus arvensis



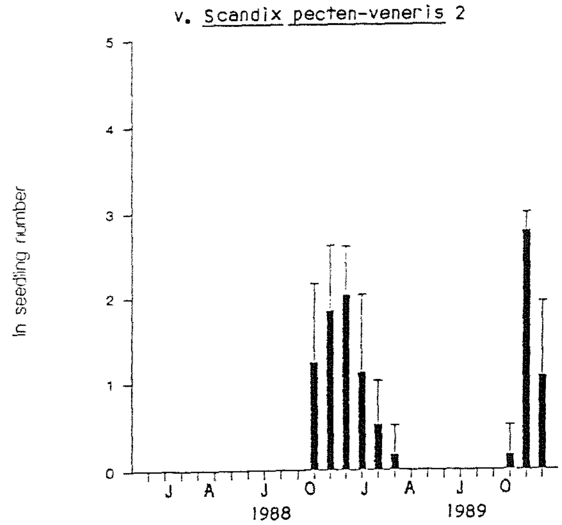
t. Silene alba



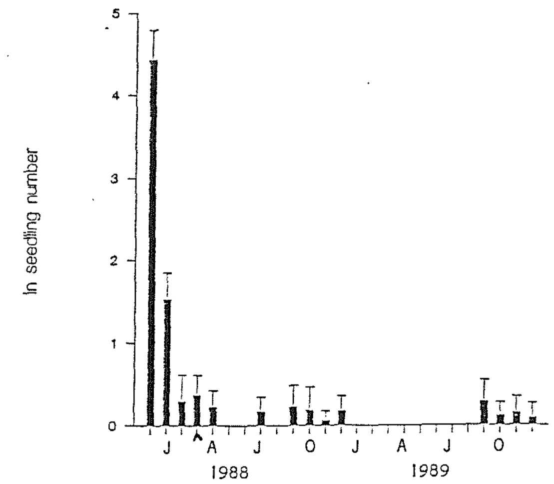
Scandix pecten-veneris 1



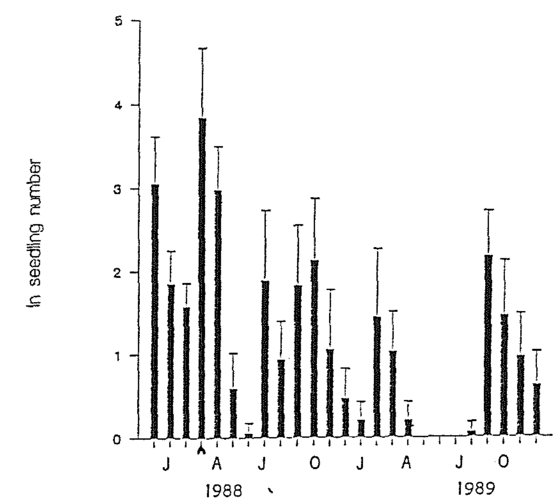
v. Scandix pecten-veneris 2



w. <u>Valerianella rimosa</u>



x. <u>Tripleurospermum inodorum</u>



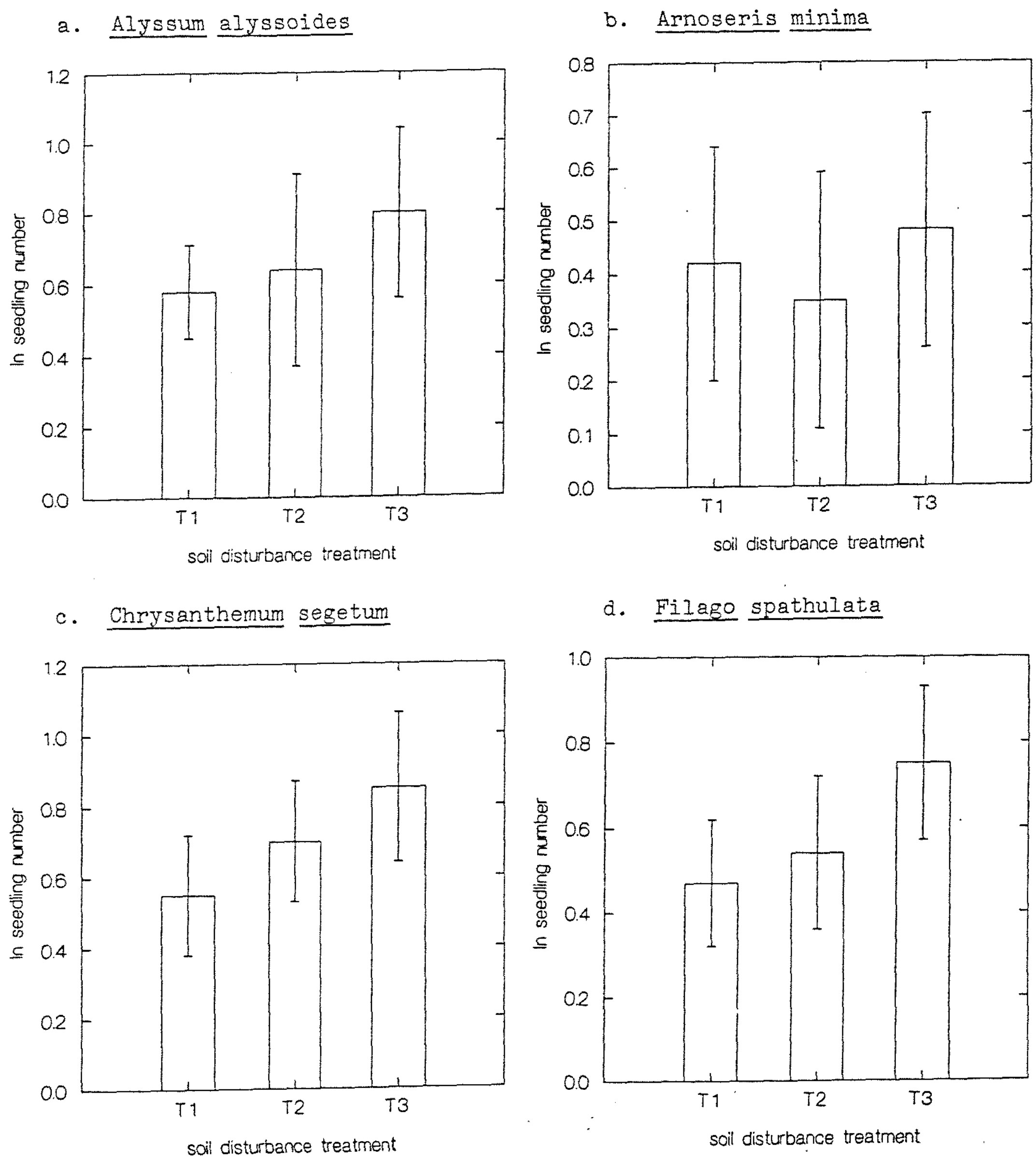
pattern of germination, but with a greater proportion of seedlings being recorded in the spring. The germination periodicity of S. noctiflora was the reverse of this, with most seedlings recorded in March and April, but with a limited autumn germination as well.

A range of commonly occurring species were also tested. Of these, M. arvensis germinated over most of the months between August and May, with fewer seedlings appearing in January and February. The patterns of germination of both common species of Papaver were similar, with relatively large numbers germinating in the autumn, and rather fewer in the spring. S. latifolia had two fairly discrete periods of germination in both years, although in the first year, most seedlings were recorded between March and May, and in the second, between August and September.

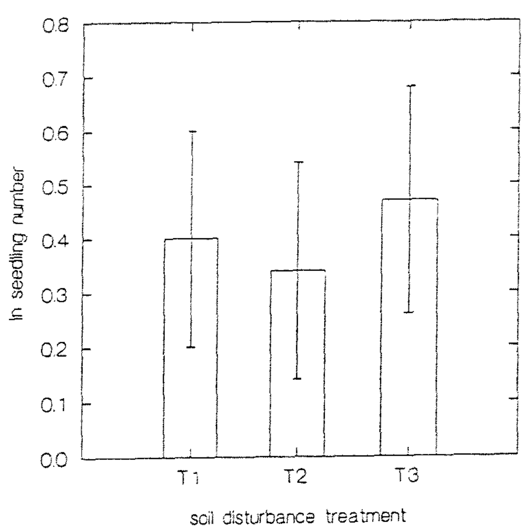
Germination under different soil disturbance treatments.

Three soil disturbance treatments were imposed in this experiment. These treatments led to significant ($P < 0.05$) differences in the numbers of seedlings of A. minima, F. spathulata, M. minimus, M. orontium, P. argemone, P. hybridum 1, S. noctiflora, C. segetum, M. arvensis, P. dubium, P. hybridum 2, S. latifolia, and T. inodorum (Figure 12). In all of the above species, disturbance at monthly intervals, caused higher numbers of seedlings to germinate than did disturbance on only one occasion. Germination of P. argemone, P. hybridum 1 and C. segetum,

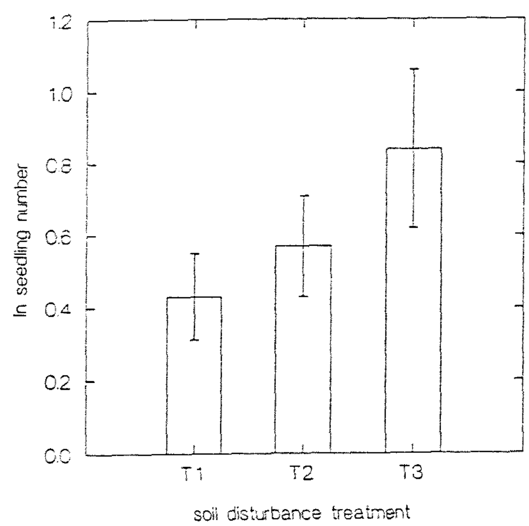
Figure 12. Mean numbers of seedlings germinating per pot in each of 3 soil disturbance treatments in a study of the germination periodicities of seeds of annual weed species. $Log_n(x+1)$ transformed data with 95% confidence limits. T1, soil disturbed in March : T2, soil disturbed in September : T3, soil disturbed monthly. Results averaged over each month of the experiment.



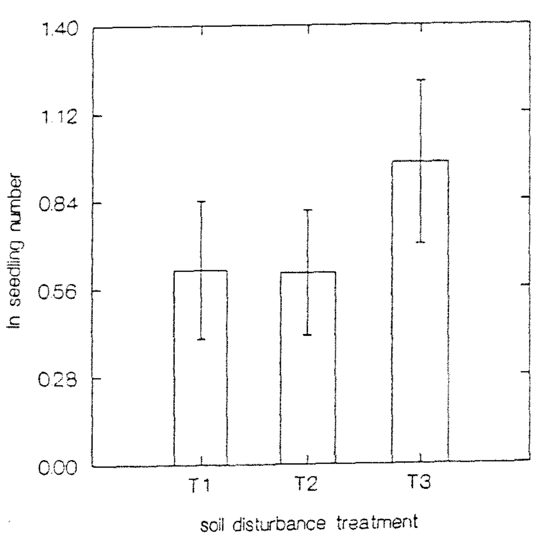
e. *Lithospermum arvense* 1



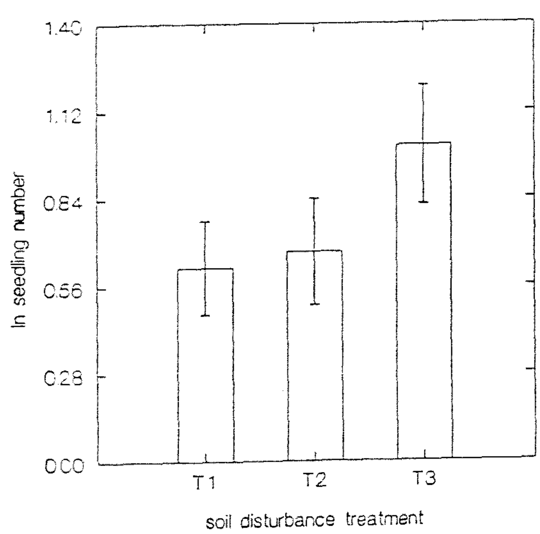
f. *Myosotis arvensis*



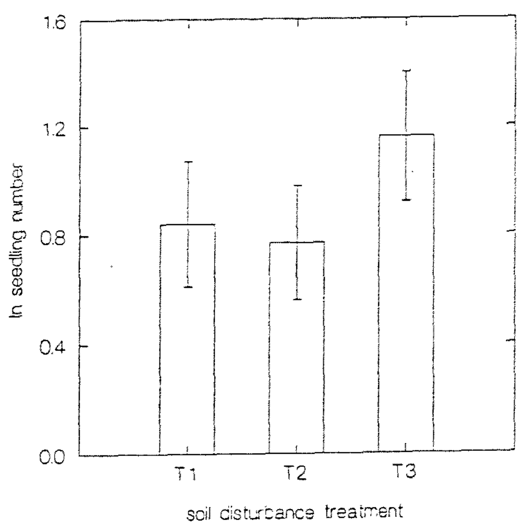
g. *Myosurus minimus*



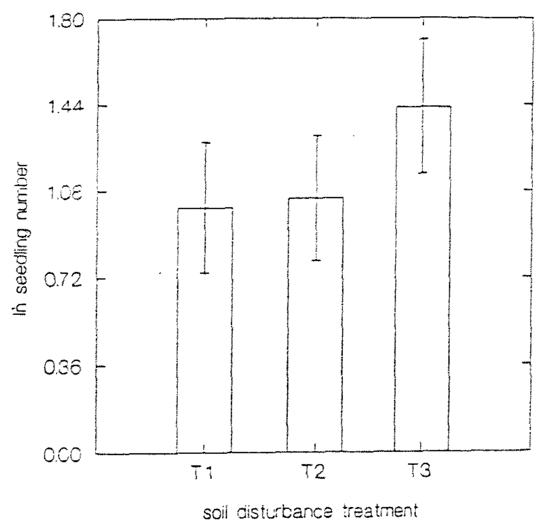
h. *Misopates orontium*



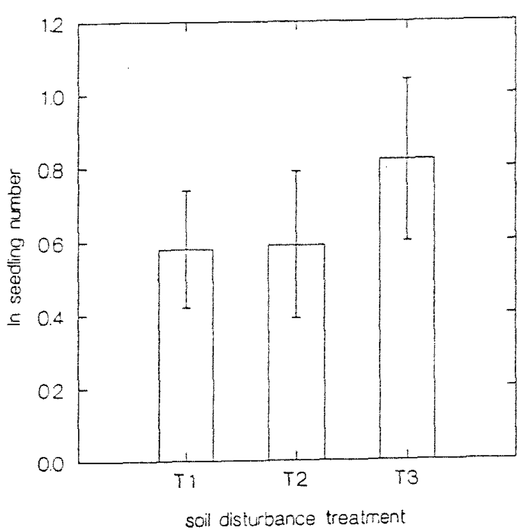
i. *Papaver argemone*



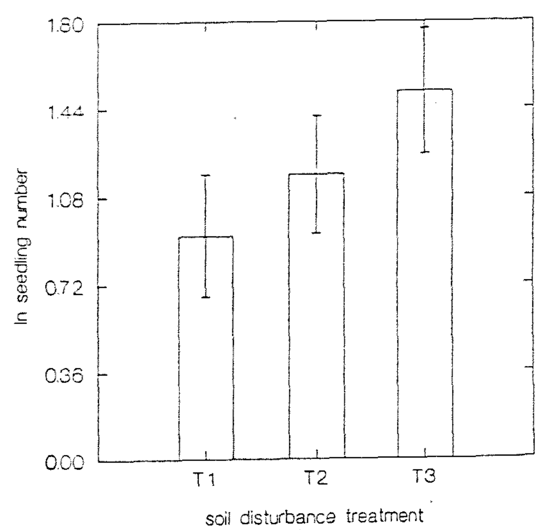
j. *Papaver dubium*



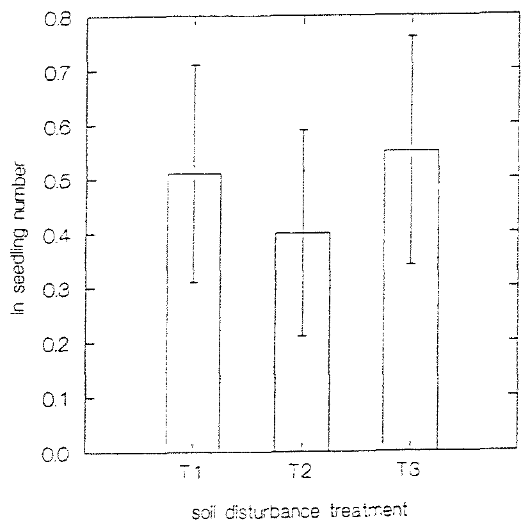
k. *Papaver hybridum* 1



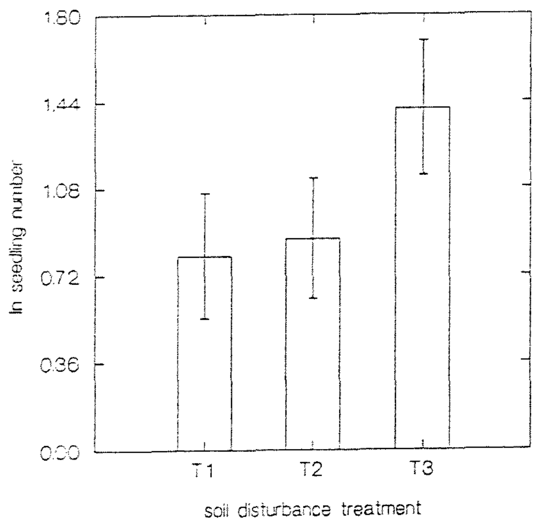
l. *Papaver lecoqii*



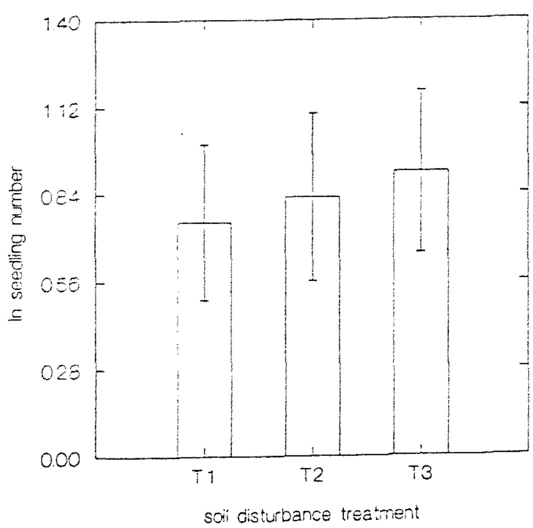
m. *Papaver hybridum* 2.



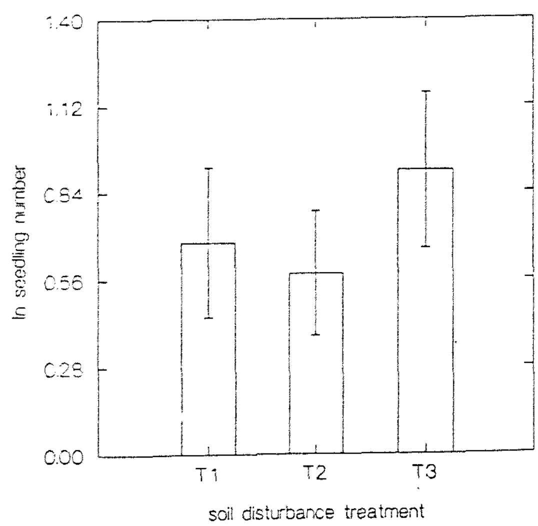
n. *Papaver rhoeas*



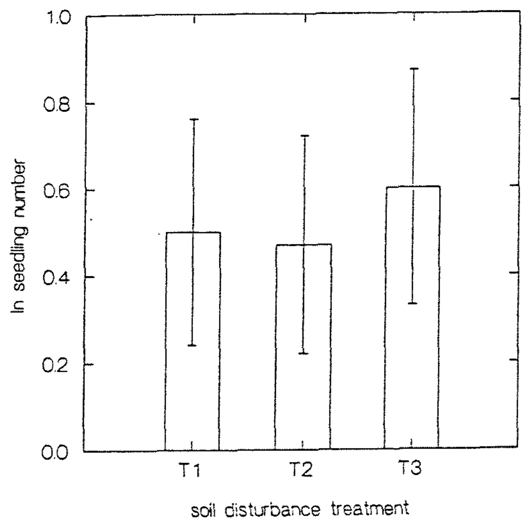
o. *Ranunculus arvensis*



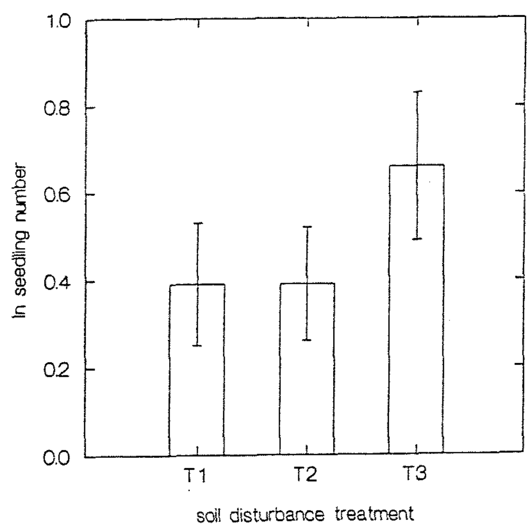
p. *Silene latifolia*



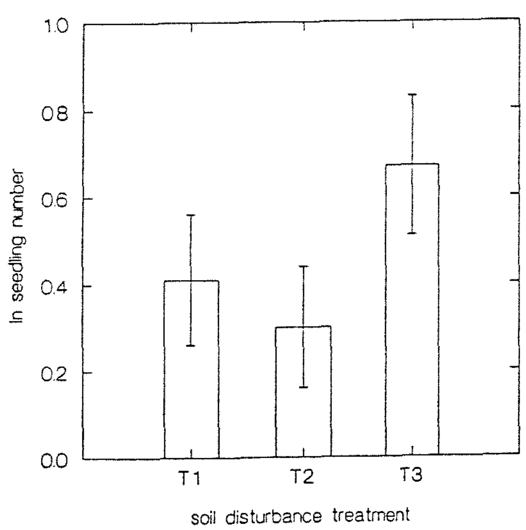
q. Scandix pecten-veneris



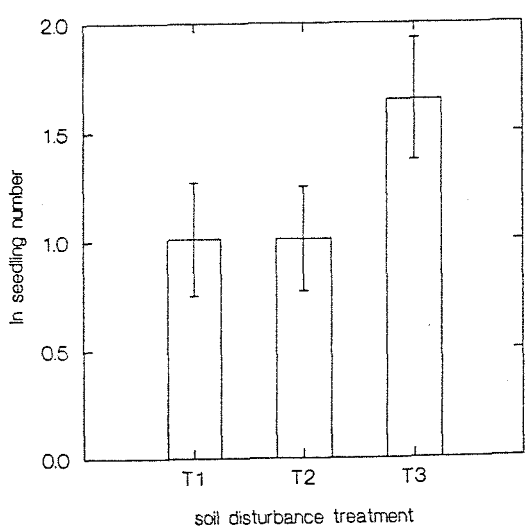
r. Silene noctiflora



s. Valerianella rimosa



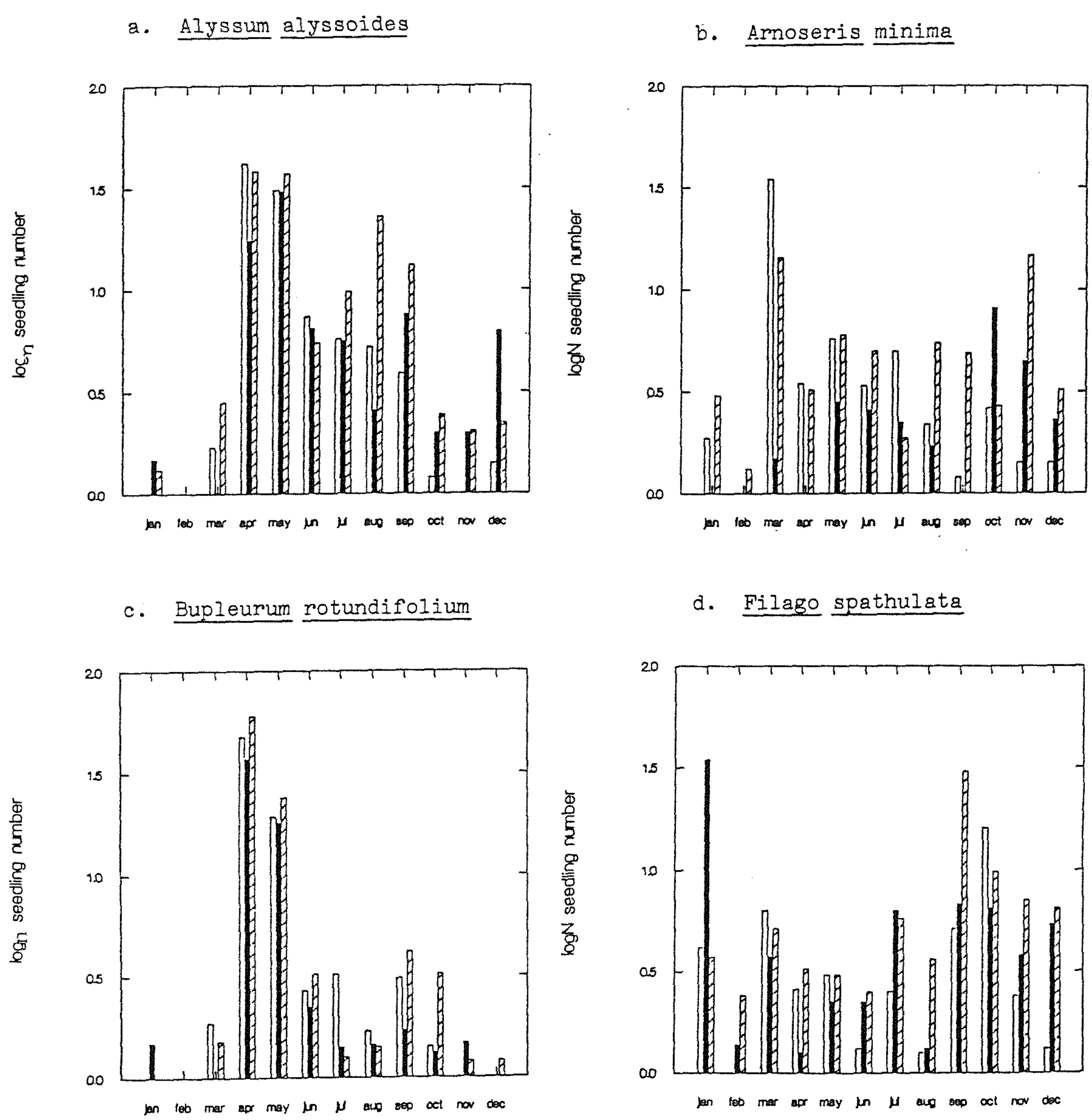
t. Tripleurospermum inodorum



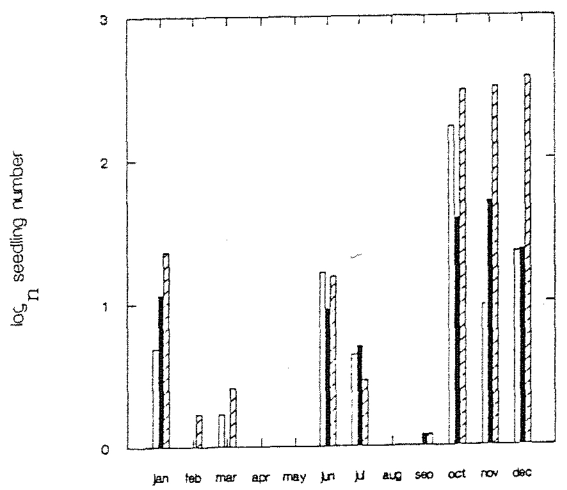
was significantly greater after disturbance in October than after disturbance in March, but P. hybridum 2 and S. latifolia germinated more after disturbance in March than after disturbance in October.

The monthly response of species to the soil disturbance treatments was more difficult to describe (Figure 13), as considerable distortion was introduced by the inclusion of the initial germination, and by the time that elapsed between sowing the seed and the first soil disturbance in October or March. Species for which germination was significantly greater ($p<0.05$) within two months after March disturbance (i.e. treatment 2), than in those pots that had not been disturbed, were A. alyssoides, A. minima, F. spathulata, P. hybridum 1, P. lecoquii, S. noctiflora, C. segetum, P. dubium, P. hybridum 2, P. rhoeas, R. arvensis, S. latifolia, T. inodorum. Species for which germination was significantly greater after October disturbance (i.e. treatment 1) than in undisturbed pots, were P. hybridum (both sowings), C. segetum, M. arvensis, P. dubium, P. rhoeas, T. inodorum, A. minima, P. argemone, F. spathulata, and P. lecoquii. The last two named responded significantly only after two months. The rate of germination of all species subsided after disturbance. The only species for which germination after March or October disturbance was greater than that observed in the pots disturbed monthly, were A. minima (in October), and P. lecoquii (in March). In all other cases, any peaks

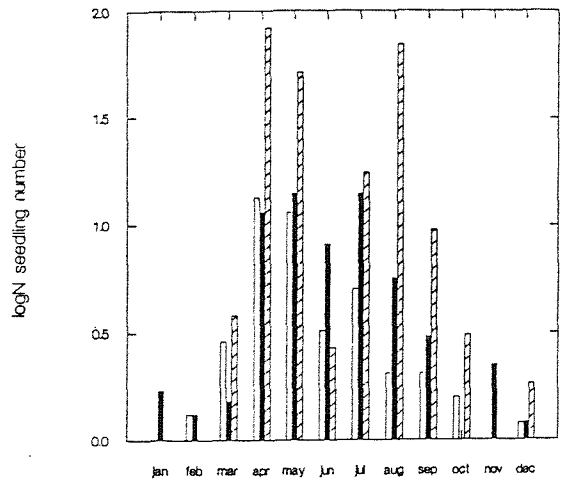
Figure 13. Mean numbers per pot ($\log_n(x+1)$ of seedlings germinating in each month of a study of the germination periodicities of seeds of 24 annual weed species, under 3 different regimes of soil disturbance: 1 ☐ , March disturbance; 2 ■ , September disturbance; 3 ▨ , disturbance each month. a - j sown in March 1987: k - w, sown in November 1987. Results averaged over the three years of the experiment.



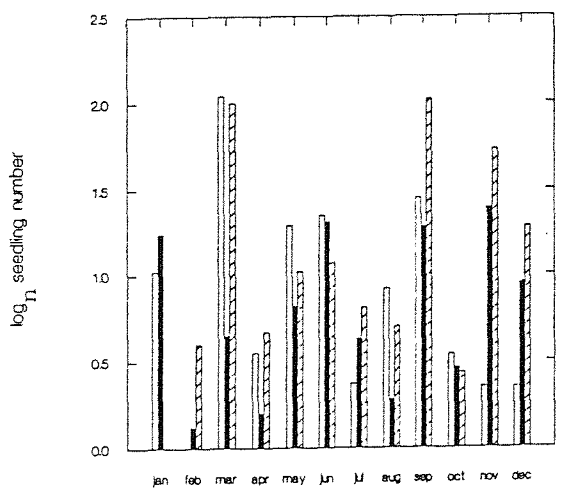
e. Myosurus minimus



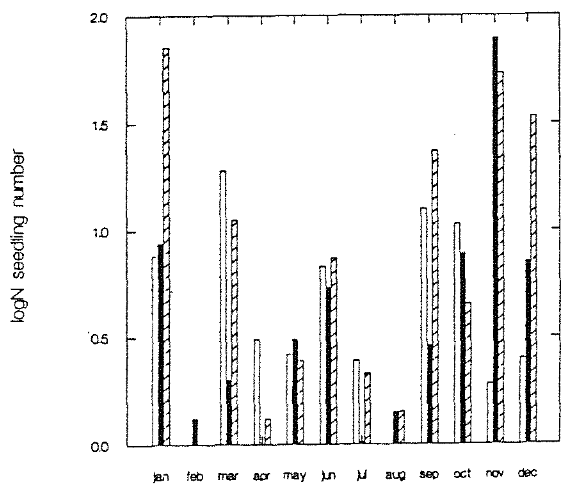
f. Misopates orontium



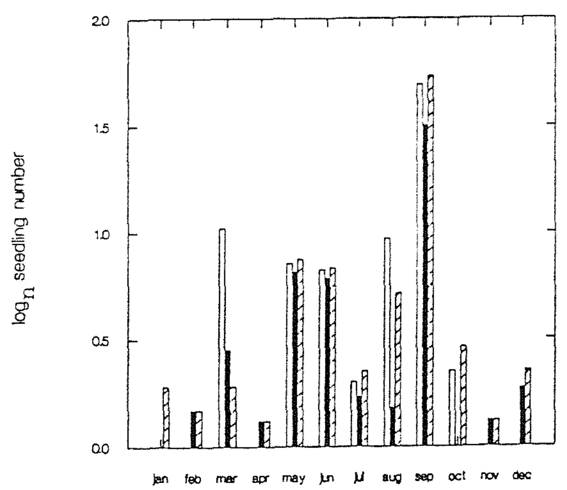
g. Papaver argemone



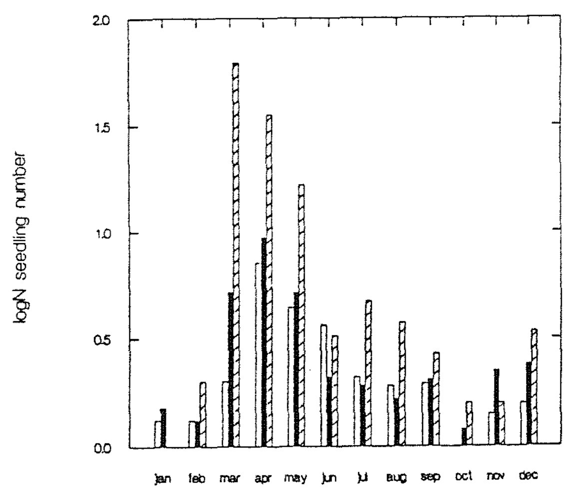
h. Papaver hybridum l.



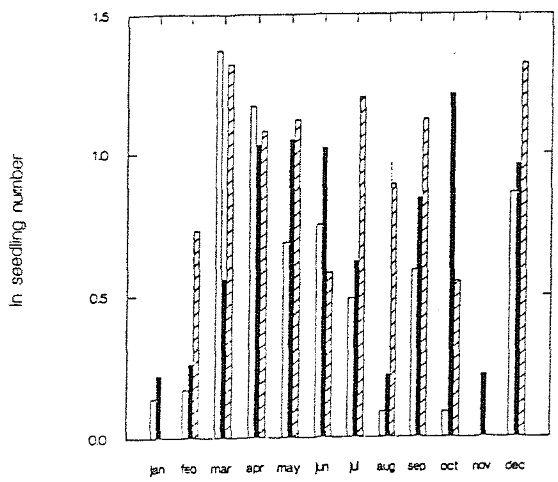
i. Papaver lecoquii



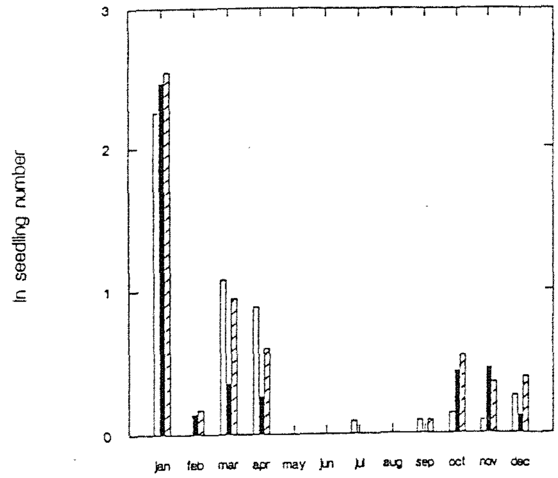
j. Silene noctiflora



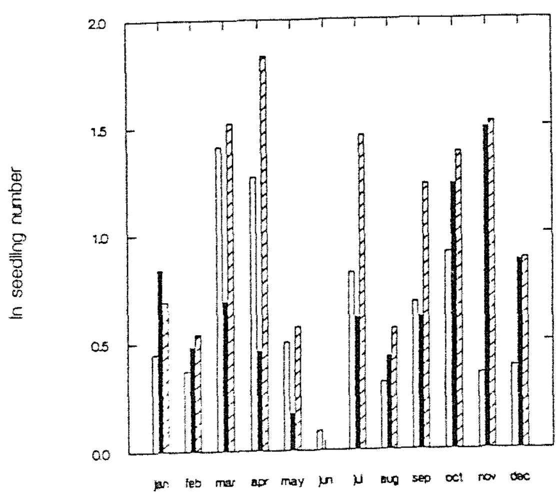
k. Chrysanthemum segetum



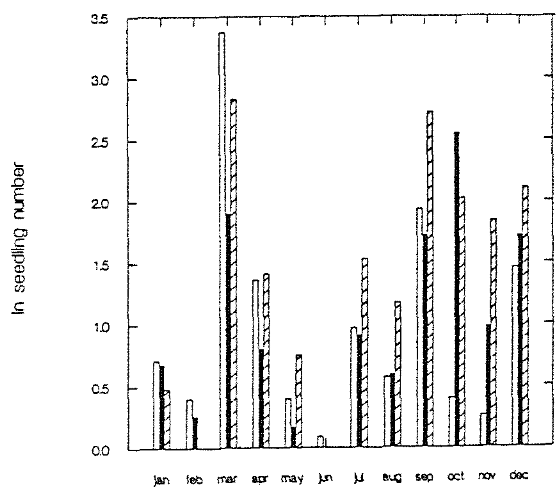
l. Buglossoides arvensis



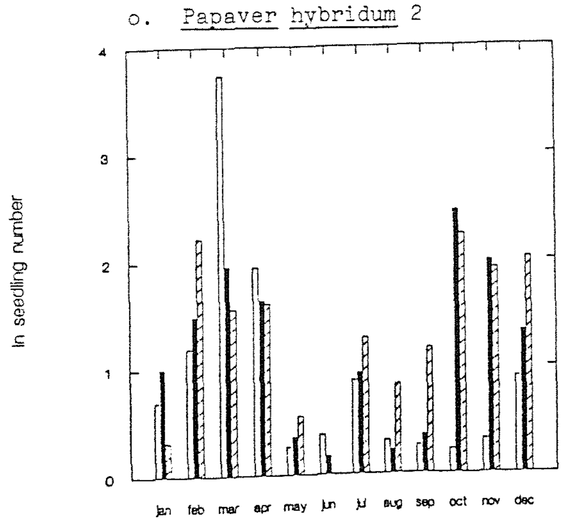
m. Myosotis arvensis



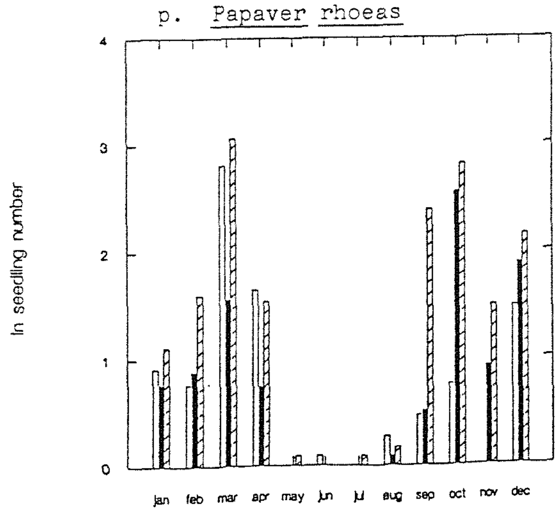
n. Papaver dubium ?



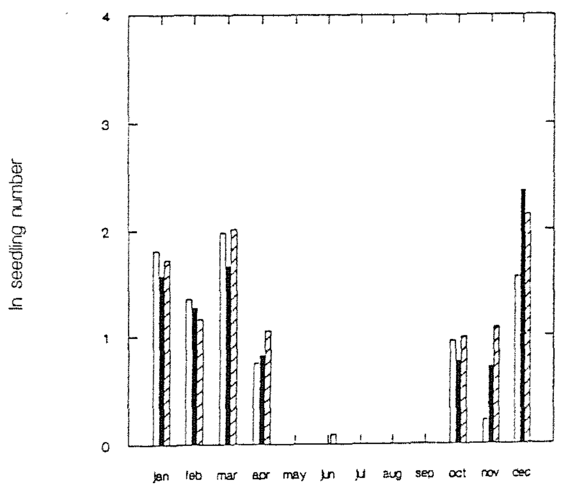
o. Papaver hybridum 2



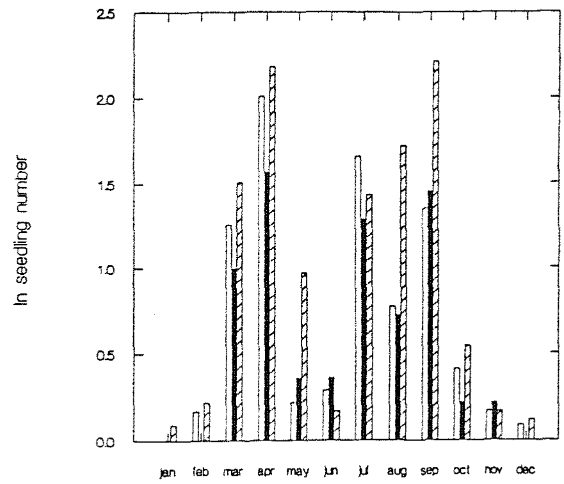
p. Papaver rhoeas



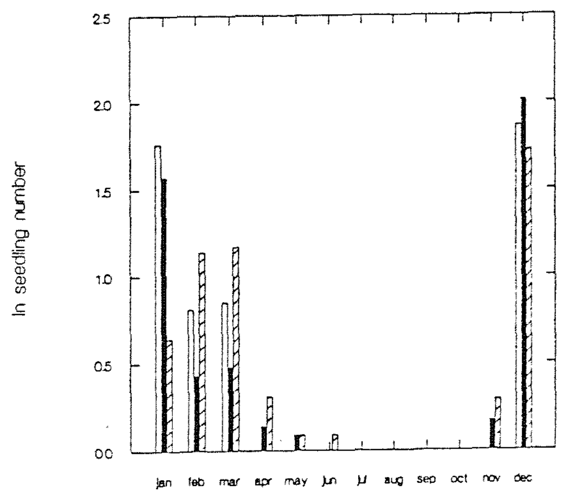
q. Ranunculus arvensis



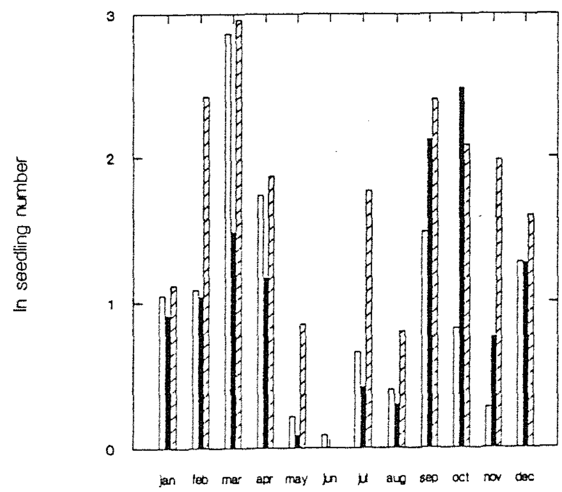
r. Silene latifolia



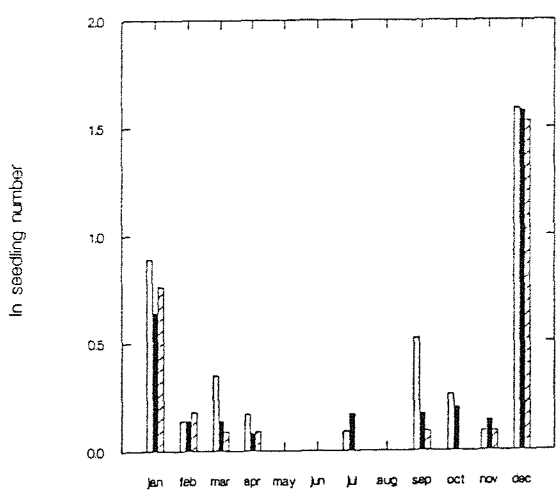
s. Scandix pecten-veneris



t. Tripleurospermum inodorum



u. Valerianella rimosa



of germination in the yearly disturbed pots were closely mirrored by peaks in germination in the monthly disturbed pots.

DISCUSSION

"Initial" germination.

The percentage of the total numbers of seed germinating initially on planting, gave an indication of the dormancy state of the seed that was planted. As the seed planted in March 1987 had been dry stored since the previous autumn, no conclusions could be made about the "innate" dormancy of the seed planted on this occasion. Any delay observed between planting the seed and initial germination was probably due merely to the lengths of time taken for the seed of different species to imbibe sufficient water, and the time taken for the cotyledons to emerge above soil level. Even in the cases of these ten species, germination declined after a few months, as environmental conditions became less favourable to germination, as an "induced" dormancy state became imposed, and as the number of seed in the surface layer of soil became depleted.

The autumn sown seed was sown sooner after harvesting, but there was nevertheless a delay of up to six weeks between harvest and planting, which may have disrupted any physiological dormancy present. It is known that dry storage can affect the dormancy of seed (Popay & Roberts, 1969). Dry storage may however have had relatively little effect on autumn harvested seed, as under natural conditions, seed would have been shed into a relatively dry environment during the summer months, and a short period of dry storage may have simulated this. Some tentative conclusions may therefore be made about the "innate" dormancy of seed of those species sown in October 1987, although these are limited because no initial viability test was made, and because no attempt was made to determine the numbers of viable seed remaining at the end of the experiment. The only species that seemed to have any appreciable amount of "innate" dormancy was Silene latifolia, few seedlings of which germinated until March. All other species exhibited an amount of initial germination, some, such as Scandix pecten-veneris, Valerianella rimosa and Buglossoides arvensis germinating almost entirely within the few months following planting. A second sowing of S. pecten-veneris in September 1988 was carried out, with the aim of reducing any effect of dry storage which may have occurred with the first sowing. Although most of the seed from the second sowing still germinated during the initial period, considerably more survived until the second year. The short period of dormancy in cultivated soil of S. pecten-veneris was also recorded by Brenchley and Warington (1930).

Roberts recorded a range of "innate" dormancies in the species that he examined. For several, such as Anchusa *arvensis*, *Euphorbia peplus*, and *Lamium* spp., a considerable proportion of the seed sown emerged before the end of the year of sowing (Roberts & Boddrell, 1983a). Others, such as *Chenopodium* spp. and *Polygonum* spp., were dormant until the spring after sowing (Roberts & Neilson, 1980). *P. argemone*, *P. dubium*, *P. lecoquii* and *P. rhoeas* were also examined (Roberts & Boddrell, 1984). In all four species, the initial germination recorded was lower than 30%.

Although the initial burst of germination was of interest, it is probably of little relevance in the arable farming situation, except where minimum cultivations are practi ed (Froud-Williams *et al*; 1984) and when considering species known to have little innate dormancy, such as *Agrostemmma githago* (Firbank, 1989) and *Bromus* spp. (Howard *et al*; 1989). In the field, seed will usually be shed into conditions that are unfavourable to germination, and will frequently be incorporated into the soil by ploughing. Seedlings of most species germinating following cultivation will result largely from the return to the surface of the buried seed-bank, and will possess a dormancy state resulting from the environmental conditions experienced in the seed-bank.

Germination periodicity.

The germination periodicities of the species investigated are summarised in Table 32.

Table 32. Summary of the results for monthly germination periodicity. From Figure 11. 1 = January, 12 = December.

	Period of germination.					
	Year 1		Year 2		Year 3	
	Main	Other	Main	Other	Main	Other
Sown March 1987						
Arnoseris minima	10-12		3-4	10-11	9-11	3
Filago spathulata	9-1		10-12	3-4	9-11	2-3
Misopates orontium	7-9		3-4	8	4-5	9,11
Myosurus minimus	10-1		10-12		10-12	
Papaver argemone	8-1		3-4	9-12	9-11	2-3
Papaver hybridum	11-1		10-12	3-4	11	3
Papaver lecoquii	8-9	12	8-10	3-5,12	9-11	2-3
Silene noctiflora	12	8-9	3-5	11	3-4	9
October 1987						
Chrysanthemum segetum	3-5	10	8-10	6,2-4		
Lithospermum arvense 1.	3-4	10-12	10-12	2-4		
L.arvense 2.	3-4	11-2	10-11	4		
Myosotis arvensis	3-4,9-12		2-5,9-11			
Papaver dubium	3-	9-11	9-11	3		
Papaver hybridum	2-	10-12	10-11	2-3		
Papaver rhoeas	3-	9-11	9-11	2-3		
Ranunculus arvensis	2-	11-12	10-11			
Silene latifolia	3-5	8-9	8-9	3-4		
October 1988						
Scandix pecten-veneris	11-12					

All of the species studied showed marked periodicities of germination. Predominantly autumn and winter germinating species included *A. minima*, *F. spathulata*, *M. minima*, *P. argemone*, *P. lecoquii*, *P. hybridum* 1, *R. arvensis*, and *S. pecten-veneris*. Those germinating mainly in spring and summer included *M. orontium*, *S. noctiflora* and *S. latifolia*, and those that appeared to germinate equally in both spring and autumn included *C. segetum*, *L. arvense*, *M. arvensis*, *P. dubium*, *P. rhoeas*, and *P. hybridum*

2. Those species that are still reasonably common were all found to fall into this last category.

In some cases, the period of maximum germination changed from one year to the next. This was especially so for those species sown in the autumn of 1987. This variability may be due to climatic factors, as the weather has been shown to affect seedling emergence from year to year (Roberts & Potter, 1980) and it is known that dormancy can be enforced by adverse weather conditions (Grime, 1979). It is possible that the effects of rainfall may be particularly important (Roberts & Potter, 1980). The patterns of climatic variables during the years of this study were not investigated, but it is of interest that the very high germination of most species in the July of 1988 coincided with a period of above average rainfall. This aberrant peak should therefore be regarded with caution, and was ignored when the results were examined. It does however imply that during the summer, the seeds of some species were in a condition of enforced dormancy, and that adverse weather conditions were important in imposing dormancy during the summer for P. hybridum, P. dubium, P. argemone, S. latifolia, S. noctiflora, V. rimosa, M. arvensis, L. arvense, A. annua, C. segetum, A. alyssoides, F. spathulata and A. minima.

Of the species examined here, the germination profiles of C. segetum, P. rhoeas, P. dubium, P. argemone, and P. lecoquii were studied by Roberts and colleagues (Roberts &

Neilson, 1981; Roberts & Boddrell, 1984; Roberts & Boddrell, 1983), those of *S. pecten-veneris*, *P. rhoeas* and *M. arvensis* were studied by Brenchley and Warington (1930), and *C. segetum*, *P. rhoeas*, *R. arvensis* and *T. inodorum* were included in Mortimer's review (1990). In almost all cases, their results are in agreement with those obtained here. The only major exception was a disagreement with Brenchley & Warington's results for *P. rhoeas*, which they found to germinate largely in autumn and winter. *C. segetum* was found to germinate proportionally more in the spring months by Roberts & Bodrell (1984) than was recorded here. It is not possible to explain these discrepancies without further experimentation. Roberts' experiments were repeated over a number of years, thereby minimising any effects of variable weather conditions. This was not possible in this limited study.

Effects of soil disturbance on germination.

Soil disturbance stimulates the germination of weed seeds, by exposing ungerminated seed in a state of enforced dormancy to light and conditions of fluctuating temperature (Grime, 1979; Wesson & Wareing, 1969a; Roberts, *et al*; 1987). It is to be expected that the greater the frequency of disturbance, the greater will be the proportion of seeds in the soil that will germinate (Roberts & Potter, 1980; Froud-Williams, Chancellor & Drennan, 1984). Of the 20 species investigated, proportions germinating of all but seven species (A. alyssoides, B. rotundifolium, P. lecoquii, B. arvensis, R. arvense, S. pecten-veneris, and V. rimosa) were greater in the monthly disturbed pots. Of these seven species, all but P. lecoquii were characterised by their very high initial germination, before any of the different disturbance treatments came into operation. It is therefore unsurprising that no significant effects between treatments were observed, as insufficient seed remained for significant differences between treatments to be detected.

Disturbance in March or October tended to stimulate the germination of most species, but the two treatment dates varied in their effects. Disturbance in March appeared to have a much larger effect than disturbance in October, even on those species with predominantly winter germination, such as M. minimus, although in this case, germination seemed to be delayed until October. In general, the effect of disturbance in October tended to be delayed relative to the much more rapid effect of disturbance in March. Different dates of soil disturbance were found to have an effect on the development of the weed flora by Roberts & Potter (1980).

No attempt was made to determine the initial viability of the seed used, or the number of viable seeds remaining at the end of the experiment. A comparison of the results here with those recorded in the experiments of Roberts and colleagues (Roberts, 1964; Roberts & Feast, 1973; Roberts &

Neilson, 1980; Roberts & Neilson, 1981b; Roberts & Boddrell, 1984) suggested that the seed used in this experiment had a rather low viability. Although this would not have altered the germination periodicity of the species studied, any conclusions about the rate of decline of seed-banks must be tentative.

The results of this experiment have considerable implications for the conservation of populations of rare annual weed species. The periodicity of germination will determine the potential frequency of weed species in crops sown at different dates. Those species such as M. minimus which germinate mainly in the autumn and winter, will be found predominantly in autumn sown crops, and if any cultivations occur after the seedlings have germinated, they will be destroyed, and will only be replaced in that season if dormancy has not been reimposed (Brenchley & Warington, 1930). Similarly, spring germinating species will not germinate readily in an autumn established crop, due to the germination suppressing influence of the light-excluding crop canopy (Wesson & Wareing, 1969a).

The seedlings germinating within a crop will be subject to competition with each other, and with the crop. The competitive ability of different crops sown on different dates was investigated in a further experiment (Chapter 7). An additional factor of potential importance is the ability of weed seedlings to survive through the winter weather conditions. It is possible that for such species as C. segetum which are normally associated with spring crops, but which are capable of germinating in the autumn as well, overwinter mortality is an extremely important factor in their ecology in Britain. It was not possible to investigate this in detail, although some conclusions were possible from the results of Chapter 7.

The ability of weed seed to persist in the soil is an extremely important adaptation to survival in a regularly disturbed habitat. Although no attempt was made to determine the numbers of seed remaining at the conclusion of this experiment, the presence of viable seed of many species is shown by their continuing germination. Species for which there was little evidence for their persistence, included A. annua, S. pecten-veneris 1, R. arvensis, L. arvense, V. rimosa, A. minima, B. rotundifolium, and A. alyssoides. The great rarity of some of these species may be partially explained by their short lives in the soil. R. arvensis and S. pecten-veneris have both become extremely rare in the last 30 years, A. minima and B. rotundifolium have now become extinct, and both V. rimosa and A. alyssoides are now restricted to very few sites. The most well known instance of the regional extinction of a weed species due to its poor seed persistence is Agrostemma githago (Firbank, 1989). There is however, evidence for considerable longevity of A. annua in undisturbed soil in Wiltshire (Horton, et al, 1972). B. arvense is still relatively common in some areas of the country, although when efforts have been made to eradicate it, this seems to have been acheived with little difficulty, and with no sign of its persistence.

Most of the other species that were still germinating at the end of the experiment were either common or relatively persistent in some areas of the country. The longevity of some *Papaver* species is well known (McNaughton & Harper, 1964). *F. spathulata* and *M. minimus* are rare, but there is little evidence to show that they were ever more common than they are now.

CHAPTER 6

THE EFFECTS OF NITROGEN APPLICATION AND CROP DENSITY ON THE GROWTH AND PERFORMANCE OF ANNUAL WEED SPECIES

INTRODUCTION.

In an arable environment, the growth and seed productivity of a weed plant are influenced by the competitive interactions with both other weed plants and with the crop. The course of competition will be determined by the relative abilities of the different plant species to compete for limited supplies of resources (Grime, 1979; Hakansson, 1986; Goldberg & Miller, 1990). These resources include water, light, nitrogen, phosphorus, potassium, and a range of other nutrients. Of these, one of the most important is nitrogen (Pulcher-Haussling & Hurle, 1986; Ellenberg, 1988; Mahn, 1988), and the amount of nitrogen available to a crop/weed system may be readily altered within the context of a conservation management programme.

One of the main advances in modern agriculture, has been the development of high yielding crop varieties which are capable of utilising much higher levels of nitrogen than in the past (Karpenstein-Machen & Scheffer, 1989; Fischbeck, in press). This has led to the increased levels of nitrogen applied to arable crops (Table 33).

Competition between mixtures of annual plants has been extensively studied. Most of these studies have studied the effects of direct manipulation of plant density, although

Table 33. Changes in the mean amounts of nitrogen applied to cereal crops in Britain since 1943. (From Church, 1981)

Year.	Kg/Ha of N Winter wheat.	Spring barley.
1943	19	21
1957	51	35
1970	90	82
1980	145	86

some have studied the effects of the addition of different quantities of nitrogenous fertilisers. Most of the work on the competitive interactions between crops and weeds has concentrated on the detrimental effects that weeds have on crop yields. Such competitive interactions have been studied for a wide range of weed/cereal mixtures, both in the field and in greenhouse conditions (Gustavson, 1986; Kaiser & Wamhoff, 1986; Pulcher-Haussling & Hurle, 1986; Wilson, 1986; Courtney & Johnston, 1988; Wilson et al; 1988; Firbank & Watkinson, 1985; Wilson & Wright, 1990). Models of competition between species mixtures have also been proposed (Vleeshouwers et al, 1989; Firbank & Watkinson, 1985; Law & Watkinson,1987; Cousens et al, 1988; Spitters et al, 1989; Wilson & Wright, 1990). In a few cases, the subject of inter-specific competition has been approached from the point of view of the productivity of weed plants, rather than the yield of the crop (Wilson et al, 1988; Firbank & Watkinson, 1985; Cousens et al, 1988; Mahn, 1988; Mahn & Muslemanie, 1989). Whichever approach has been taken to the study of weed/crop competition, the findings have demonstrated that different species of annual plant exhibit different competitive abilities when the availability of resources was limited.

It is therefore to be expected that communities of weed species will not be uniformly affected by the improved performance of the crop in response to increased nitrogen supply, but that some species may increase, while others may decrease, even to the point of extinction. Mahn (1984; 1988) has demonstrated the structural changes in response to nitrogen inputs in experimental populations of weeds both with and without the presence of a crop, and the differences within the populations of weeds in the Broadbalk experiment under different levels of nitrogen were demonstrated by Brenchley & Warington (1930). Impoverishment of weed communities after nitrogen application has been recorded in Poland (Milijic, 1980), but in comparison with the effects of herbicides, the influence of nitrogen inputs has been poorly documented.

The effects of eutrophication on plant and animal communities in a range of habitats in Europe have been considered to be among the most serious problems confronting the maintenance of biological diversity in Europe (Maitland, 1984; Edwards, 1984; Ellenberg, 1988 & 1989; Dierben, 1989; Hopner, 1989; Kratochwil, 1989; Roelofs et al; 1989), and more specifically the detrimental effects on arable habitats have also been recorded, although usually as an interaction with the use of herbicides (Holzner, 1978; Oesau, 1979; Eggers, 1984b).

It has been suggested that many of those weed species that have declined in recent years, are poorly competitive in relation to crops and other weed species when supplied with large amounts of nitrogenous fertiliser. Two species characteristic of very infertile soils, *Caucalis platycarpos* on basic soils, and *Arnoseris minima* on sandy soils, are thought to have become much rarer in Europe partially as a result of increasing fertiliser use (Eggers, 1984a). These two species are now extinct in Britain, and the phytosociological groups of which they were once characteristic have suffered considerable degradation (Silverside, 1977; Eggers, 1984a). A knowledge of the response of weed species to increased supplies of nitrogen is essential to an understanding of the change of weed communities in recent years.

Two experiments were carried out to investigate the effects of nitrogenous fertiliser. The first studied the response of a mixture of weed species to three levels of supplied nitrogen in spring barley and winter wheat crops, both sown at two seed rates in field plots. The second studied the response of populations of single weed species to three levels of nitrogen supply, with or without the presence of a crop of spring barley,

MATERIALS AND METHODS.

Experiment 1.

Experiments were set up at two sites in Hampshire. An analysis of the soil at the two sites is given in Table 34.

Table 34. Soil analysis of the two sites used in experiment 1.

	1. Chilworth	2. Manydown
Texture	Sandy loam	Very calcareous silty clay loam
Sand	71.3%	15.1%
Silt	15.2%	53.8%
Clay	13.5%	31.1%
Organic matter	6.3%	4.1%
pH	7.0	7.5

The experiments were of a randomised block design, with three replicates of each treatment. Nitrogenous fertiliser was applied (as ammonium nitrate pellets) at one of three levels, 0, 75, and 150 kg nitrogen/ha, as two equal applications at the beginning and end of March. Phosphate + potassium fertiliser was applied to all plots at a level of 52.5:80 kg/ha. Two crop types, winter wheat (cv. Mercia) and spring barley (cv. Doublet) were hand-drilled at two seed densities, 125 and 75 kg/ha; the wheat between the 19th and 24th of October 1987, and the barley between the 22nd and the 25th of February 1988. Uncropped plots cultivated in autumn and spring were also included.

Each plot measured 3m x 3m, and a mixture of weed seed of known composition (Table 35) was sown onto the soil surface of the central 2m x 2m portion of each plot at the time of drilling the cereal crop. The weed seed was obtained mostly from plants grown in 1987 from seed supplied by the Suffolk Wildlife Trust, although seed of *Viola arvensis*, *Chrysanthemum segetum*, *Buglossoides arvensis*, *Papaver rhoeas*, *Myosotis arvensis*, *Scandix pecten-veneris* and *Ranunculus arvensis* was obtained from commercial seed suppliers. Every effort was made to ensure that the seed used was fresh, i.e. harvested in autumn 1987. The seed mixtures sown at the two sites differed due to the short supply of some species. In the cases of species where supply was limited, the seed was sown in the experiment with the most appropriate soil type. The weed seed for the spring barley plots was buried over the winter in the plots at a depth of about 15 cm in porous nylon net bags, in order to simulate a natural seed-bank, and the bags were exhumed at the time of drilling. The 0.5m strip around each plot which did not receive weed seed, acted as a buffer zone in order to reduce edge effects.

Table 35. Composition of the weed-seed mixtures sown in the central $4m^2$ portion of $9m^2$ plots of cereal. - = species not sown.

	Seeds per plot.	
	Manydown.	Chilworth.
Alyssum alyssoides.	-	50
Arnoseris minima.	-	50
Bupleurum rotundifolium.	50	-
Chrysanthemum segetum.	50	50
Filago spathulata.	50	50
Buglossoides arvens .	50	-
Misopates orontium.	100	100
Myosurus minimus.	-	50
Papaver argemone.	-	100
Papaver hybridum.	100	100
Ranunculus arvensis.	50	-
Scandix pecten-veneris.	50	-
Silene noctiflora.	100	100
Valerianella rimosa.	50	-
Myosotis arvensis.	100	100
Papaver rhoeas.	100	100
Silene ____.	100	100
Tripleurospermum inodorum.	100	100

Assessments of the numbers of sown weed plants present were carried out in January and August (pre-harvest). In August, sample plants were harvested for determination of fruit production and dry weight. Ideally six plants were harvested per plot, although in some cases the effect of the treatment on the survival of weed plants to fruition was so great as to make this impossible. No attempt was made to differentiate between plants germinating from the sown seed and from the existing soil seed-bank, and it was assumed that the native seed-bank was distributed across the experimental areas independently of the experimental layout.

In the case of most species, direct determination of seed production was impossible in practice. Numbers of "fruiting units" were counted instead, on the assumption that the numbers of individual propagules produced per "unit" counted, would remain constant over all treatments. For some species, e.g. B. arvensis, Bupleurum rotundifolium, S. pecten-veneris, Alyssum alyssoides and M. arvensis, this assumption was valid, the numbers of seed produced per flower being a fixed number. For some species however, such as Papaver spp., Silene spp., Misopates orontium and species of Compositae and Ranunculaceae, it was probable that the number of seeds per "fruiting unit" varied according to environmental conditions (Salisbury, 1961). Under extreme conditions of nutrient deprivation, it is known that P. rhoeas plants can produce seed capsules containing as few as 4 seeds, while in more favourable conditions, capsules can contain as many as 1000. The other *Papaver* spp. studied, *P. hybridum* and *P. argemone*, are said to show less variation (McNaughton & Harper, 1964). Numbers of seed produced per "unit" were counted for samples from *P. hybridum*, *S. noctiflora*, *C. segetum*, *M. orontium* and *V. rimosa*, in the 3 different fertiliser levels, but there was found to be no significant difference between the numbers of seed produced per pod, Some figures for seed production per "fruiting unit", and the nature of the unit counted for each species, are presented in Table 36.

Table 36. Nature of the "fruiting unit" counted for each species, and numbers of seed produced per "fruiting unit".

Species.	Fruiting unit	Numbers of seeds
Papaver hybridum	Ripe capsule	465
Silene noctiflora	Ripe capsule	113
Chrysanthemum segetum	Involucre with ripe seed	102
Misopates orontium	Ripe capsule	60
Buglossoides arvensis	Calyx with ripe seed	3.8
Ranunculus arvensis	Flower with ripe seed	4.5
Scandix pecten-veneris	Pair of ripe seed	2
Bupleurum rotundifolium	Pair of ripe seed	2
Valerianella rimosa	Cyme with ripe seed	11.8
Filago spathulata	Flower with ripe seed	-
Papaver argemone	Ripe capsule	-
Alyssum alyssoides	Ripe siliqua	4
Arnoseris minima	Involucre with ripe seed	13.0
Myosurus minimus	Flower with ripe seed	-
Papaver rhoeas	Ripe capsule	575
Silene latifolia	Ripe capsule	-
Myosotis arvense	Calyx with ripe seed	3.6
Tripleurospermum inodorum	Flower with ripe seed	-

Crop plants were counted in January (wheat) and May (barley); samples of crop were also harvested from 4 x

$0.1m^2$ quadrats in the buffer strips for dry weight determination in May; crop ears per m^2 were counted and crop height was measured (at Manydown only due to collapse of the Chilworth crop) immediately before harvest.

Numbers of indigenous weeds developed from the seed-bank were recorded in 4 x $0.25m^2$ quadrats in May, and 4 x $0.1m^2$ quadrat samples were harvested at the same time from the buffer strips for dry weight determination.

Experiment 2.

In order to investigate the behaviour of three weed species in response to different supplies of nitrogen in the presence or absence of a crop, a further experiment was carried out during the summer of 1989.

In February 1989, 54 polythene tanks, each measuring 45cm x 25cm, and with a depth of 30cm, were sunk into the ground in three blocks of 18 tanks each. An exposed rim of about 5cm was left protruding above ground level, 3 cm depth of gravel was placed in the bottom of each tank, which was then filled to ground level with sterilised, John Innes No.1 soil containing no added fertiliser. After this had been allowed to settle, barley (cv. Arena) was drilled in nine tanks in each block, at a density of 125 kg/ha. In practice this meant three rows along the long axis of each tank, and two rows at right angles to these at the ends of the tank.

Phosphate and Potassium fertiliser was added to the soil of all 54 tanks at a level of 52.5:80 kg/ha, and 100 seeds of one of three naturally spring germinating weed species (Chapter 5), Papaver rhoeas, Papaver hybridum, or Silene noctiflora, were sown into each one. Ammonium nitrate was then added at either 125 kg/ha, 62.5 kg/ha or was not added, to give a fully factorial design in which each fertiliser level was replicated three times for each weed species both with and without barley added. The tanks were watered at intervals of 2-3 days until the end of June.

All extraneous weeds were removed from the tanks as they appeared, and in order to minimise all competition other than that between weed plants and the crop, the sown weed seedlings were counted and thinned to between 10 and 20 individuals per tank on the 10th of May. Crop plants were also counted on this date and weed seedlings were counted again on the 25th of May. The entire crop production, and 10 weed plants (or all, if fewer were present) were harvested from each tank on the 8th of August. Crop and weed dry weights were determined, and number of crop ears counted. Seeds produced per capsule were counted for five weed plant capsules from each tank as far as was possible.

RESULTS.

Experiment 1.

Mean number of plants (square-root transformed), total dry matter production ($\log_{10}(n+1)$ transformed), and total fruit production ($\log_{10}(n+1)$ transformed) per plot for each species, the number of rare and common species per plot, total numbers of rare and common weed plants and crop plants per plot (square-root transformed), crop biomass and indigenous weed biomass ($\log_{10}(n+1)$ transformed) and crop height were analysed with respect to fertiliser level and crop seed density and crop type by analysis of variance (Tables 37 - 41).

a. Crop performance.

Due to a total crop failure of spring barley at the Manydown site due to a combination of drought and bird damage, results were not collected from the spring barley treatments at this site, and a comparison between the performance of weed species in spring barley and winter wheat was possible only at Chilworth.

Even at Chilworth, germination of the barley was poor, but was considered sufficient for the purposes of the experiment. No significant differences were observed between the dry matter production or the numbers of ears produced by the crops when sown at different densities, although the crop seedling numbers were found to be significantly higher in the plots drilled at the high seed density in both crop types. Crop dry matter production however showed a very significant positive response to increasing fertiliser rate, (Table 37) as did the dry matter production by the associated weed flora (Table 40).

Table 37. Effect of nitrogen and crop type on crop performance (means from square-root transformed data for numbers of ears and numbers of plants, and $\log_{10}(n+1)$ transformed data for crop dry weight; crop height was untransformed) in winter wheat and spring barley sown at two different densities, at three nitrogen application levels (See Appendix 2 for transformed results with confidence limits). [1] Wheat counted in January, barley counted in May.
Crop type; B = Spring barley; W = Winter wheat.
Significance level (F-test); C = Crop type, S = Crop seed density, N = Nitrogen level : P < 0.05 *; P < 0.01 **; P < 0.001 ***; N.S. = not significant.

		Nitrogen level, kg N/ha.							
		0	0	75	75	150	150		
		Crop seed density, kg N/ha.							
	Crop	150	75	150	75	150	75		
CHILWORTH.									P
Number of ears/m².	W	222.6	203.3	220.2	163.1	221.7	184.4	C	***
	B	156.5	201.6	134.1	141.3	130.9	97.4		
No. plants /m². after sowing.[1]	W	215.5	154.8	223.8	149.6	233.2	139.2	C	***
								S	***
	B	39.6	48.3	43.4	36.1	24.5	31.8		
Mean dry wt. of crop g/m².	W	10.5	12.3	35.6	21.7	46.9	30.7	N	**
								C	**
	B	1.3	1.9	4.6	6.7	4.9	4.9		
MANYDOWN. (Winter wheat only).									
No. of ears/m².		306.6	291.4	468.3	402.8	505.8	490.2	N	**
No. plants /m²; January.		235.0	191.8	267.0	151.5	180.4	162.8	S	**
Crop height (cm.)		51.5	48.4	71.5	75.5	76.8	82.3	N	***
Mean dry wt. of crop. g/m².		33.0	36.1	90.4	63.9	72.0	63.0	N	**

The level of nitrogen supply had no observable effect on crop establishment at either site, as it was applied after the crop had established (5 months after wheat drilling, and between 1 & 2 months after barley drilling). The only significant differences in the numbers of ears produced per m^2 were recorded at Manydown, where increasing amounts of nitrogen caused a significant increase in the number of crop ears/m^2, although the crop dry matter production was greatest at 75kg/ha, decreasing slightly between that and the full nitrogen application. Crop height was also positively related to increasing application of nitrogen (Table 37).

b. The effects of nitrogen application on weed numbers.

At Chilworth, an increase in the supply of nitrogen significantly reduced both the total number of rare weed plants producing fruit and on the mean number of rare species recorded (Table 38). In some of the winter wheat plots, very few weeds were present at the higher fertiliser levels, although in spring barley, higher fertiliser levels tended to favour the growth of a very few common species such as Stellaria media and Capsella bursa-pastoris at the expense of the significantly greater variety of common species found at lower levels.

All but two (Chrysanthemum segetum and Silene noctiflora) of the rare species sown at Chilworth showed a very marked negative response to an increase in the level of fertiliser applied. Two, Myosurus minimus, and

Table 38. Effect of nitrogen and crop type on the mean numbers of weed species per 4m^2 plot (from square-root transformed data) in an experiment in which nitrogenous fertiliser was applied at three levels to winter wheat and spring barley. Crop type; B = Spring barley; W = Winter wheat. (See Appendix 2 for transformed results with 95% confidence limits).
Crop type: B Spring Barley, W Winter wheat.
Probability (F-test): $P < 0.05$ *; $P < 0.01$ **; $P < 0.001$ ***; N.S. = not significant.

	Crop	Nitrogen level, kg/ha. 0	75	150	P
CHILWORTH.					
Total no. of rare species/plot	B	6.83	5.68	2.11	Nitrogen ***
	W	7.63	5.29	3.89	
Total no. of rare plants/plot.	B	58.83	30.80	11.97	Nitrogen ***
	W	45.16	20.88	11.76	
Total no. of common species/m^2.	B	16.54	14.09	11.99	Nitrogen **
	W	15.29	13.81	12.69	
Total no. of common plants/m^2.	B	145.20	129.50	91.01	Nitrogen **
	W	156.75	121.66	116.86	
MANYDOWN. (Winter wheat only).					
Total no. of rare species/plot.		11.47	10.64	10.26	N.S.
Total no. of rare plants/plot.		60.37	38.44	30.47	Nitrogen **
Total no. of common species/m2.		18.92	16.97	15.44	N.S.
Total no. of common plants/m^2.		113.21	108.58	91.20	N.S.

Arnoseris minima were not present at all in the fully fertilised plots, and as single individuals only in the 75 kg N/ha plots (Table 39). Numbers of both Filago spathulata and Alyssum alyssoides showed highly significant decreases with increasing nitrogen supply, as did Papaver hybridum and Misopates orontium, although in both of these cases, the effects were greater in spring barley (Table 39). The numbers of P.argemone decreased significantly with increasing supply of nitrogen in the winter wheat plots only, and few plants were to be found at all in the spring barley plots.

Numbers of C. segetum, S. noctiflora, P. rhoeas and Myosotis arvensis were not significantly affected by fertiliser application, although mean numbers did decrease as fertiliser increased. The numbers of the other common species, Silene latifolia increased significantly with increasing nitrogen level (Table 39).

Results from the experiment at Manydown were less satisfactory than those from Chilworth. As mentioned above, the spring barley failed completely, and differences in soil quality across the experiment led to differences in crop performance that were not compensated for by the experimental design. In addition, the existing weed population was considerable, and cultivations in the autumn failed to kill off all established plants. A particular problem species was P. rhoeas.

The total number of rare plants recorded per plot

Table 39. Effect of nitrogen and crop type on the mean number of plants of weed species per $4m^2$ plot (derived from square-root transformed data) in two experiments in which nitrogenous fertiliser was supplied at three levels to crops of winter wheat and spring barley. (See Appendix 2 for transformed results with 95% confidence limits). Crop type. B = Spring barley; W = Winter wheat. Significance levels (F-test): * < 0.05, ** < 0.01, *** < 0.001.

		Nitrogen supply, kg/Ha.				
		0	75	150		
CHILWORTH.	Crop				P	
Papaver	B	8.3	5.4	1.9	N.S.	
rhoeas	W	2.0	3.0	3.5		
Myosotis	B	2.3	2.4	1.0	N.S.	
arvensis	W	0.9	0.5	0.3		
Silene	B	0.1	3.4	2.8	Nitrogen	**
latifolia	W	0.03	0	0.03	Crop	***
Papaver	B	7.0	4.0	0	Nitrogen	***
hybridum	W	2.3	0.7	0.2		
Silene	B	14.4	12.7	7.3	Crop	***
noctiflora	W	4.1	3.2	2.0		
Chrysanthemum	B	8.5	6.3	4.0	Crop	***
segetum	W	0.8	0.8	0.6		
Misopates	B	6.2	1.6	0.03	Nitrogen	***
orontium	W	0.6	0	0	Crop	***
Papaver	B	0.6	0.6	0.1	Nitrogen	*
argemone	W	5.3	1.6	1.1	Crop	***
Filago	B	11.6	1.2	0	Nitrogen	***
spathulata	W	14.2	6.1	2.4	Crop	***
Alyssum	B	7.9	0.7	0	Nitrogen	***
alyssoides	W	10.5	6.8	2.8	Crop	***
Arnoseris	B	0.2	0.03	0	Nitrogen	***
minima	W	1.6	0	0		
Myosurus	B	0	0	0	Nitrogen	**
minimus	W	2.6	0.03	0	Crop	**

Table 39. Continued.

MANYDOWN. Winter wheat only.

	Nitrogen level, kg/Ha. 0	75	150	
Papaver rhoeas	27.7	22.6	19.6	N.S.
Myosotis arvensis	16.9	19.5	14.9	N.S.
Tripleurospermum inodorum	15.1	10.00	8.3	N.S.
Scandix pecten-veneris	7.1	4.4	3.1	N.S.
Ranunculus arvensis	12.1	7.3	6.2	Nitrogen **
Papaver hybridum	1.4	1.2	0.6	N.S.
Buglossoides arvensis	7.9	4.9	8.8	N.S.
Valerianella rimosa	11.8	6.8	2.1	Nitrogen ***
Filago spathulata	7.7	5.7	2.3	N.S.
Bupleurum rotundifolium	5.6	4.2	4.3	N.S.

became significantly less in relation to the increase in fertiliser rate (Table 39). The numbers of Ranunculus arvensis and Valerianella rimosa declined significantly as the nitrogen supply increased, and there was a tendency for numbers of some other species (P. hybridum, P. rhoeas, Scandix pecten-veneris and Filago spathulata) to decrease, but differences between treatments were not significant (Table 39).

c. Effects of nitrogen application on dry matter production

The responses to fertiliser level of weed dry matter production per plot, tended to be similar to the responses of numbers surviving to harvest time for all species, although differences between treatments tended to be less consistent and clear. One exception to this was at Manydown, where highest dry matter production was recorded for B. arvensis at the highest nitrogen level (Table 40).

Dry matter production by the indigenous weeds showed a significant increase with fertiliser level at both sites (Table 40).

d. Effects of nitrogen application on fruit production.

The effect of crop competition on the numbers of plants surviving to produce fruit was so great that a full analysis of fruit production per individual plant could not be carried out for all treatments and species. It was however possible to analyse the production of fruits per plot (Table 41), and to analyse fruit production per plant

Table 40. Effect of nitrogen and crop type on geometric mean dry weight production/4m² plot by plants of different weed species (from $\log_{10}(n+1)$ transformed data), in an experiment in which three levels of nitrogenous fertiliser were applied to winter wheat and spring barley. (See Appendix 2 for transformed data with 95% confidence limits). Crop type B = Spring barley; W = Winter wheat. Significance levels (F-test): $P < 0.05$ *; $P < 0.01$ **; $P < 0.001$ ***; N.S. = not significant.

	Crop	Nitrogen supply, kg/Ha. 0	75	150	P	
CHILWORTH.						
Papaver rhoeas	B	6.5	13.2	2.5	N.S.	
	W	2.9	5.9	11.3		
Myosotis arvensis	B	3.2	1.7	1.5	N.S.	
	W	0.8	1.2	1.0		
Silene latifolia	B	0.2	9.5	11.1	Nitrogen	**
	W	0.3	0	0.4	Crop	***
Papaver hybridum	B	2.9	3.3	0	Nitrogen	*
	W	1.0	1.5	0.6		
Silene noctiflora	B	8.1	10.8	12.2	Crop	*
	W	2.1	3.5	5.7		
Chrysanth. segetum	B	19.4	82.6	43.9	Crop	***
	W	2.0	2.5	1.9		
Misopates orontium	B	1.7	1.6	0.3	Crop	***
	W	0.2	0	0		
Papaver argemone	B	0.8	0.9	0	Crop	***
	W	6.8	3.6	2.9		
Filago spathulata	B	9.6	0.3	0	Nitrogen	***
	W	35.1	5.2	2.9	Crop	***
Alyssum alyssoides	B	3.2	0.6	0	Nitrogen	*
	W	4.1	4.0	1.9	Crop	*
Arnoseris minima	B	0.03	0.01	0	Nitrogen	**
	W	0.35	0	0	Crop	**
Myosurus minimus	B	0	0	0	Nitrogen	*
	W	0.16	0.01	0	Crop	*
Mean dry wt. of indigenous species/m²	B	5.5	26.2	36.7	Nitrogen	***
	W	3.0	9.4	12.5	Crop	***

Table 40. Continued.

MANYDOWN.

	Nitrogen supply, kg/Ha. 0	75	150	
Papaver rhoeas	216.3	138.4	279.5	N.S.
Myosotis arvensis	12.3	31.5	13.0	N.S.
Tripleurospermum inodorum	30.1	46.8	28.3	N.S.
Scandix pecten-veneris	7.9	7.6	5.7	N.S.
Ranunculus arvensis	7.0	4.4	4.6	N.S.
Papaver hybridum	1.8	1.0	0.6	N.S.
Buglossoides arvensis	10.2	16.0	50.1	*
Valerianella rimosa	2.0	1.7	0.7	N.S.
Filago spathulata	2.7	1.4	0.4	N.S.
Bupleurum rotundifolium	6.4	4.5	13.7	N.S.
Mean dry wt. of associated weeds/m^2.	7.5	23.8	33.2	***

Table 41. Effect of nitrogen and crop type on the geometric mean fruit production by plants of different weed species per $4m^2$ plot (derived from $\log_{10}(n+1)$ transformed data) in two experiments in which nitrogenous fertiliser was supplied at three levels to crops of winter wheat and spring barley. (See Appendix 2 for transformed results and 95% confidence limits).
Crop type: B = Spring barley; W = Winter wheat.
Significance levels (F-test): * P < 0.05; ** < 0.01; *** < 0.001; N.S. = not significant.

CHILWORTH.

Species.	Crop	Nitrogen level, kg/ha. 0	75	150	P	
Papaver rhoeas	B	44.7	57.9	12.2	N.S.	
	W	11.6	21.4	40.7		
Myosotis arvensis	B	301.0	280.8	1.1	Nitrogen	*
	W	43.7	10.2	6.6		
Silene latifolia	B	0	3.8	5.0	Crop	***
	W	0.3	0	0		
Papaver hybridum	B	15.1	8.3	0	Nitrogen	**
	W	5.6	3.5	1.3		
Silene noctiflora	B	31.1	44.5	30.8	N.S.	
	W	7.4	7.3	11.1		
Chrysanth. segetum	B	66.5	108.9	101.3	Crop	***
	W	4.1	4.2	4.1		
Misopates orontium	B	15.0	8.1	0	Nitrogen	***
	W	0.9	0	0	Crop	***
Papaver argemone	B	3.7	2.3	0.5	Crop	*
	W	44.7	9.5	4.4		
Filago spathulata	B	198.5	2.0	0	Nitrogen	***
	W	811.8	113.8	27.2	Crop	***
Alyssum alyssoides	B	644.7	16.8	0	Nitrogen	***
	W	1046.1	811.8	185.2	Crop	***
Arnoseris minima	B	0.8	0.4	0	Nitrogen	***
	W	8.0	0	0		
Myosurus minimus	B	0	0	0	Nitrogen	**
	W	4.4	0.3	0	Crop	**

Table 41. Continued.

MANYDOWN. Winter wheat only.

	Nitrogen level, kg/ha. 0	75	150	P
Papaver rhoeas	474.3	414.9	668.9	N.S.
Myosotis arvensis	2408.9	3110.7	1635.8	N.S.
Tripleurospermum inodorum	133.9	127.8	96.7	N.S.
Scandix pecten-veneris	163.4	129.9	107.9	N.S.
Ranunculus arvensis	126.1	68.0	63.1	N.S.
Buglossoides arvensis	200.8	201.8	888.2	N.S.
Valerianella rimosa	195.0	111.2	43.7	N.S.
Filago spathulata	23.6	15.2	5.3	N.S.
Bupleurum rotundifolium	238.9	99.0	345.7	N.S.

between some nitrogen levels for a few species (Table 42).

At Chilworth, significant decreases were recorded between the numbers of fruit produced per plot with increasing applications of nitrogen for *M. arvensis*, *P. hybridum*, *A. alyssoides* and *M. orontium* in spring barley plots, *M. minimus* in the winter wheat plots, and *F. spathulata* and *A. minima* in both crops (Table 41). Fruit production by *C. segetum* and *P. argemone* was not significantly affected by the amount of nitrogen applied, while that of *S. latifolia* inceased with fertiliser level (Table 41). No significant responses were recorded for fruit production per plot in relation to nitrogen input at Manydown.

It was possible to analyse fruit production per plant with respect to fertiliser level for a total of 14 species at both sites. The only species for which differences were significant, were *C. segetum* in spring barley at Chilworth, and *B. rotundifolium*, *B. arvensis*, and *V. rimosa* in winter wheat at Manydown (Table 42). Fruit production per plant for all of these species was significantly greater at the highest nitrogen level, although fruit production by *B. rotundifolium* was lowest at 75kg N/Ha. All of the other species present apart from *F. spathulata* showed an increasing fruit production with increasing nitrogen supply, although results only approached significance for *P. rhoeas* and *S. noctiflora* at Chilworth.

Table 42. Effect of nitrogen and crop type on the geometric mean numbers of fruit produced per plant of some weed species/$4m^2$ plot (from $Log_{10}(n+1)$ transformed data), in an experiment in which three levels of nitrogenous fertiliser were applied at three levels to winter wheat and spring barley. [1] Kruskal-Wallis analysis of variance. (See Appendix 2 for transformed results with 95% confidence limits).
Crop type; B = Spring barley; W = Winter wheat.
Significance levels: P < 0.05 *; P < 0.01 **; P < 0.001 ***; N.S. = not significant.

	Crop	Nitrogen supply, kg/Ha. 0	75	150	P
CHILWORTH.					
Papaver[1] rhoeas	B	5.72	11.92	15.04	N.S.
	W	10.12	9.83	19.59	
Papaver[1] hybridum	B	3.46	3.44	-	N.S.
	W	2.64	5.80	5.84	
Silene[1] noctiflora	B	2.45	3.75	6.45	N.S.
	W	2.37	3.72	12.13	
Chrysanthemum segetum[1]	B	8.27	24.94	32.54	Nitrogen **
Papaver argemone[1]	W	8.7	10.52	13.58	N.S.
Filago[1] spathulata	W	57.47	30.49	27.27	N.S.
	B	17.22			
Alyssum alyssoides[1]	W	98.86	167.61	201.27	N.S.
MANYDOWN.(Winter wheat only).					
Papaver rhoeas		17.62	19.65	36.14	N.S.
Myosotis arvensis		158.12	163.93	113.76	N.S.
Tripleurospermum inodorum		9.26	13.93	15.60	N.S.
Ranunculus arvensis		10.64	9.59	10.30	N.S.
Buglossoides arvensis		26.61	56.54	104.95	Nitrogen *
Bupleurum rotundifolium		59.95	24.47	128.42	Nitrogen *
Scandix pecten-veneris		23.62	26.23	36.04	N.S.
Filago spathulata		4.67	2.78	12.8	N.S.
Valerianella rimosa		16.80	17.20	46.4	Nitrogen *

e. Effects of crop presence and seed density.

Crop seed density had few significant effects on the numbers or performance of any of the weed species. The few significant results that were recorded are difficult to explain, and probably mean little.

Results from uncropped plots were compared by analysis of variance with the unfertilised plots drilled at both high and low crop seed densities from each experiment.

No significant differences were observed between the numbers of plants of any species in cropped or uncropped plots. Fruit production per plot (Table 43) was however significantly greater in the uncropped plots than in plots sown at either the high or low crop seed-rates for *V. rimosa* at Manydown, and *P. hybridum* and *A. alyssoides* at Chilworth. Fruit production by *A. minima* was significantly greater in the uncropped plots than in the low crop-seed rate plots, and *P. rhoeas* produced significantly more fruit per plot in uncropped plots than in the high crop-seed rate plots. The mean fruit production per plant was analysed as far as was possible (Table 44). At Manydown, it was significantly greatest in uncropped plots for *P. rhoeas* and *V. rimosa*. At Chilworth, results from autumn cultivated and spring cultivated plots were analysed separately. In the autumn cultivated plots, *A. alyssoides* plants were significantly more productive in the uncropped plots, and *P. hybridum* plants were more productive in the spring cultivated uncropped plots. No significant differences

Table 43. Geometric mean numbers of fruit produced by a range of weed species per $4m^2$ plot (from $Log_{10}(n+1)$ transformed data), in uncropped cultivated plots, and plots cultivated on the same date and sown with crops of spring barley and winter wheat. No fertiliser added. Results averaged over crop type. Significant results presented only. (See Appendix 2 for transformed results with 95% confidence limits).
Significance levels; Kruskal-Wallis test: P < 0.05 *; P < 0.01 **; P < 0.001 ***; N.S. = not significant.

	Crop sowing density			
	Uncropped	75 kg/ha	150 kg/ha	P
CHILWORTH.				
Papaver hybridum	82.0	8.1	10.5	**
Alyssum alyssoides	2065.4	570.2	1180.3	**
Arnoseris minima	16.0	1.1	6.6	*
MANYDOWN.				
Papaver rhoeas	1457.8	817.5	275.1	*
Valerianella rimosa	641.7	192.6	198.1	*

Table 44. Geometric mean numbers of fruit produced per plant by a range of weed species (derived from $\log_{10}(n+1)$ transformed data), in uncropped cultivated plots, and plots cultivated on the same date and sown with crops of spring barley and winter wheat. Significant results only presented. (See Appendix 2 for transformed results with 95% confidence limits).
Crop type; B = Spring barley; W = Winter wheat.
Significance levels; Kruskal-Wallis test : P < 0.05 *; P < 0.01 **; P < 0.001 ***; N.S. = not significant.

	Crop	Crop sowing density.			
		Uncropped	75 kg/ha	150 kg/ha	P
MANYDOWN.					
Papaver rhoeas	W	58.8	29.4	10.4	*
Valerianella rimosa	W	47.9	17.1		*
CHILWORTH.		Uncropped		With crop	
Papaver hybridum	B	9.5		3.5	*
Alyssoides alyssoides	W	303.6		108.3	*

were observed for other species.

f. Effects of crop type on the numbers and performance of weed species.

Crop type was examined as a variable at Chilworth only. It had a considerable influence over the numbers and performance of individual species. M. minimus was not recorded at all in the spring sown plots, and F. spathulata and A. alyssoides both showed highly significant preferences for winter crops at higher levels of nitrogen, in terms of numbers surviving to fruition. P. argemone was recorded significantly more in winter wheat at the lowest nitrogen level. A. minima was also significantly more abundant in winter wheat (Table 39).

S. noctiflora, C. segetum, P. hybridum, M. orontium and S. latifolia were all significantly more frequent in spring barley (Table 39). Results for mean seed production and mean dry matter production per plot were similar to those for plant number, although much less clear. P. rhoeas and M. arvensis showed no significant preferences for either crop. No significant differences were observed for pooled data (Table 38) either.

Experiment 2.

The following variables were examined for each species: percentage mortality between the 10th of May and the 8th of August; dry matter production per weed plant and per tank; number of seeds produced per capsule, per plant, and per tank; number of capsules produced per plant and per tank; crop dry weight per tank, and number of ears per tank. Analysis of variance was carried out on the results after arcsine transformation of percentage mortality, and $\log_{10}(n+1)$ transformation of all other variables (Tables 45, 46 & 47).

The presence or absence of crop cover was found to have an overwhelming effect on all parameters of weed growth measured for all three species (Tables 45, 46 & 47). The mortality of Papaver rhoeas and Papaver hybridum was very high when the crop was present. Because of this extremely high mortality, data for P. rhoeas were reanalysed with respect to fertiliser level only, using the results from the uncropped tanks. All significant results for this species, apart from those for percentage mortality (Table 46), were taken from this analysis.

a. The effect of nitrogen level on Papaver hybridum.

Dry weight of the crop showed no significant response to fertiliser level, and as described above, the presence of a crop exerted an overwhelming effect on the survival of weed seedlings, no matter how much fertiliser was applied.

Nitrogen application level had a significant effect only on the mean dry weight production per tank, which was greatest at a level of 62.5 kg/ha. Several of the other parameters showed a maximum at this level, but in no other case were they significant (Table 45).

Table 45. Performance and productivity of <u>Papaver hybridum</u> grown with or without a spring barley crop, supplied with one of three levels of nitrogenous fertiliser. Analysis of variance carried out on arcsine transformed percentage mortality; all other parameters, $\log_{10}(n+1)$ transformed. Results presented with 95% confidence limits. Significance levels; C crop presence or absence; N level of nitrogen application. $P < 0.001$ ***, $P < 0.01$ **, $P < 0.05$ *, N.S. not significant.

	Crop absent			Crop present			
	Nitrogen level. kg.nitrogen/ha.						
	0	62.5	125	0	62.5	125	P
Plants left after thinning.	12.7	13.7	12.3	17.7	16.0	11.3	
Plants remaining at harvest.	13.3	15.0	13.3	2.3	2.0	0.3	
Percentage mortality.	17.5 -6.9 -30.0	14.6 -9.4 -32.8	15.6 -8.4 31.9	96.2 88.0 72.8	96.4 87.2 73.1	99.6 98.9 92.5	C ***
Mean dry weight/plant (g).	3.6 2.5 1.6	6.4 4.6 3.2	4.2 2.9 1.9	0.3 0.0 0	0.4 0.05 0	0.8 0.4 0.03	C ***
Mean no. of seeds/capsule.	3373 512 77	3872 588 90	4149 630 95	12.7 1.1 0	23.4 2.7 0	42.5 5.6 0.01	C ***
Mean no. of capsules/plant.	17.7 11.9 8.0	24.0 16.4 11.1	14.9 10.0 6.7	0.8 0.3 0	0.7 0.2 0	0.8 0.2 0	C ***
Mean no. of seeds/plant.	51520 6025 704	81650 9549 1116	53950 6309 737	16.9 1.1 0	26.0 2.2 0	111.7 12.2 0.5	C ***
Mean dry weight /tank (g).	43.4 31.7 23.1	90.6 66.5 48.7	52.3 37.6 27.4	0.4 0.0 0	0.7 0.2 0	0.9 0.4 0.01	C *** N *
Mean no. of seeds/tank.	831763 79432 7586	1479108 141253 13489	870963 83175 7943	31.9 2.0 0	35.3 2.5 0	137.0 12.2 0.3	C ***
Mean no. of capsules/tank.	324 157 76	495 241 117	273 132 64	2.3 0.6 0	1.7 0.2 0	3.3 1.1 0.01	C ***
Mean dry wt. of crop/tank (g).	-	-	-	119 103 88	86 74 64	129 111 95	
Mean no. of crop ears/tank	-	-	-	122 111 101	107 98 89	136 124 112	

b. The effect of fertiliser level on *Papaver rhoeas*.

Crop dry weight production was significantly greater in the two fertilised treatments than when unfertilised. Crop presence caused very high mortality of seedlings, and mortality also showed a tendency to increase significantly with fertiliser level (Table 46).

The following results, apply to *P. rhoeas* growing in the absence of a crop only. The only weed performance parameter that showed a significant response to nitrogen level was the mean total dry weight production per tank, which was higher in the tanks supplied with 125 kg/ha of nitrogen than in the other treatments.

c. Effects of fertiliser level on *Silene noctiflora*.

The barley sown in tanks containing this species showed no significant response to nitrogen level.

There was no significant effect of crop presence or fertiliser rate on the mortality of weed seedlings during the experiment. Sufficient plants of this species were therefore present to allow assessment of the effects of fertiliser both with or without crop (Table 47).

Dry weight production, seed production and capsule production per plant and per tank, all responded to fertiliser level in similar ways. When grown in monoculture, all weed performance parameters increased with amount of nitrogen supplied. When a crop was present however, mean numbers of capsules per plant, mean numbers of seeds per plant, mean dry weight per tank, mean number

Table 46. Performance and productivity of <u>Papaver rhoeas</u> grown with or without a spring barley crop, supplied with one of three levels of nitrogenous fertiliser. Analysis of variance carried out on arcsine transformed percentage mortality; all other parameters, $\log_{10}(n+1)$ transformed. Results presented with 95% confidence limits. Variation with respect to fertiliser is analysed for the uncropped tanks only, for all variables other than percentage mortality.
Significance levels; C crop presence or absence; N nitrogen application levels. P <0.001 ***; P <0.01 **; P <0.05 *; N.S. not significant.

	Crop absent			Crop present			
	Nitrogen level, kg N/ha.						
	0	62.5	125	0	62.5	125	P
Plants left after thinning.	11.3	13.3	12.7	20.0	18.0	26.0	-
Plants remaining at harvest.	11.7	14.7	13.3	8.0	2.7	0	-
Percentage mortality.	27.9 -3.0 -33.6	24.0 -7.0 -37.4	26.0 -5.0 -35.5	82.7 61.5 34.2	99.9 94.0 78.9	100.0 100.0 95.2	C ***
Mean dry weight per plant (g).	16.1 12.0 8.9	13.7 10.2 7.5	12.9 9.5 7.0	(0.6	-	-)	N.S.
Mean no. of seeds/capsule.	828 587 416	718 509 360	839 595 421	(6.41	-	-)	N.S.
Mean no. of capsules/plant.	47.2 36.4 28.1	39.9 30.0 23.1	36.4 28.0 21.6	(0.9	-	-)	N.S.
Mean no. of seeds/plant.	32809 21378 13931	23334 15136 9908	25468 16595 10814	(22	0	0)	N.S.
Mean dry weight per tank (g).	184 136 100	200 148 109	372 275 203	(1.8	0.03	0.0)	N *
Mean no. of seeds/tank.	380014 251188 163005	338688 223872 145278	336357 218776 144278	(22	0	0)	N.S.
Mean no. of capsules/tank.	544 425 333	559 438 343	477 373 292	(3.3	0.0	0.0)	N.S.
Mean dry wt. of crop/tank (g).	-	-	-	82.5 67.1 54.5	142.8 115.4 93.9	134.7 119.6 89.2	N *
Mean no. of crop ears/tank	-	-	-	108.2 93.8 81.3	144.3 125.2 108.6	140.7 122.0 105.8	C ***

Table 47. Performance and productivity of <u>Silene noctiflora</u> grown with or without a spring barley crop, supplied with one of three levels of nitrogenous fertiliser. Analysis of variance carried out on arcsine transformed percentage mortality; all other parameters, $\log_{10}(n+1)$ transformed. Results presented with 95% confidence limits.
Significance levels; C crop presence or absence; N level of nitrogen application. P <0.001 ***; P <0.01 **; P <0.05 *; N.S. not significant.

	Crop absent			Crop present			
	Nitrogen level. kg.nitrogen/ha.						
	0	62.5	125	0	62.5	125	P
Plants left after thinning.	12.0	11.7	10.3	14.7	16.7	12.3	
Plants remaining at harvest.	11.7	12.3	9.7	14.7	16.7	13.3	
	9.7	3.4	2.1	8.4	7.7	0.1	
Percentage mortality.	1.3	-5.0	-6.3	0	-0.7	8.3	N.S.
	-7.1	-13.4	-14.6	-8.4	-9.1	-16.6	
	3.72	7.00	12.55	0.34	0.51	0.36	C ***
Mean dry weight /plant (g).	2.93	5.65	10.27	0.11	0.26	0.13	N ***
	2.27	4.53	8.3	0	0.04	0	
	182	189	208	69	130	82	
Mean no. of seeds/capsule.	142	148	163	54	101	64	C ***
	111	116	128	42	79	50	
	7.08	14.55	26.52	0.91	1.23	0.61	C ***
Mean no. of capsule/plant.	5.47	11.44	21.02	0.53	0.78	0.29	N **
	4.18	8.96	16.64	0.23	0.43	0.03	
	1380	2979	5861	51	138	33	C ***
Mean no. of seeds/plant.	777	1678	3304	28	77	18	N *
	438	945	1861	16	43	9	
	48.9	82.3	135.0	2.4	5.4	2.4	C ***
Mean dry weight /tank (g).	33.8	64.9	106.9	1.7	4.1	1.7	N ***
	26.5	51.2	83.6	1.2	3.0	1.1	
	15451	35074	54701	745	2182	396	C ***
Mean no. of seeds/tank.	9016	20464	31915	433	1272	231	N *
	5260	11939	18620	253	742	134	
	74.1	161.8	237.0	9.7	14.7	2.6	C ***
Mean no. of capsules/tank.	63.4	138.6	203.2	8.1	12.5	2.1	N ***
	54.3	118.8	174.2	6.8	10.6	1.6	
				114	133	143	
Mean dry wt. of crop/tank (g).	-	-	-	88	102	109	N.S.
				68	79	84	
				130	130	138	
Mean no. of crop ears/tank	-	-	-	110	110	117	N.S.
				94	94	99	

of seeds per tank and mean number of capsules per tank were significantly greatest at 62.5 kg Nitrogen\ha. Differences for mean dry weight per plant between fertiliser levels in the presence of crop were not significant. Mean dry weight per tank did not differ between full fertiliser rate and unfertilised treatments, but seed production per plant, capsule production per plant, seed production per tank and capsule production per tank were all significantly greater when unfertilised than when fully fertilised (Table 47).

Numbers of seeds produced per capsule were not significantly different with respect to nitrogen level, but were significantly greater in uncropped tanks than in those with a crop present.

DISCUSSION.

In the experiments described here, especially Experiment 1., the complex combined effects of inter-specific weed competition and weed/crop competition processes are not separable, and little attempt was made to investigate the mechanisms involved. The limiting resource for which the plants were considered to be competing was nitrogen, although the effects of nitrogen on competition between plants may be complicated by the decrease in availability of light with increasing above-ground biomass. This may be the main factor responsible for the mortality of the less competitive species (Goldberg & Miller, 1990).

Results of Experiment 1 are summarised in Table 48.

Table 48. A summary of results from Experiment 1. (Tables 38- 44), in which a range of weed species were grown in field plots of winter wheat and spring barley, at three levels of nitrogen.

a. Effects of fertiliser.

Significance levels: positive response; + P < 0.05; ++ P < 0.01; +++ P < 0.001: negative response - P < 0.05; -- P < 0.01; --- P < 0.001% .

	Plants /plot	Dry wt. /plot	Seed /plot	Seed /plant
Papaver hybridum	---	-	--	
Misopates orontium	---		---	
Papaver argemone	-			
Filago spathulata	---	---	---	
Alyssum alyssoides	---	-	---	
Arnoseris minima	---	--	---	
Myosurus minimus	--	-	--	
Ranunculus arvensis	--			
Valerianella rimosa	---			+
Buglossoides arvense		+		+
Bupleurum rotundifolium				+
Chrysanthemum segetum				++
Silene latifolia	++	++		

	Chilworth	Manydown
Mean no. of rare species/plot.	---	
Mean no. of common species/m².	--	
Mean no. of rare plants/plot.	---	--
Mean no. of common plants/m².	--	
Dry weight/0.4m² of indigenous weeds.	+++	++

b. Effects of crop type. (Chilworth only).

Significance levels; preference for barley, b P < 0.05; bb P < 0.01; bbb P < 0.001: preference for wheat, w P < 0.05; ww P < 0.01; www P < 0.001

	Plants/plot	Dry wt./plot	Seed/plot
Misopates orontium	bbb	bbb	bbb
Papaver argemone	www	www	ww
Filago spathulata	www	www	www
Alyssum alyssoides	www	w	www
Arnoseris minima		w	
Myosurus minimus	ww	w	ww
Silene noctiflora	bbb	b	
Chrysanthemum segetum	bbb	bbb	bbb
Silene alba	bbb	bbb	bbb

Dry weight/0.4m² of associated weeds. bbb

The effects of nitrogen application.

In Experiment 1, the enhanced crop growth following the addition of nitrogen was demonstrated to have very marked effects on the survival to produce fruit of nine out of the thirteen rare weed species sown. In the cases of Arnoseris minima and Myosurus minimus in both crop types, Papaver hybridum, Filago spathulata and Alyssum alyssoides in spring barley, and Misopates orontium in winter wheat, no plants at all survived in plots subjected to the highest supply of nitrogen, a level typical of that used in modern arable farming.

The only four uncommon species for which the numbers surviving were not significantly reduced in either experiment by increasing the amount of fertiliser, were Chrysanthemum segetum, Buglossoides arvensis, Scandix pecten-veneris and Bupleurum rotundifolium. Both C. segetum (Courtney & Johnston, 1988) and B. arvensis (Wilson, 1986) are known to be competitive in relation to spring barley and winter wheat crops respectively. The rates of decline in recent years of both of these species have been less than those of many other species, and both are still very locally frequent. S. pecten-veneris may still be found in considerable quantity at the few sites at which it still occurs, and it is possible that the increase in quantities of nitrogen used in recent years has played a relatively small role in the decline of this species. The decline of B. rotundifolium predates the modern revolution in agricultural practices. Four common species, Papaver rhoeas, Myosotis arvensis, Silene latifolia and Tripleurospermum inodorum, were included in this experiment as a comparison. The only significant effect on any of these species of increasing the nitrogen level was to increase the numbers of S. latifolia surviving until harvest time. An ability to compete effectively with the crop at high nitrogen levels is an attribute that might be expected in a weed species that is successful in modern farming conditions.

The ultimate success of an annual plant must be measured in terms of its seed production. Practical considerations prevented the direct determination of seed production, and in most cases, "fruit" production (Table 36) was assessed instead. Some samples of fruit were gathered from each treatment and numbers of seed counted, but no significant effect of fertiliser could be discerned. It is probable that for some species the numbers of seed produced per fruiting unit may be plastic, as described for Papaver spp. (McNaughton & Harper, 1964), Agrostemma githago (Firbank, 1988) and Viola arvensis and other species (M.Reed, pers. comm.) and further investigation is required. The only significant effects observed on seed production per capsule of S. noctiflora, P. rhoeas and P. hybridum in Experiment 2 were due to the presence or absence of the crop.

The effect of the higher levels of nitrogen on the numbers of most of the species examined in Experiment 1 was so great as to prohibit analysis of fruit production per individual plant. It is interesting to note however, that for all but one of those species for which sufficient plants were present, the numbers of fruits produced per plant increased with increasing amounts of fertiliser, and this was statistically significant for four species, V. rimosa, L. arvense, B. rotundifolium and C. segetum. This contrasted with the results for total fruit production per plot, which for most species (exceptions being non-significant increases for B. rotundifolium and B. arvensis) decreased with increasing amounts of nitrogen supplied.

The contrast between the fruit production per plot and the fruit production per plant reflected the effect that increasing nitrogen level had on the numbers of plants that survived to produce fruit. It is possible that the chief effect of competition was to reduce the growth of the less competitive plants to the point at which they were no longer capable of surviving, possibly by restriction of the amount of light that reaches them (Goldberg & Miller, 1990). Those plants which did survive, for one reason or another, are evidently able to utilise the applied nitrogen to their advantage. It has been suggested that the relative time of emergence of weed and crop seedlings is of great importance in determining the outcome of competition (Hakansson, 1986). If a weed species is capable of germinating before the crop and other weeds, it may possess a significant advantage. Many weed species show patterns of germination that are spread over several months, or which show more than one peak, and it is therefore possible that some seedlings of a single species may have an advantage over others by virtue of their earlier germination. This would explain the differences between the two parameters of seed production described above.

The value of Experiment 2 as an investigation of the effects of nitrogen supply on competition was rather limited. Some conclusions about the behaviour of the three weed species under varying conditions of competition may be drawn from this experiment however. Plants of S. noctiflora survived in similar numbers in all treatments. The pattern of response to increasing fertiliser level was however different depending on the presence or absence of a crop. Where a crop was present and the effect of nitrogen level was significant, all measures of weed performance were highest at the half-application level of nitrogen (62.5 kg/ha), while in monoculture, the maximum values were all at the maximum nitrogen supply level. Similar behaviour has been recorded for Stellaria media (Mahn, 1988) and Veronica persica (M.Reed, pers.comm.). Although mortality of plants was low in all treatments, seed production parameters were all much lower when a crop was present. Many of the plants which did survive, had not produced flowers by the end of the experiment, and had survived the summer as established seedlings. This was one of the species that was observed to produce fruit in post-harvest stubbles in the experiment described in Chapter 7.

For the other two species, too few plants were present in the cropped tanks to allow much discussion. When grown in monoculture, the only significant differences for either species were noted for dry matter production per tank, which was greatest at 62.5 kg N/ha for P. hybridum and 125 kg N/ha for P. rhoeas. It is difficult to explain the behaviour of P. hybridum, but it may be an experimental artifact, as the dry weight at 62.5 kg N/ha was not significantly greater than at the highest rate. It might be expected that dry matter production by weed plants would increase with increasing supply of nitrogen when grown in monoculture (Mahn, 1988; Pulcher-Haussling & Hurle, 1986). It is interesting to note that the numbers of seed produced per pod did not significantly differ between the levels of nitrogen. This observation is of relevance to Experiment 1, where seed production was estimated indirectly by assessment of fruit production.

The role of light in determining the course of competition at different levels of supplied nitrogen demands some further consideration. The species that suffered most at the higher nitrogen levels were mainly those of low stature relative to the crop, and therefore those that might be expected to have experienced low light intensities and consequent high mortality. The potentially critical effects of small differences in height and the importance of relative growth rates of competing species on the course of competition have been emphasised by other authors (Grime, 1979; Gustavsson, 1986). The species of low stature that performed badly at higher nitrogen levels included _A. minima_, _M. minimus_, _M. orontium_ and _A. alyssoides_. The decline of _A. minima_ has been linked to habitat eutrophication by a number of authors (Silverside, 1976; Dierben, 1989; Eggers, 1984). The two localities at which _A. alyssoides_ survives in Britain are on extremely poor sandy soils, supporting very sparse and non-competitive vegetation, and both _M. minimus_ and _M. orontium_ tend to be found now in root and vegetable crops or in poorly grown cereals where competition for light is at a low level.

Effects of crop type.

It was possible to compare the numbers and seed productivity of weed species in winter wheat and spring barley. Most of the species included here were also included in the experiment described in Chapter 7, in which winter wheat, winter barley and spring barley were sown on seven dates. The effects of crop drilling date on weed communities are fully discussed in that chapter, and results for the species included in both experiments are discussed there. _S. latifolia_, _A. minima_ and _M. minimus_ were not included in the Chapter 7, and _A. alyssoides_ and _F. spathulata_ were present in insufficient numbers to give usable results. In Experiment 1, described here, _S._

latifolia was more abundant in spring barley, but all four of the other species were significantly more abundant in winter wheat. *M. minimus* was not recorded at all in spring cultivated plots. In the field, these four winter germinating species are only to be found in situations that offer little competition, and in this experiment were significantly most frequent in unfertilised crops.

Effects of crop density and crop presence.

The density at which a crop is sown would appear to be important to the density of the crop cover produced, and to the performance of the crop (Andersson, 1986; Wilson *et al*; 1988). In Experiment 1 however, although the density of sowing affected the number of plants germinating, no effect on crop dry matter production or stem density was observed. The lack of effect of sowing density on the spring barley may be accounted for by the relatively poor crop germination. The reasons for the lack of effect in winter wheat are not known, as the sowing densities used are within the range used by Andersson (1986) who noted significant differences between weed dry weight production under different crop sowing densities. It may be that the wheat variety used (cv. Mercia) is one which responds to low seed density by producing numerous tillers as compensation.

Given the lack of differences in crop performance between sowing densities, it is not surprising that few effects of crop seed density on weed number or performance were observed. This topic would however repay further study. It is known that the spacing of crop rows has decreased in recent years (Johnston & Garner, 1968), as hoeing became obsolete as a form of weed control. It is possible that this greater spacing may have provided an area of low competitivity which may have benefitted less competitive weed plants. In the survey described in Chapter 2 , the vigorous growth of many species was noted in widely spaced crops such as sugar beet or potatoes.

In view of our knowledge of competition between crop and associated weeds, it is surprising that so few significant effects were observed in Experiment 1 between weeds growing in the presence of a crop, and those growing without. Other workers have demonstrated that the presence of a crop, even at a low seed rate and without any added nitrogen, will exert a considerable influence over both the dry matter and seed production of many weed species (Mahn, 1988; Gustavsson, 1986; Wilson et al; 1988).

The results of Experiment 2 also demonstrate the effects of crop presence to weed performance. The mortalities of both P. rhoeas and P. hybridum were very high even in an unfertilised crop, and the number of seeds produced was negligible in comparison with that produced in the absence of a crop. S. noctiflora on the other hand showed no significant mortality as a result of the presence of a crop, but in common with the two Papaver species, produced very little seed when grown in association with barley. The anomalies between the two sets of results may be partially due to the differences in physical and climatic conditions experienced by the plants in the two experiments. The summer of 1989 was characterised by an extremely low rainfall, and although the tanks were watered regularly until the end of May, ensuring a plentiful germination of both crop and weed plants in all treatments, it is likely that water was the chief limiting factor in this experiment. The confinement of the plants' roots within plastic tanks probably also had an effect on the availability of water.

The paucity of significant differences between cropped and uncropped plots in Experiment 1 may have been due to the poor performance of the crops grown at low nitrogen levels, resulting in the differences between plots of those crops and plots in which no crop was grown at all, being less than might have been expected. Some significant results were recorded however. The productivity of seed per plot of P. hybridum, A. alyssoides, A. minima, P. rhoeas and V. rimosa was significantly higher in uncropped plots, and seed production per plant was also higher for all of these species other than A. minima. It may be that under the conditions of this experiment at least, the effect of presence of a crop when nitrogen supply was limited was not sufficient to cause significant mortality of weed plants, but could reduce seed production of less competitive species (Mahn, 1988). The work of Wilson *et al.* (1988) also suggests this, although in their experiment, fertilisers were applied at typical farm levels only. As suggested above, the major effect of crop competition on weeds at high levels of nitrogen appears to be a reduction of vigour to a point at which they die, possibly as a result of insufficient light intensity (Mahn, 1988; Goldberg & Miller, 1990). If, in a very poorly fertilised crop, light reaches the crop floor, seedlings may survive, but may be restricted in growth by direct competition for limited supplies of nutrients, resulting in reduced seed production.

Although few significant differences were recorded between the numbers and seed productivity of some species in uncropped plots and plots sown with cereals, uncropped areas may be of value in the conservation of populations of some rare weed species, especially when populations are small, and the species are poor competitors.

Effects of nitrogen application on weed communities.

In addition to the effects that nitrogen inputs have on individual weed species, they must also have contributed to changes in the composition and diversity of weed communities. Such changes are to be expected mainly in communities adapted to growing on nutrient poor soils, and which might be expected to be naturally rich in species that are most competitive in the presence of very low levels of nitrogen. The influence of nutrients on the composition of weed communities was first described from the Broadbalk experiment by Brenchley & Warington (1930), who noted differences between experimental plots treated with different nutrient regimes, although they did not investigate the effects of different levels of nitrogen. It is possible that eutrophication had its earliest effects on water-retentive clay soils such as those to be found at Broadbalk, and may have contributed to the rapid decline of a number of those weed species characteristic of heavier soils, such as R. arvensis and Torilis arvensis. This is however rather a matter of conjecture, and the increases in nitrogen use must be considered in conjunction with other changes in agricultural practices.

Silverside (1976) discussed the disappearance of the *Arnoseridion minimae* alliance from Britain. This phytosociological group was characteristic of extremely nutrient poor sandy soils, and has largely been replaced by communities of more nitrogen-responsive species. Two of the characteristic species of the alliance, A. minima and Galeopsis segetum, are now extinct. In Europe, changes in weed communities in response to nitrogen inputs have been documented more extensively. In Germany, Eggers (1984) considered that nitrogen inputs had played a large role in the transformation of communities of both calcareous and acidic soils, Dierben (1989) also explained the decline of the *Arnoseridion minimae* as partially due to increases in nitrogen use, and Oesau (1979) documented the decrease of the *Papaveretum argemone* in the upper Rhine valley in relation to nitrogen use. In Experiment 1 the numbers of both sown rare species and common species plus those derived from the native seed-bank were less in fully fertilised plots at both sites, although these differences were only significant at Chilworth.

The results of these experiments have directly applicable implications for the conservation management of arable weed communities. For most of the species studied, especially the rarer ones, the amount of nitrogen supplied in the form of fertiliser was demonstrated to have a considerable effect on the course of competition with the crop and with other weed species, both in terms of plant mortality and fruit production. It can be seen that the large quantities of nitrogen applied to modern crop varieties may have played a large role in the long-term decline of some species, the transformation of weed communities and the reduction of habitat diversity in the arable ecosystem (Holzner, 1978). Reduction, or elimination of nitrogen inputs will be incorporated in a programme of management recommendations for arable weed conservation (Chapter 10). The reduction of nitrogen inputs may also have the additional beneficial effect of disadvantaging populations of species that have increased in recent years, and which are known to be very responsive to nitrogen inputs. These species include Alopecurus myosuroides, Galium aparine and Stellaria media. It is probable that such species can exert a considerable pressure in their own right on less competitive ones under conditions of high nitrogen input.

CHAPTER 7.

THE EFFECTS OF CROP TYPE AND SOWING DATE ON THE PERFORMANCE OF UNCOMMON ARABLE WEEDS

INTRODUCTION.

The association of weed species and weed communities with different crops, and the importance of crop rotations for weed control have been appreciated for a long time (Newman & Newman, 1918; Brenchley, 1920; Brenchley & Warington, 1930; Evans, 1963). Such associations have been recorded from many areas of the world, and have usually been accounted for by the different times of crop sowing interacting with the dormancy mechanisms of the weed species (Brenchley & Warington, 1930; Dvorak & Krejcir, 1980; Froud-Williams & Chancellor, 1982; Dale & Thomas, 1987; Saavedra et al, 1989).

Although the natural periodicity of germination of individual species is undoubtedly of primary importance in determining the potential weed flora of a locality in a particular year, the fate of the emerged seedlings and their performance will be affected by competition with the crop (Harper, 1977; Grime, 1979). Different cereal crops have different competitive abilities (Chancellor & Froud-Williams, 1982; Moss, 1983; Sa tore, 1988), and different cereals sown on the same date may have different effects on populations of weed seedlings.

There have been many changes in crop rotations in recent years (Table 49). There have been considerable increases in the areas of winter cereals, oil-seed rape, sugar beet and peas, and decreases in the areas of spring barley, oats, root vegetables and bare fallow over the whole of England and Wales. In some areas of the country, changes have been even more marked. In one part of Sussex for example, the area sown to spring barley decreased by over 50%, and the area sown to winter wheat increased nearly fivefold between 1970 and 1987 (Potts et al; 1989).

Table 49. Areas of crops in hectares grown in 1958 and 1987 in England and Wales. From M.A.F.F. agricultural statistics for 1962/3 and 1987 (Anon, 1965; Anon, 1989).

Crop.	1958	1987	Change	1987 area as a % 1958 area
Winter wheat*	855,907	1,888,196	+1,032,289	221%
Winter barley	0	889,431	+889,431	-
Spring barley	**1,022,278	553,732	-468,546	54%
Oats	504,461	74,507	-429,954	15%
Turnips/fodder beet	157,095	36,800	-120,295	23%
Peas	41,736	103,660	+61,924	248%
Potatoes	232,803	148,523	-84,280	64%
Sugar beet	171,264	202,500	+31,236	118%
Rape***	42,110	342,584	+300,474	814%
Bare fallow	99,495	34,481	-65,006	35%
Total arable area	3,729,350	5,907,284	+2,177,934	158%

* Includes a small area of spring sown wheat
** Includes a small area of winter sown "spring" barley
*** Includes rape grown for fodder and oil.

If seed production by a weed population is significantly affected by the type of crop grown and the date on which it is sown, then changes in these factors will affect the weed seed bank. Such changes may be to the detriment of small populations of species with restricted germination periods, particularly if they are not very competitive in relation to the crop, if a crop of low competitive ability is replaced by a more competitive one. Long-term changes in cropping patterns may be among the factors that have led to the declines of a number of species.

An experiment was designed in which three different cereal crops were sown at different dates, with the aim of discovering whether the performance of a number of weed species was affected.

METHODS.

Experiments were set up at two sites in Hampshire. Site 1 was on a calcareous silty loam soil on an arable farm near Basingstoke, and site 2 was near Fordingbridge, on a loam soil that had previously supported a rye-grass ley. Four blocks of nine plots, each measuring 3.5m X 3.5m were marked out, with 0.5m strips left as paths between each plot. Winter wheat, winter barley and spring barley were sown on three dates each, at a density of approximately 148kg/ha, at a row spacing of 14.3 cm, using a hand operated garden seed drill. The treatments are detailed in Table 50, and were randomised in each of the four blocks. Compound PK fertiliser was added to each plot at a rate of 52.5:80 kg./ha, and nitrogenous fertiliser was added at a rate of 100kg N/ha to the spring barley, as a single dressing shortly after drilling, and at a rate of

122 kg N/ha to the winter cereals as two half dressings in mid-March and early April.

Weed seed was added to the central 2m X 2m portion of each plot on the date of crop sowing, with a 1.5m wide buffer zone remaining around each plot. The weed seed for all plots other than the first winter barley sowing was buried in sealed nylon net bags until required, in order to expose the seed to environmental conditions and ensure the appropriate dormancy state.

Table 50. Crop type, sowing and harvest dates, in an investigation of the effect of crop type and sowing date on arable weeds.

	Cereal type.	Date of sowing	Date of harvest
1	Winter barley cv. *Magi*	29 Sept.	10 July.
2	" " "	13-14 Oct.	14 July.
3	" " "	2-3 Nov.	22 July.
4	Winter wheat cv. *Mercia*	13-14 Oct.	4 Aug.
5	" " "	2-3 Nov.	4 Aug.
6	" " "	19-20 Nov.	24 Aug.
7	Spring barley cv. *Arena*	16-17 Feb.	4 Aug.
8	" " " "	9-10 Mar.	4 Aug.
9	" " " "	28 Mar.	24 Aug.

The composition of the seed mixtures (Table 51) differed at the two sites due to the restricted supply of the seed of some species. Where insufficient seed of a species was available for use at both sites, seed was sown at the site with the most appropriate soil type.

Both experiments were treated with diclofop-methyl for the control of grass weeds (Alopecurus myosuroides at site 1, and Lolium perenne at site 2)(Boatman, 1989). It was

Table 51. Number of weed seeds sown in an investigation of the effects of crop type and sowing date on arable weeds.

Species.	Site 1.	Site 2.
Adonis annua	20	-
Agrostemma githago	-	50
Alyssum alyssoides	-	50
Bupleurum rotundifolium	100	-
Chrysanthemum segetum	-	100
Filago spathulata	100	100
Buglossoides arvensis	100	100
Misopates orontium	-	150
Myosotis arvensis	100	100
Papaver argemone	100	100
Papaver hybridum	100	100
Papaver rhoeas	100	100
Petroselinum segetum	100	100
Ranunculus arvensis	100	-
Scandix pecten-veneris	50	-
Silene noctiflora	100	100
Torilis arvensis	100	100
Tripleurospermum inodorum	100	100
Valerianella rimosa	100	-

applied at a concentration of 954 g a.i./ha, and a pressure of 2.5 bar, using an Oxford precision sprayer. Methiocarb pellets were applied to the soil surface at the time of drilling for slug control.

Seedling numbers in the winter cereal crops were recorded in January, and an attempt was made to mark 10 plants of each species in each plot, although this was not always possible. Numbers of the marked plants surviving after the winter were recorded in May and additional plants were marked. Due to the small numbers of seedlings emerged by January in the third winter wheat crop at Site 1, these plots were not recorded until May. Seedling numbers in the spring sown crops was also recorded in May. Survival of plants to harvest time and production of ripe fruits (Table 36) was recorded immediately before harvest of each treatment. The crop was cut at a height of 15-20cm (mean height of stubble left in the field in which Site 1 was situated) when the grain was ripe (Growth stage 92-93, Tottman & Broad, 1987)(Table 50), and was removed from the plots and burnt.

The production of seed by the previously marked weed plants was then followed in the stubble of each plot, until the first severe frost occurred on the fifth of November. Additional plants were also marked.

RESULTS.

The numbers of seedlings of seven sown species recorded in each treatment are presented in Table 52, along with the numbers of marked plants surviving and added between assessments. No attempt was made to determine whether the differences between the numbers of seedlings germinating were significant, as the extended period of germination of most species and the different patterns of germination in each treatment made comparison difficult.

There were considerable differences in the mortality of seedlings of different species during the course of the experiment. Mortality accounted for almost all seedlings of Chrysanthemum segetum in all autumn sown crops apart from the first sown winter barley. All of the few seedlings of Misopates orontium and Silene noctiflora found in the autumn sown crops, (with the exception of the third sowing of winter wheat at site 1 where the germination assessment

Table 52. The total numbers of weed seedlings recorded on the first assessment date (a.), numbers of seedlings marked (in brackets, b.) and the percentage mortality (%m) of marked seedlings between assessment dates in all replicates of winter barley, winter wheat and spring barley crops each sown at three different dates. + = additional plants marked for next assessment. Results for *Scandix pecten-veneris*, *Ranunculus arvensis* and *Adonis annua* are from Site 1. only, and for *Chrysanthemum segetum* and *Misopates orontium* from Site 2 only. Results for *Buglossoides arvensis* and *Silene noctiflora* are averaged over the two sites.

Crop	Sowing Date	Date of assessment. 8th Jan. a. b.	15th May +	15th May %m	Harvest +	Harvest %m	19th Sept. %m
Scandix pecten-veneris							
Barley	29th Sept.	1 (1)	(6)	0	(1)	14	100
"	13th-14th Oct.	15(15)	(11)	0	(1)	17	95
"	2nd-3rd Nov.	12(12)	(6)	8	(5)	18	100
Wheat	13th-14th Oct.	15(15)	(6)	7	(5)	18	100
"	2nd-3rd Nov.	7 (7)	(9)	0	(3)	6	95
"	19th-20th Nov.		16(16)		(1)	13	100
Barley	16th-17th Feb.		8 (8)		(0)	38	100
"	9th-10th March		2 (2)		(0)	50	100
"	28th March		2 (2)		(0)	100	-
Ranunculus arvensis							
Barley	29th Sept	18(16)	(4)	50	(3)	33	100
"	13th-14th Oct.	42(31)	(2)	13	(6)	14	95
"	2nd-3rd Nov.	37(29)	(6)	10	(6)	9	90
Wheat	13th-14th Oct.	43(23)	(15)	17	(0)	9	98
"	2nd-3rd Nov.	35(30)	(7)	7	(1)	20	100
"	19th-20th Nov.		25(25)		(1)	16	100
Barley	16th-17th Feb.		1 (1)		(0)	100	-
"	9th-10th March		1 (1)		(0)	100	-
"	28th March		0 (0)		(0)	0	-
Buglossoides arvensis							
Barley	29th Sept.	42(40)	(2)	25	(8)	13	81
"	13th-14th Oct.	186(80)	(2.5)	14	(9)	10	77
"	2nd-3rd Nov.	98(78)	(3)	20	(0)	14	100
Wheat	13th-14th Oct.	206(80)	(2)	9	(0)	0	100
"	2nd-3rd Nov.	82(42)	(3)	21	(4)	16	97
"	19th-20th Nov.		53(72)		(0)	10	84
Barley	16th-17th Feb.		19(17)		(0)	27	95
"	9th-10th March		58(49)		(1)	30	96
"	28th March		45(45)		(2)	12	96

Crop	Sowing Date	Date of assessment. 8.Jan. a. b.	15.May +	%m	Harvest +	%m	19.Sept. %m
Silene noctiflora							
Barley	29th Sept.	0 (0)	(0)	-	(0)	-	-
"	13th-14th Oct.	0 (0)	(0)	-	(0)	-	-
"	2nd-3rd Nov.	1 (0)	(0)	-	(0)	-	-
Wheat	13th-14th Oct.	22(22)	(0)	18	(0)	0	-50*
"	2nd-3rd Nov.	2 (2)	(0)	0	(0)	0	-50*
"	19th-20th Nov.		6	(6)	(14)	25	12
Barley	16th-17th Feb.		26	(26)	(9)	27	48
"	9th-10th March		56	(46)	(40)	13	43
"	28th March		100	(67)	(22)	10	39
Adonis annua							
Barley	29th Sept.	1 (1)	(1)	100	(0)	-	-
"	13th-14th Oct.	1 (1)	(6)	0	(4)	0	90
"	2nd-3rd Nov.	5 (5)	(11)	20	(1)	7	93
Wheat	13th-14th Oct.	5 (5)	(3)	0	(7)	13	100
"	2nd-3rd Nov.	8 (8)	(7)	0	(5)	8	100
"	19th-20th Nov.		30	(30)	(0)	3	100
Barley	16th-17th Feb.		1	(1)	(0)	0	-
"	9th-10th March		2	(2)	(0)	100	62
"	28th March		0	(0)	(0)	0	-
Chrysanthemum segetum							
Barley	29th Sept.	30(26)	(2)	47	(2)	0	67
"	13th-14th Oct.	12(12)	(0)	83	(0)	100	-
"	2nd-3rd Oct.	3 (3)	(0)	100	(2)	0	100
Wheat	13th-14th Oct.	19(19)	(1)	63	(1)	13	100
"	2nd-3rd Nov.	12(12)	(0)	100	(0)	0	-
"	19th-20th Nov.		5	(5)	(0)	25	68
Barley	16th-17th Feb.		25	(25)	(3)	0	81
"	9th-10th March		29	(28)	(8)	4	69
"	28th March		34	(31)	(4)	6	32
Misopates orontium							
Barley	29th Sept.	0 (0)	(0)	-	(0)	-	-
"	13th-14th Oct.	1 (1)	(0)	100	(0)	-	-
"	2nd-3rd Oct.	0 (0)	(0)	-	(0)	-	-
Wheat	13th-14th Oct.	0 (0)	(0)	-	(0)	-	-
"	2nd-3rd Nov.	0 (0)	(0)	-	(0)	-	-
"	19th-20th Nov.		0	(0)	(0)	-	-
Barley	16th-17th Feb.		0	(0)	(0)	-	-
"	9th-10th March		1	(1)	(1)	0	-280*
"	28th March		6	(6)	(18)	50	-120*

was carried out in May, rather than in January), also died. High mortality of Ranunculus arvensis was also recorded from the first sown winter barley at site 1, and most of the few seedlings of this species and Scandix pecten-veneris that emerged in the spring barley plots had disappeared by harvest-time.

Analysis of variance was carried out on square-root transformed results for the number of plants present per plot (Table 53), and the number of fruits produced per plot at harvest time in both experiments (Table 54). Due to the overwhelming effects of the treatments on the number of plants surviving, it was only possible to analyse fruit production per plant for seven species (Table 55).

Numbers of plants surviving at harvest time.

Numbers of Alyssum alyssoides, Bupleurum rotundifolium and Filago spathulata were too small to permit meaningful interpretation, and results are not presented.

Petroselinum segetum, Torilis arvensis and Agrostemma githago were all found exclusively in the autumn sown crops, and Adonis annua, Ranunculus arvensis and Scandix pecten-veneris were almost entirely recorded from the winter cereal plots, very few being found in spring barley (Table 53). Buglossoides arvensis and Valerianella rimosa were more abundant in winter crops than in spring barley, although small numbers were present in the spring crops. Papaver argemone was also more abundant in winter crops, although at site 1, plants were present in small numbers in

Table 53. Geometric mean numbers of weed plants (with 95% confidence limits) at harvest, in $4m^2$ plots of winter barley, winter wheat, and spring barley each sown on three different dates at two sites. Significance levels: *** P<0.05, ** P<0.01, * P<0.001, N.S. not significant. Analysis carried out on square root transformed data.

Site 1.	Crop and sowing date. Winter barley			Winter wheat			Spring barley			
	29 Sept	13/14 Oct	2/3 Nov	13/14 Oct	2/3 Nov	19/20 Nov	16/17 Feb	9/10 Mar	28 Mar	P
Petroselinum segetum.	12.8 4.3 0.3	9.5 8.0 6.6	6.2 5.0 3.9	21.8 6.1 2.0	3.0 0	0	0	0	0	***
Torilis arvensis.	16.8 8.1 2.5	15.1 12.4 9.9	17.0 14.4 12.1	13.0 8.0 4.3	16.1 12.2 8.9	11.6 8.0 2.3	0	0	0	***
Scandix pecten-veneris.	2.4 1.4 0.7	7.7 5.4 4.2	6.8 5.2 3.8	10.9 5.6 2.0	6.2 5.0 3.9	4.8 4.2 3.8	1.8 0.4 0	0.6 0.1 0	0	***
Ranunculus arvensis.	4.8 2.5 0.9	16.1 10.3 5.7	19.6 13.0 7.8	28.3 12.4 3.0	21.5 16.5 12.1	7.4 5.4 3.7	0	0.6 0.1 0	0	***
Buglossoides arvensis.	7.8 3.7 1.3	18.1 14.6 11.5	20.2 16.6 13.4	33.1 17.4 6.7	20.3 17.3 14.5	12.4 9.6 7.2	4.2 2.2 0.8	13.7 9.5 6.0	12.8 8.7 5.4	***
Adonis annua.	0.6 0.1 0	5.4 1.7 0.1	5.1 3.7 2.4	4.0 3.3 2.7	10.0 5.7 2.6	9.4 7.1 5.2	2.0 0.2 0	2.7 0.9 0	0	***
Myosotis arvensis.	7.9 3.2 0.6	11.3 7.2 4.0	13.7 10.3 7.4	19.0 4.5 0	11.9 4.4 0.6	8.9 4.8 1.9	4.9 3.3 2.0	3.5 0.7 0	3.1 1.1 0.1	*
Papaver argemone.	0.6 0.1 0	2.9 0.6 0	4.6 2.8 1.5	2.0 0.2 0	7.5 4.9 3.1	9.7 5.9 0	2.7 0.7 0	5.9 2.0 0.3	3.8 1.3 0.1	**
Valerianella rimosa.	10.3 2.6 0	11.1 5.2 1.5	15.3 9.5 5.1	3.6 0.9 0	11.0 6.0 2.4	17.9 12.7 8.4	6.4 4.4 1.9	13.0 7.4 3.4	9.0 5.1 2.3	*
Papaver rhoeas.	8.1 2.6 0.2	14.9 6.9 1.9	27.7 23.9 20.4	37.7 16.1 3.5	22.5 16.1 10.7	18.0 14.9 12.1	17.2 7.7 2.0	35.0 26.6 19.3	23.8 17.7 12.5	***
Tripleurospermum inodorum.	0	8.4 2.4 0.04	7.5 5.7 4.1	9.1 4.2 1.2	7.2 6.0 4.9	9.1 6.9 4.9	14.5 9.4 5.4	11.4 8.9 6.6	12.3 9.6 7.3	
Papaver hybridum.	0	0	6.8 2.4 0.3	0	5.6 2.7 0.9	14.5 13.5 12.5	9.1 2.1 0	10.9 4.8 1.2	10.0 3.5 0.3	***
Silene noctiflora.	0	0	0	0	0	6.8 3.6 1.6	14.1 6.6 2.0	9.7 7.1 4.9	26.1 15.5 7.6	***

Table 53. Continued.

Site 2. Crop and sowing date.

	Winter barley			Winter wheat			Spring barley			
	29 sept	13/14 oct	2/3 nov	13/14 oct	2/3 nov	19/20 nov	16/17 feb	9/10 mar	28 mar	P
Agro- -stemma githago.	22.7 20.2 17.9	11.6 6.1 2.4	0	12.1 7.3 3.7	0	0	0	0	0	***
Petro- -selinum segetum.	13.1 10.1 7.5	9.7 5.9 3.0	4.9 1.2 0.1	20.6 12.8 6.9	6.9 4.9 3.2	0	0	0	0	***
Torilis arvensis.	16.8 13.9 11.3	16.1 10.0 2.3	11.7 5.3 1.3	26.3 14.1 5.6	16.0 5.4 0.4	6.0 1.9 0.1	0	0	0	***
Buglo- -ssoides arvensis.	10.2 5.4 2.2	31.1 19.2 10.1	6.2 3.4 1.5	28.0 20.3 13.8	3.8 1.2 0.1	3.3 0.4 0	1.2 0.3 0	3.8 1.2 0.1	5.4 3.0 1.3	***
Papaver argemone.	0	1.2 0.3 0	1.7 0.2 0	4.1 0.7 0	1.8 0.4 0	9.8 4.1 0.8	0	0	0	**
Myosotis arvensis.	3.3 2.2 1.3	3.3 1.8 0.8	4.2 1.5 0.1	3.2 1.1 0.1	2.8 0.3 0	3.2 1.9 0.9	1.3 0.1 0	0	0	*
Papaver rhoeas.	3.4 2.4 1.6	2.3 0.5 0	4.7 1.0 0	13.4 5.8 1.4	4.8 3.4 2.2	19.3 10.2 3.9	0.6 0.1 0	1.1 0.1 0	4.1 0.7 0	***
Papaver hybridum.	0	1.2 0.3 0	0.6 0.1 0	2.9 0.6 0	1.2 0.3 0	3.5 0.7 0	0	0	2.9 0.8 0	N.S.
Tripleuro- -spermum inodorum.	8.1 5.6 3.5	4.7 4.2 3.8	6.7 3.7 1.6	9.4 4.6 1.5	2.2 2.2 0.1	4.2 1.5 0.1	7.9 2.8 0.3	13.6 7.6 3.3	5.3 4.2 3.3	**
Chrysanth- -emum segetum.	7.4 3.4 1.0	0	1.7 0.2 0	4.6 1.0 0	0	3.3 0.4 0	12.9 5.7 1.4	11.3 9.7 8.3	13.7 8.9 5.1	***
Silene noctiflora.	0	0	0	1.7 0.4 0	0	0.6 0.1 0	3.8 2.1 0.9	20.7 9.7 2.9	16.7 10.5 5.7	**
Misopates orontium.	0	0	0	0	0	0	0	1.2 0.3 0	7.5 4.8 2.6	*

spring barley (Table 53).

Papaver hybridum was recorded mostly from spring barley and from the plots of winter wheat sown between the 19th. and 20th. of November. Two other uncommon species, *Misopates orontium* and *Silene noctiflora*, were recorded almost exclusively from spring barley. *Chrysanthemum segetum* was mainly found in the spring barley plots, but was also present in small numbers in the first sown winter barley plots, although these plants produced relatively few flowers (Table 53).

As well as the considerable differences existing between the weed communities developing in the winter and spring crops, differences were also recorded within crop types between dates on which they were sown, and between winter wheat and winter barley when sown on the same dates. At Site 1, significantly fewer plants of most of the winter germinating weed species were found in the winter barley crops sown on the 29th of September (Table 53). At Site 2, however, *T. arvensis*, *P. segetum*, *Papaver rhoeas*, *A. githago* and *C. segetum* were all significantly more frequent in barley plots sown on the 29th. of September than in the other winter barley plots. *T. arvensis*, *P. segetum*, *A. githago* and *B. arvensis* were more frequent in the winter wheat plots sown between the 13th. and 14th. of October at Site 2, than in the other wheat plots.

Plants of *S. pecten-veneris*, *R. arvensis*, *B. arvensis* and *T. arvensis* were most frequent in winter cereals sown between the 13th. of October and the 3rd. of November at Site 1. *A. annua*, *P. hybridum*, *P. argemone* and *V. rimosa* were all significantly more frequent in winter wheat sown between the 19th. and 20th. of November at either one or the other of the sites.

Numbers of plants of *B. arvensis*, *S. noctiflora*, *P. rhoeas*, and *M. orontium* were significantly fewer in spring barley sown between the 16th. and 17th. of February than in the spring barley crops sown on the other two dates.

It was possible to make a direct comparison between winter wheat and barley sown on two dates, 13th to 14th of October, and 2nd to 3rd of November. At Site 1, *P. segetum*, *T. arvensis* and *V. rimosa* were more frequent in winter barley than in winter wheat sown between the 13th. and 14th. of October, while *A. annua* was more frequent in wheat than in barley. *P. segetum*, *Myosotis arvensis* and *Papaver rhoeas* were more frequent in barley than in wheat sown between the 2nd. and 3rd. of November, and *P. argemone* was more frequent in wheat than in barley. At Site 2, more plants of *P. segetum* and *P. rhoeas* were recorded in wheat than in barley sown on both dates, while *B. arvensis* was more frequent in barley than in wheat sown between the 2nd. and 3rd. of November.

Fruit production.

Comparisons between numbers of fruits produced per plant were possible only for seven species, and only

Table 54. Geometric mean numbers of fruits (with 95% confidence limits) produced at harvest per $4m^2$ plot of winter barley, winter wheat, and spring barley each sown on three different dates at two sites. Significance levels: *** P<0.05, ** P<0.01, * P<0.001, N.S. not significant. Analysis carried out on square root transformed data.

Site 1.	Crop and sowing date.									
	Winter barley			Winter wheat			Spring barley			
	29 Sept	13/14 Oct	2/3 Nov	13/14 Oct	2/3 Nov	19/20 Nov	16/17 Feb	9/10 Mar	28 Mar	P
Torilis arvensis.	0	0	0	0	0	770 607 464	0	0	0	***
Scandix pecten--veneris.	20 5 0	310 158 57	121 64 25	304 165 68	361 202 89	159 93 44	12 3 0	0	0	***
Ranunculus arvensis.	15 5 0.3	134 59 15	292 154 60	576 219 31	1007 558 241	107 73 45	0	12 1 0	0	***
Buglo--ssoides arvensis.	388 161 33	3763 1880 644	1695 1052 562	10201 3249 169	2842 1666 807	562 362 206	46 26 11	1011 632 341	1834 957 362	**
Adonis annua.	25 3 0	97 20 0	37 20 8	12 3 0.03	53 19 6	43 32 22	6 1 0	4 1 0	0	*
Myosotis arvensis.	21 2 0	141 16 0	457 347 253	1040 150 0	626 191 7	464 284 148	294 160 67	970 25 0	95 31 2	*
Papaver argemone.	0.6 0.1 0	3 0.7 0	32 16 6	3 2 0.2	47 27 13	126 78 42	4 0.9 0	24 7 0.2	40 10 0	***
Valer--ianella rimosa.	584 157 1	631 320 113	690 401 189	115 29 0	130 82 13	486 351 181	99 43 1	362 249 157	315 132 28	*
Papaver rhoeas.	109 33 1	157 50 3	590 261 60	1327 512 78	1018 480 142	685 524 384	180 95 9	586 288 95	607 355 171	**
Tripleuro--spermum inodorum.	0	0 0 0	6 1 0	26 17 9	66 32 11	130 112 97	61 35 16	322 166 51	366 223 115	***
Papaver hybridum.	0	0	21 7 1	0	44 24 10	200 119 59	49 12 0	107 39 5	85 28 2	***
Silene noctiflora.	0	0	0	0	0	2.1 2 1	28 12 3	150 38 0.003	307 123 21	**

Table 54. Continued.

Site 2.	Winter barley			Winter wheat			Spring barley			
	29 sept	13/14 oct	2/3 nov	13/14 oct	2/3 nov	19/20 nov	16/17 feb	9/10 mar	28 mar	P
Agrostemma githago.	288 204 134	63 29 8	0	353 164 47	0	0	0	0	0	***
Torilis arvensis.	0	0	0	0	0	17 1.9 0	0	0	0	ns.
Buglossoides arvensis.	901 468 176	2739 1976 873	526 265 92	6980 4310 2281	565 126 0	113 23 0	18 4 0	96 28 1	188 77 15	***
Papaver argemone.	0	6 1 0	8 1 0	25 4 0	26 11 0	103 51 6	0	0	0	**
Myosotis arvensis.	129 55 13	37 20 9	105 25 0	120 38 2	139 37 0.2	131 61 18	46 5.1 0	0	0	*
Papaver rhoeas.	20 12 6	36 8 0	48 10 0	403 137 11	0	291 120 23	2 0.3 0	7 0.8 0	54 10 0	**
Papaver hybridum.	0	6 1.2 0	2 0.2 0	89 11.3 0	6 1.3 0	13 2.7 0	6 1.6 0	5 1.8 0.1	22 4.2 0	N.S
Tripleurospermum inodorum.	11 1 0	35 5 0	2 0.2 0	120 79 0	106 51 16	27 6 0	56 18 1	167 94 20	113 75 45	*
Chrysanthemum segetum.	54 27 9	0	5 0.6 0	0	0	3 0.4 0	148 80 14	243 152 82	402 315 239	***
Silene noctiflora.	0	0	3 0.3 0	4 0.5 0	0	0	0	0	29 10.5 1	**
Misopates orontium.	0	0	0	0	0	0	0	4 0.8 0	173 47.5 0.4	**

Table 55. Mean number of fruits produced per plant at harvest (with 95% confidence limits) of a number of weed species, in crops of winter wheat, winter barley and spring barley each sown on three different dates at two sites. Significantly different results only. Significance levels (Kruskal-Wallis test), *** P<0.001, ** P<0.01, * P<0.05. - Insufficient plants recorded. Insufficient plants recorded in winter barley sown on 29th of September at site 1.

Crop and sowing date.

Site 1.	W.barley		Winter wheat			Spring barley			
	13/14 oct	2/3 nov	13/14 oct	2/3 nov	19/20 nov	16/17 feb	9/10 mar	28 mar	P
<u>Buglossoides arvensis.</u>	209 131 53	85 63 41	314 204 93	127 78 29	60 40 20	-	80 66 52	157 109 61	**
<u>Papaver hybridum.</u>	-	4.3 3.1 1.9	-	-	13.6 9.3 5.0	-	13.6 8.4 3.3	10.7 8.4 6.1	**
<u>Valerianella rimosa.</u>	86.3 64.8 43.2	64.8 44.8 24.8	-	39.5 27.3 15.1	33.4 27.3 21.2	28.4 19.1 9.8	43.8 35.8 27.8	40.7 25.6 10.4	***
<u>Tripleurospermum inodorum.</u>	0 0 0	1.1 0.5 0	3.9 3.3 2.7	8.9 5.7 2.4	24.3 18.3 12.2	4.8 3.7 2.6	39.3 18.7 0	33.1 23.4 13.6	***
<u>Papaver rhoeas.</u>	7.9 5.9 3.9	16.9 14.6 12.2	41.5 26.9 12.2	78.9 45.6 12.2	48.1 36.3 24.5	93.4 42.7 0	23.9 17.5 11.1	26.4 19.9 13.3	***

Site 2.	Winter barley			W.wheat	Spring barley			
	29 sept	13/14 oct	2/3 nov	13/14 oct	16/17 feb	9/10 mar	28 mar	
<u>Buglossoides arvensis.</u>	120 84 49	134 104 73	120 86 52	281 213 145	-	-	-	*
<u>Agrostemma githago</u>	13.7 10.3 6.9	8.0 5.3 2.5	-	33.0 22.3 11.6	-	-	-	*
<u>Chrysanthemum segetum.</u>	-	-	-	-	17.8 15.0 12.2	14.2 9.6 5.0	69.4 42.0 27.4	*

between some treatments (Table 53). Plants of B. arvensis produced most seed in winter wheat sown between the 19th. and 20th. of October. P. hybridum was least productive, and V. rimosa was more productive in winter barley. T. inodorum produced most fruits in spring barley crops and winter wheat sown between the 19th. and 20th. of November. P. rhoeas was least productive of seed in the winter barley crops. C. segetum produced most flowers in spring barley sown on the 28th. of March (Table 53).

In most of the cases described above, trends shown by the results for the production of fruits per plot tended to be similar to those for the number of plants recorded per plot. P. segetum and T. arvensis produced very few fruits before harvest time. Most fruits were produced per plot by C. segetum in spring barley sown on the 28th. of March, and Papaver argemone produced more fruits per plot in winter wheat sown between the 19th. and 20th. of November (Table 54).

It was possible to compare fruit production per plant in wheat and barley crops sown on the same dates as described above for plant number. At site 1, T. inodorum produced more fruit in wheat than in barley sown on both dates, P. rhoeas produced significantly more fruit in winter wheat sown on the first date only, while P. hybridum, S. pecten-veneris and R. arvensis produced significantly more fruit in wheat sown on the second date only. At site 2, Lithospermum arvense, Papaver rhoeas and Agrostemma githago produced more fruit in winter wheat sown between the 13th. and 14th. of October, while Tripleurospermum inodorum produced more fruit in wheat sown between the 2nd. and 3rd. of November.

Performance of the three crop types.

Crop height and stem density were measured as a measure of the competitive pressure exerted by the crop (Table 56). In both experiments, the second sowing of wheat (2nd-3rd November), gave the tallest crop, and in general, winter wheat was the tallest crop, followed by winter barley and then by spring barley. Although crop densities in both experiments were significantly different between treatments, these were not consistent between experiments.

At site 1, the number of sown rare species was greatest in the third winter barley and winter wheat sowings, and were least in spring barley. At site 2,, numbers of sown weed species were lowest in the spring barley plots and the November-sown winter cereal plots, and highest in the first two autumn sowings (Table 56). In contrast, the number of weed species arising from the indigenous seed-bank was significantly higher in the third sown spring barley than any of the winter sown treatments at Site 1, and greater than in the first two winter barley and the first winter wheat sowings at Site 2.

Seed production after harvest.

The fate of surviving, marked plants was followed in

Table 56. Height (cm.) and density (stems/m²) with 95% confidence limits, of crops of wheat and barley sown on three different dates each, and number of weed species per 4m² plot. Analysis of crop density performed on square-root transformed data. Significance levels; *** P<0.001, ** P<0.01.

Site 1.	Winter barley			Winter wheat			Spring barley			
	29 Sept	13/14 Oct	2/3 Nov	13/14 Oct	2/3 Nov	19/20 Nov	16/17 Feb	9/10 Mar	28 Mar	P
Crop height.	80.1	79.0	69.2	98.6	91.8	83.9	56.3	49.7	49.6	
	68.5	64.9	60.6	82.9	88.0	77.9	54.3	44.6	44.6	***
	56.9	50.7	51.4	67.1	84.2	70.9	52.3	39.5	39.6	
Crop density.	516	408	335	559	352	342	429	116	66	
	433	322	219	330	337	292	358	82	34	***
	355	246	128	161	323	246	294	53	14	
No. of sown weed spp.	11.1	11.8	14.3	13.2	13.3	14.0	11.0	10.5	9.2	
	8.5	11.0	13.7	12.0	12.8	14.0	9.8	9.5	8.3	***
	5.9	10.2	13.3	10.8	12.3	14.0	8.6	8.5	7.3	
No. of indigenous weed spp.	10.5	12.2	11.8	11.8	10.5	11.5	13.5	13.8	15.1	
	6.8	11.0	10.0	8.8	8.0	9.8	9.8	12.5	13.8	**
	3.0	9.8	8.2	5.8	5.5	8.1	6.1	11.2	12.5	

Site 2.	Winter barley			Winter wheat			Spring barley			
	29 Sept	13/14 Oct	2/3 Nov	13/14 Oct	2/3 Nov	19/20 Nov	16/17 Feb	9/10 Mar	28 Mar	
Crop height.	73.7	80.2	92.0	83.2	95.9	85.8	60.3	62.2	46.2	
	63.4	71.0	75.5	77.7	91.5	83.8	56.9	57.6	43.4	***
	53.2	61.8	59.0	72.2	87.1	81.8	53.5	53.0	40.6	
Crop density.	244	396	389	165	424	276	522	384	192	
	170	298	320	131	350	229	382	358	143	***
	109	214	258	100	282	187	264	332	101	
No. of sown weed weed spp.	8.8	9.8	6.8	11.9	7.5	8.6	6.0	6.8	7.7	
	8.3	8.0	6.0	9.5	5.8	7.5	4.7	5.5	6.8	**
	7.8	6.2	5.2	7.1	4.1	5.4	3.4	4.2	5.9	
No. of indigenous weed spp.	7.6	10.7	14.0	9.8	12.9	11.5	11.0	14.7	16.3	
	6.3	8.8	11.5	9.0	9.5	10.5	10.0	12.8	13.8	**
	6.0	6.9	9.0	8.2	6.1	9.5	9.0	10.9	11.3	

the stubbles left after the crop and upper parts of the weed plants had been removed. Mortality during harvest is expressed as a percentage of the total number of plants present before harvest per treatment in Table 57. Very few plants of S. pecten-veneris, R. arvensis, L. arvense or A. annua, survived harvesting, although L. arvense did persist in small numbers in some treatments. S. noctiflora and M. orontium survived considerably better, and indeed, new plants of both of these species were recorded from the stubbles of some plots.

Production of ripe seed by T. arvensis and P. segetum occurred almost entirely after the crop was harvested (Table 57). The only other species which produced relatively large numbers of ripe fruit after harvest, was T. inodorum, and then mainly in the winter barley. These patterns of fruit production were similar at the two sites.

The mean numbers of fruit produced over the whole period of the experiment per plot of each treatment by these three species and some others that survived after harvest is presented in Table 58. At both sites, T. arvensis was most productive in the first (29th.September) and second (13th-14th October) sowings of winter barley. At Site 1, P. segetum was most productive in the first two sowings of winter barley and at Site 2, it produced most fruits in the first sowing of winter barley (29th September) and very few fruits in winter cereals sown in November. Differences in seed production between plots by

Table 57. Total numbers of fruits produced per treatment ($16m^2$) before harvest and in post-harvest stubbles, by a number of weed species in an experiment in which winter barley, winter wheat and spring barley were sown on three separate dates. Results for Chrysanthemum segetum and Misopates orontium and for all species from the 5th of November assessment are from Site 2 only; results for Silene noctiflora, Tripleurospermum inodorum, Petroselinum segetum and Torilis arvensis from the 16th of October assessment date are averaged over the two sites.

		pre-harvest	stubble 16th Oct.	stubble 5th Nov.
Silene noctiflora				
Barley	29th Sept.	0	0	0
"	13th-14th Oct.	0	0	0
"	2nd-3rd Nov.	0.5	0	0
Wheat	13th-14th Oct.	1	1.0	0
"	2nd-3rd Nov.	0	0	0
"	19th-20th Nov.	2	0.6	0.7
Barley	16th-17th Feb.	7	2.4	0.8
"	9th-10th March	33	4.1	0
"	28th March	84	4.5	1.1
Tripleurospermum inodorum				
Barley	29th Sept.	2.5	11.5	2.2
"	13th-14th Oct.	7.5	19.0	6.1
"	2nd-3rd Nov.	2.0	14.0	2.4
Wheat	13th-14th Oct.	77.5	4.1	0.5
"	2nd-3rd Nov.	46.5	4.3	1.3
"	19th-20th Nov.	62.0	2.4	2.5
Barley	16th-17th Feb.	31.5	2.3	4.2
"	9th-10th March	149.5	2.9	0
"	28th March	157.0	4.3	0
Petroselinum segetum				
Barley	29th Sept.	0	333	340
"	13th-14th Oct.	0	154	433
"	2nd-3rd Nov.	0	29	2
Wheat	13th-14th Oct.	0	58	101
"	2nd-3rd Nov.	0	5	29
"	19th-20th Nov.	0	2	2
Barley	16th-17th Feb.	0	0	0
"	9th-10th March	0	0	0
"	28th March	0	0	0

Table 57. Continued.

Winter barley.	pre-harvest	stubble 16th Oct.	stubble 5th Nov.
Torilis arvensis			
Barley 29th Sept.	0	3273	0
" 13th-14th Oct.	0	2899	0
" 2nd-3rd Nov.	0	1433	0
Wheat 13th-14th Oct.	0	660	0
" 2nd-3rd Nov.	0	490	0
" 19th-20th Nov.	312	127	0
Barley 16th-17th Feb.	0	0	0
" 9th-10th March	0	0	0
" 28th March	0	0	0
Chrysanthemum segetum			
Barley 29th Sept.	30	1	0.9
" 13th-14th Oct.	0	0	0
" 2nd-3rd Nov.	3	0	0
Wheat 13th-14th Oct.	0	0	0
" 2nd-3rd Nov.	0	0	0
" 19th-20th Nov.	2	0	0.7
Barley 16th-17th Feb.	101	0	0.8
" 9th-10th March	169	1.6	1.9
" 28th March	319	2.3	1.9
Misopates orontium			
Barley 29th Sept.	0	0	0
" 13th-14th Oct.	0	0	0
" 2nd-3rd Nov.	0	0	0
Wheat 13th-14th Oct.	0	0	0
" 2nd-3rd Nov.	0	0	0
" 19th-20th Nov.	0	0	0
Barley 16th-17th Feb.	0	0	0
" 9th-10th March	2	1.6	0.6
" 28th March	77	2.8	1.9

Table 58. The mean numbers of fruits produced per $4m^2$ plot (with 95% confidence limits) by some weed species in post-harvest stubbles, in an experiment in which winter barley, winter wheat and spring barley were sown on three different dates. Analysis carried out on square-root transformed results.
Significance levels: *** P < 0.001; ** P < 0.01; * P < 0.05; N.S. not significant.

	Winter barley			Winter wheat			Spring barley			
	29 Sept	13/14 Oct	2/3 Nov	13/14 Oct	2/3 Nov	19/20 Nov	16/17 Feb	9/10 Mar	28 Mar	P
Site 1.										
<u>Silene noctiflora</u>	0	0	0	0.1 (0–0.6)	0	2.7 (1.5–4.8)	15.1 (1.7–42.2)	50.5 (1.7–166)	136 (25–337)	***
<u>Torilis arvensis</u>	4028 (2177–6442)	3923 (3059–4480)	2800 (1822–3988)	1166 (309–2575)	1252 (230–3091)	1558 (752–2652)	0	0	0	***
<u>Petro-selinum segetum</u>	200 (41–477)	311 (85–679)	60 (15–186)	7 (0.3–23)	8 (0.2–18)	0	0	0	0	***
<u>Tripleur-ospermum inodorum</u>	0	60 (3–186)	40 (4–114)	33 (15–59)	28 (9–68)	110 (98–123)	40 (25–59)	208 (122–316)	236 (134–367)	***
Site 2.										
<u>Silene noctiflora</u>	0	0	0.3 (0–2.8)	0.5 (0–4.1)	0	0	0	0.9 (0–4.1)	13.0 (1.0–38.0)	**
<u>Torilis arvensis</u>	3709 (2831–4706)	3036 (411–8089)	464 (11–1585)	1420 (125–4124)	270 (18–813)	263 (0–1353)	0	0	0	***
<u>Petro-selinum segetum</u>	1022 (408–1912)	161 (2–579)	16 (0–46)	271 (35–728)	5 (0–26)	3 (0–28)	0	0	0	***
<u>Tripleur-ospermum inodorum</u>	82 (16–199)	60 (21–91)	43 (0–283)	80 (0–318)	58 (23–68)	49 (0–219)	20 (1–61)	108 (5–249)	75 (45–113)	N.S.
<u>Misopates orontium</u>	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–0)	1 (0–2.3)	60 (36–190)	***

S. noctiflora and M. orontium were similar to those recorded before harvest. Seed production by T. inodorum was not significantly different between treatments at Site 2, but at Site 1, differences were similar to those recorded before harvest.

DISCUSSION.

Results for fruit production per plot are summarised in Table 59. The crop and sowing date in which each species produced most fruit are indicated.

Table 59. Summary of results for mean fruit production of weed plants per $4m^2$ plot of one of three cereal types sown on one of three different dates each. + = highest fruit production.
wb=winter barley, ww=winter wheat, sb=spring barley.
See Table 50 for sowing dates.

	Crop and sowing date. Site 1			Site 2		
	WB 123	WW 123	SB 123	WB 123	WW 123	SB 123
Best performance in winter sown crops.						
Agrostemma githago	Not sown			+	+	
Petroselinum segetum	++			+		
Torilis arvensis	++			++		
Scandix pecten-veneris	+	++		Not sown		
Ranunculus arvensis	+	++		Not sown		
Adonis annua	++	++		Not sown		
Buglossoides arvensis	++	++		++	+	
Valerianella rimosa	++	+	+	Not sown		
Papaver rhoeas		+++			+ +	
Myosotis arvensis	+	+		+	+	
Papaver argemone		++			+	
Papaver hybridum		+				
Best performance in spring sown crops.						
Tripleurospermum inodorum		+	++		+	++
Chrysanthemum segetum	Not sown					+++
Silene noctiflora			+			+
Misopates orontium	Not sown					+

Germination periodicity and seed dormancy.

Weed species vary in the times of the year in which they are able to germinate, as a result of the types of dormancy experienced by the weed seed (Chapter 5). The relative times of germination of weed species and crop will greatly influence the subsequent course of competition (Grime, 1979; Sattore, 1987). The sooner that a weed emerges after the cultivation of the soil, the greater the advantage it will have in competition with the crop. A cultivation time that coincides with a natural peak in the germination of a weed species, will therefore be more favourable to its subsequent growth and seed productivity.

The numbers of weed seedlings which germinated in plots sown on different dates were noticably different, although these differences were not analysed statistically. Few seedlings of *S. pecten-veneris*, *R. arvensis*, *T. arvensis*, *A. annua*, *P. segetum* and *A. githago* were recorded from the spring crops, whereas few seedlings of *S. noctiflora* or *M. orontium* were recorded from autumn-sown crops. Both *S. noctiflora* and *M. orontium* were almost entirely spring and summer germinating in an experimental investigation of germination periodicity (Chapter 5), while *S. pecten-veneris* and *R. arvensis* were largely autumn germinating. *C. segetum* had a germination peak in spring, and an additional one in September and October, and the numbers of seedlings recorded here reflect those peaks. A germination maximum was recorded for *L. arvense* in October and November, but with seedlings emerging throughout the other winter and spring months (Chapter 5). L. arvense behaved slightly differently at the two sites. At Site 1, it germinated mainly in the plots sown on the second two autumn sowing dates, both in plots sown to wheat and to barley. At Site 2 however, germination was greatest on the plots sown on the second date only, with relatively few seedlings emerging in the other plots.

Some weed species show relatively little ability to persist in the soil as dormant seed. An outstanding example of this phenomenon is A. githago, which germinates as soon as the availability of moisture permits, and has become dependent on being harvested and resown with the host crop (Firbank, 1988), a relationship which has broken down with improved methods of crop seed cleaning. It is possible that other species such as S. pecten-veneris and R. arvensis exhibit relatively little enforced or induced dormancy, and may germinate mostly in the autumn after they are produced. It was observed here that an unknown but large proportion of seed of S. pecten-veneris, R. arvensis and A. githago germinated in the buried seed storage bags over the winter. A. githago was recorded only in the plots sown on the first two dates in the autumn.

Seedling mortality.

The survival of weed seedlings after germination depends on their ability to withstand weather conditions, and on their ability to compete with the crop for nutrients, water and light.

The death of weed seedlings after periods of severe winter weather has been noted by other workers (e.g. Salisbury, 1961). Despite the post-winter assessment having been carried out rather late, relatively little mortality was recorded here among those species which were monitored over the winter. The only species which did suffer appreciable losses were those that were mainly spring germinating, but which had produced autumn seedlings. The most notable of these was *C. segetum*, of which the majority of seedlings in winter sown crops, apart from those in the first sowing of winter barley, had disappeared by May. All of those seedlings of *S. noctiflora* and *M. orontium* which germinated in the autumn, had disappeared by harvest-time. The winter of 1988-89 was exceptionally mild, with no days of settled snow recorded at either site.

Mortality between May and harvest-time was rather low for most species. It was greatest for seedlings of mainly winter germinating species such as *S. pecten-veneris*, *R. arvensis* and *A. annua*, which germinated in the spring.

Effects of crop type.

Competition between mixtures of annual species has been extensively studied (e.g. Harper, 1977; Grime, 1979; Firbank & Watkinson, 1985; Law & Watkinson, 1987; Vleeshouwers *et al*; 1989). Some crop species and varieties are known to be more competitive than others in relation to weeds by virtue of their long straw, dense leaf canopies or large numbers of tillers, and crop ground cover has been shown to be negatively related to weed ground cover (Orson, 1987; Satore, 1987, Karpenstein-Machan & Scheffer, 1989; Richards, 1989; Fischbeck, in press). It is possible that some varieties of winter barley, sown early in the autumn are able to suppress most species of weeds, due to their particularly vigorous tillering habit, and their early growth relative to the weeds.

A direct comparison of the competitive ability of cereal crops sown on different dates is confounded by differences in the spectra of weeds germinating after cultivations at different times (Roberts & Potter, 1980). Such interpretation is doubly difficult if spring cultivations are also considered. Notwithstanding this, it was possible to make a direct comparison between winter wheat and barley sown on two dates, 13-14 October, and 2-3 November. There appeared to be little difference between the germination of seedlings in the wheat and barley plots, but significant differences were recorded between the numbers of plants of several species at harvest, seven of which were more frequent in barley than in wheat, but four of which were more frequent in wheat than in barley. The mean number of fruits produced per plot was significantly greater in the barley than the wheat for V. rimosa and M. arvensis only however, and for eight species, was significantly greater in wheat than in winter barley. The fruit productivity per plant was greater in wheat than in barley for four species, *L. arvense*, *A. githago*, *P. rhoeas*, and *T. inodorum*. It seems that there was a tendency for more plants of more species to occur in winter barley, but for those plants which did occur in winter wheat to be more successful and productive of seed. It is difficult to interpret these results without much more experimentation. It is however interesting to note that at both sites, in the plots sown between the 2nd and 3rd of November, the crop stem density of wheat at harvest exceeded that of the barley, although in neither case was the difference significant, and in the cases of crops sown between the 13th and 14th of October at site 2, the density of barley stems was higher than that of wheat. It is possible that there was a relationship between weed seed production and crop stem density, and it may be that the variety of winter barley used here is inherently less competitive than the variety of wheat used when sown at later dates.

Effects of sowing date.

At Site 1, the numbers of most of the winter-germinating weed species surviving to harvest were highest in crops sown between the 13th and 14th of October and the 2nd and 3rd of November, whereas at Site 2, the most favourable crops were those sown on the 29th of September and the 13th and 14th of October. This discrepancy may have been due to damage caused to the first-sown winter barley crop at Site 2 by rooks (*Corvus frugilegus*).

The traditional time for sowing winter wheat was between the second week of October and the middle of November (Dadd, 1963), a period that included the second and third winter barley, and the first and second winter wheat sowings in these experiments. It was therefore not surprising that winter germinating arable weed species were most successful in crops sown on these dates.

If fruit production per plot is considered, additional differences can be seen. Both *T. arvensis* and *P. segetum* tended to be more productive in those plots sown on the first two dates in the autumn, although only producing ripe seed in the stubbles after harvest. These two species appear to require a very long growing season in order to flower and produce seed, and it was observed that plants grown from dry-stored seed planted in March did not flower until the following year. *B. arvensis* tended to be more productive in winter wheat sown between the 13th and 14th of October, and the size of some plants sown on this date was impressive, some having numerous stems overtopping the crop, each over 1 metre in length. This species has been found to be highly competitive in relation to winter wheat crops (Wilson, 1986).

The poor fruit production by some species such as *S. pecten-veneris*, *R. arvensis*, *B. arvensis*, and *B. rotundifolium* in the first sown winter barley, can be further explained by harvest occurring in July before weed seed had ripened. Seed shedding by *Alopecurus myosuroides*, another typical species of autumn sown cereal crops was recorded by Moss (1983) as occurring largely between typical harvest-times for winter barley and winter-wheat.

In spring barley, highest numbers of fruit were produced by plants of all species in crops sown on the 28th of March. Both the crop density and height were highest in the first spring barley sowing, but were very low at both sites in the third sowing, probably due to the extremely dry weather after drilling. It is possible that the different densities of crop had an effect on the survival and seed productivity of the weeds.

Survival and fruit productivity of plants after harvest.

Plants of some weed species had already senesced and set seed by the time of harvesting. Others were species of tall stature, with the greater part of the plants above the level at which the plots were cut. These included *S. pecten-veneris*, *R. arvensis*, *L. arvense*, *A. annua*, *P. hybridum*, *P. argemone*, *P. rhoeas*, *A. githago*, *C. segetum*, *V. rimosa*, and *B. rotundifolium*. Of these species, *A. annua*, *P. hybridum*, *P. argemone*, *P. rhoeas*, and *C. segetum* have been observed in the field to produce new growth and flowers after harvest, but although some regrowth of these species was observed in these experiments, very little seed was ripened.

S. noctiflora, *T. arvensis*, *P. segetum*, *M. orontium* and T. inodorum were observed to ripen seed in the stubbles. Of these, the only species that set seed almost entirely after harvest, were P. segetum and T. arvensis. P. segetum is a plant of erect habit, with a main stem growing as tall as the crop, but it branches extensively from the base, and these branches bore most of the fruit. Fruit ripened gradually throughout the autumn, and had not all ripened before the first winter frosts and senescence of the plant. This requirement for a long growing season may partially explain the restriction of this species to areas in the south of England with relatively mild climates (Perring & Walters, 1976), where it frequently occurs on the occasionally disturbed and drought-prone soils of sea-walls and hedge-banks.

T. arvensis is a plant of relatively low stature, and although the uppermost umbel tended to be removed at harvest, most inflorescences remained. All seed had set and plants had senesced by the time of the first assessment of the stubbles on the 19th of September.

The other two rare species which persisted in the post-harvest stubbles, M.orontium and S.noctiflora, are predominantly spring germinating, and were recorded here almost exclusively from the second and third sowings of spring barley. In the survey of rare weed sites (Chapter 2), these species were both observed to grow best in relatively non-competitive, spring-sown root and vegetable crops, which also tend to be harvested late in the autumn, thereby ensuring a long growing season, and a crop cycle corresponding with the phenology of the weed species.

A number of other weed species have been recorded as being prominent in post-harvest cereal stubbles. These are mostly low-growing species, frequently of prostrate habit, which are able to escape the cutter bar of the combine harvester. These include the relatively uncommon Kickxia spp., Stachys arvensis and Galeopsis angustifolia, and more common species such as Polygonum aviculare, Aethusa cynapium and Sherardia arvensis. Most of these species are spring germinating, and it is possible that they require a longer period of growth in the late summer to compensate for their late germination.

The earlier a crop is harvested, the less able are many species to set seed before harvest. There is however, little evidence that the mean time of harvesting either winter wheat or spring barley has changed. Before the advent of the combine harvester, harvest started earlier in the year, and the grain was allowed to ripen in stooks of the harvested crop. However, harvest was a much slower process, especially when carried out by scythe, and harvesting frequently carried on until November (Cobbett, 1830). The most important changes in harvesting times are connected with changes in cropping patterns. Table 49 illustrates changes in the areas sown to particular crops since 1958, and the increase of oil-seed rape and winter barley is striking. These crops are harvested much earlier than the more traditional cereal crops, but the effect of date of harvest is probably less important than the effects of early sowing date and competitivity.

Adaptation of weeds to specific cropping systems.

The results discussed above illustrate the synchronisation of life cycles of many weed species with the phenologies of crops and most of the species studied performed differently in crops sown on different dates.

The most extreme cases of synchronisation between crop and weed phenology are to be found in the linicolous species such as *Cuscuta epilinum*, *Camelina alyssum*, *Lolium remotum* and *Spergula maxima*, which have seeds that are harvested and resown with the crop, and which have declined to the point of extinction over much of Europe following the abandonment of traditional flax culture (Salisbury, 1961; Kornas, 1988). The dependance of *A. githago* on harvest and sowing along with the crop seed, and its decline in association with improved methods of seed cleaning has been well documented (Salisbury, 1961; Firbank, 1988). Most other species have seeds that exhibit a range of dormancy mechanisms and thereby form banks of seed in the soil which can buffer a weed population against the effects of adverse conditions (Firbank, 1989). Despite the resilience conferred on a weed population by this seed-bank, long-term changes in cropping systems will cause changes in the composition and size of weed seed-banks.

A species such as *M. orontium* may be taken as an example. This species was found to grow and produce fruit only in late-sown spring barley. If the crop rotation in a field in which this species occurs were to be changed from one consisting mainly of spring barley and root crops, to one consisting entirely of winter cereals, then the continued existence of this species would be threatened. This is an extreme example, but it serves to illustrate the potential effect of a change of cropping regime on populations of weeds which often exist as small, isolated populations under pressure from the effects of herbicides and crop competition enhanced by increased nitrogen applications.

Many of the species that have shown the greatest declines in recent years, such as _S. pecten-veneris_, _R. arvensis_ and _T. arvensis_ are restricted to winter crops, and in the absence of herbicides and at low rates of fertiliser application, appear to grow very successfully. These species still grow vigorously at some sites in Britain. Species included here which are still common, such as _P. rhoeas_, _T. inodorum_ and _M. arvensis_, and those which are still relatively widespread or locally frequent, such as _B. arvensis_, _P. argemone_, _P. hybridum_, _C. segetum_, _S. noctiflora_ and _M. orontium_, grow and produce seed mainly in spring sown crops or in crops sown on a wider range of dates. These results imply that the ways in which winter cereals in particular are grown have changed in a way that is detrimental to these species, despite the increased area sown of these crops. Changes in farming practice which may have been responsible for these declines include increases in fertiliser and herbicide use, and the tendency towards earlier crop drilling.

The consequences of changes in crop rotations for other farming practices, and the effects of interactions of farming practices on weed species and communities are discussed in Chapters 8 & 9.

CHAPTER 8

DISCUSSION

The effects of some agricultural practices on populations of uncommon arable weeds have been considered in isolation from each other in the foregoing chapters. Crop drilling date (Chapter 7), herbicide use (Chapter 4), level of nitrogen application (Chapter 6), and density of crop sowing (Chapter 6) were all investigated experimentally, and their individual effects have been discussed. In reality however, changes in modern farming have involved parallel changes in all of these parameters (Orson, 1987), and these have been closely interconnected, as described in Chapter 1. Some of these parallel changes are illustrated in Table 60.

Table 60. Some changes in farming practice since 1943. Information from Anon, 1965 & 1989; Sly, 1974; Steed & Sly, 1977; Sly, 1984, Church, 1981.
WW Winter wheat; WB Winter barley; SB Spring barley.

Year.	Area of crop. (ha x 10^3).			% of area sprayed with herbicide.			Mean nitrogen supply(kgN/Ha).	
	WW	WB	SB	WW	WB	SB	WW	SB
1943				0	0	0	19	21
1957							51	35
1958	856	0	1022					
1970							90	82
1974	1139	217	1595	158	141	130		
1977	1025	332	1614	168	120	130		
1980							145	86
1982	1620	828	886	251	208	154		
1987	1888	889	554					

It may be seen from this table that, as well as the area of arable land sown to winter wheat and winter barley having increased at the expense of that sown to spring barley, the amounts of both herbicide and nitrogenous fertiliser applied to winter cereals have increased much more than the amounts applied to spring barley. The results of investigations into the effects of fertiliser, herbicide and crop sowing date on weed populations must therefore be considered in combination. Ideally, the interactions between factors should be investigated experimentally, but even if one takes a conservative approach, and considers their additive effects on weed populations, it becomes apparent that the situation in the field will be very different to that demonstrated experimentally for single variables.

The combined effects of these changes and others not investigated here, on the distributions of individual species and weed communities, were illustrated in the field by two surveys. The distributions of arable weed species and communities were found to be associated with a range of environmental factors and cropping variables, in a survey of rare weed sites carried out between 1987 and 1989 (Chapter 2). Correlations were also recorded between the number of rare species present at a site and the length for which that site had been used for arable farming. The second of the two surveys (Chapter 3) demonstrated that, not only have many species of annual weed become rarer in the country as a whole, but are also restricted to very small areas of the fields in which they are still found.

It would theoretically be possible to construct mathematical models for the response of weed species to changes in farming practices, incorporating results from investigations similar to those described here. Many such models have been proposed, but chiefly for simple mixtures of species grown in controlled conditions (e.g. Spitters & Aerts, 1983). It is considered however, that such attempts at producing accurate models, although coincidentally generating data of value, are themselves of limited use. The variables involved are so numerous, interact to such an extent, and are of such complexity that any model would offer a misleading degree of accuracy. At the same time, most aspects of farming practice that may be incorporated into a management plan have such large effects on the populations of annual weed species, that an attempt to produce a fully deterministic model is unnecessary. These issues have been fully discussed by Mortimer (1987) and Firbank (1989 & in press).

It is probable that the ability of seed to persist in the seed-bank is a crucial factor in the survival and success of an annual weed species, especially when they are strongly constrained by some other aspect of their ecology, such as restricted germination period, herbicide sensitivity, or non-competitiveness with crops. Species which have poorly persistent seed and which have a relatively specialised ecology will show considerable fluctuations following changes in farming practice. In some cases, e.g. Galium aparine (Chancellor & Froud-Williams, 1986) and Bromus sterilis (Howard et al, 1989) the weeds have become more abundant, but in most other cases, e.g. Agrostemma githago (Firbank, 1988), Scandix pecten-veneris and Ranunculus arvensis, declines have been the consequence.

Although an intensive study of weed seed-bank characteristics was beyond the scope of this project, results of the investigation into the germination periodicity of weed species (Chapter 5) and the survey of seed-bank distribution (Chapter 3), have allowed some inferences to be drawn. Of the 21 species examined in Chapter 5, five, Bupleurum rotundifolium, Adonis annua, R. arvensis, S. pecten-veneris and Valerianella rimosa, showed an initial germination of more than 40% of the initial number of seed planted, implying the presence of relatively little seed dormancy, and an inability to form a seed bank of very long persistence. These species have all experienced extremely severe declines in recent years (Table 2). The more common species included in the experiment all showed less initial germination and seedlings were still germinating at the end of the experiment. Chapter 3 compared the numbers of seedlings present in seven spring cultivated fields with the numbers of seed in the seed-bank. All of the species examined were still frequent at least locally, and emerged seedlings represented a relatively small proportion of the seed-bank.

It is possible to consider some of the major interactive effects between the farming variables investigated here. There is an apparent contradiction between the fact that those weed species which have declined most in recent years are all predominantly winter germinating (Chapter 5) or performed significantly better in autumn-sown cereal crops (Chapter 7), while the acreage of these crops has in fact increased during the last 30 years (Table 49). From this result alone, it might be expected that, in general, winter germinating weeds should have increased. Winter wheat however is farmed very intensively, with a mean of 2.5 herbicide applications per year, and a mean level of nitrogen application of nearly twice as much as to spring barley. Results for the survival and seed production of weed species in crops grown with different amounts of nitrogen demonstrate that in a fully fertilised wheat crop, extremely effective weed control could be achieved, even without the use of herbicides. Some species such as S. pecten-veneris and R. arvensis which were found to be characteristic of winter-sown crops were also found to be highly sensitive to the herbicides tested (Chapter 4). The behaviour of weed species in the Broadbalk experiment, and in experiments described by other workers (Ubriszy, 1968; Dvorak & Krejcir, 1980; Roberts & Neilson, 1981; Hume, 1987) also implied that herbicide use can lead to long term declines in weed populations, even when these populations are of very productive species such as Papaver rhoeas, which showed little response to nitrogen application level (Chapter 6), and which are known to have relatively long-lived seed (Brenchley & Warington, 1930). The synergistic effects of herbicide use, high nitrogen supply, and early crop sowing date on a species such as S. pecten-veneris which is thought to have relatively little seed dormancy (Brenchley & Warington, 1930), grows well only in crops sown in a restricted period of the year (Chapter 7), produces little seed, and is very susceptible to many commonly used herbicides (Flint, 1987), can be imagined to be considerable, and could account for its remarkably rapid decline.

It appears that most of the weed species that have declined to the greatest extent in recent years, grow best in non-intensively farmed winter cereals, with low inputs of nitrogen and herbicide. Examples of such species included in the experiments and surveys described here, include S. pecten-veneris, R. arvensis, Torilis arvensis, Arnoseris minima, Petroselinum segetum, Myosurus minimus and Adonis annua (Chapters 2,3,4,5,6 & 7).

Species such as Chrysanthemum segetum, Misopates orontium and Silene noctiflora which are mainly spring germinating, and others with a rather more flexible ecology such as Buglossoides arvensis, P. hybridum, and P. argemone, evidently possess mechanisms by which the dormancy state of the seed can be regulated by environmental processes. They are probably capable of withstanding adverse changes in farming practices to a much greater degree than the species which have declined most in recent years. Such species have become rarer in recent years, but still seem to be able to persist in some parts of the country.

It is paradoxical that some of the species which have become pests of modern cereal farming, such as *Alopecurus myosuroides*, *Bromus sterilis* and *Galium aparine*, are also mainly winter germinating, and are known to have seed of short longevity, forming a seed-bank of short persistence or indeed no seed-bank at all (Chancellor & Froud-Williams, 1986; Howard et al, 1989), in common with some of the rare species. These species are however responsive to high levels of nitrogen, are resistant to many herbicides (Farahbakhsh & Murphy, 1988; Orson, 1987), and *B.sterilis* in particular germinates very early in the autumn, thereby coinciding with the early drilling dates favoured in modern cereal husbandry (Howard *et al*; 1989). They are therefore well adapted to the very conditions which have led to the decline of many other species.

The less intensive regimes under which spring barley is grown, have not disadvantaged spring germinating weeds as much as winter germinating species in winter cereals. It has therefore been suggested that spring cereals are "better" for rare weeds than are winter cereals, while the real differences lie in the degrees of intensity of the farming methods practised. If a large scale switch to spring cultivations occurred, as has been suggested in some proposals for the extensification of cereal production, then many surviving populations of winter germinating weed species such as *S. pecten-veneris* and *R. arvensis* could be eliminated, although there could be benefits to some of the less endangered spring-germinating species. While acknowledging some of the general environmental benefits resulting from an increased acreage of spring barley, it is important that the extensification of arable farming is considered in the context of a return to more sustainable farming systems, under which the natural diversity of the arable ecosystem may be maintained.

Conclusion.

As a result of the experiments and surveys described, it is now possible to propose some management guidelines for the conservation of endangered weed species and communities. These are included in Chapter 10. It must be re-emphasised that there is no single factor responsible for the declines of annual weeds and the impoverishment of their communities, rather, these declines are a result of several factors, the importance of which will vary between species. There is consequently no single factor which may be manipulated to enable populations to recover, although there are some which will be of general benefit.

Recommendations for conservation management will ideally be specific both to locality and species, although a set of general guidelines is also proposed. Descriptions of the ecology of the eight selected rare species are included in Chapter 9.

If the suggested management guidelines are to be effective, it is essential that they are tested on naturally occurring weed populations in the field. It is hoped that further work will be possible, by means of which the efficacy of these recommendations may be experimentally determined.

CHAPTER 9.

A REVIEW OF THE ECOLOGY AND STATUS OF EIGHT UNCOMMON ARABLE WEED SPECIES

The ecology and status of the eight selected annual weed species is discussed in relation to the results of the surveys and experiments described in Chapters 2 to 7 and in relation to the findings of previous work.

The decrease in frequency of each species is described in terms of the numbers of 10km. squares from which it was recorded between 1930 and 1960 (Perring & Walters, 1976), and the numbers of 10 km squares from which the species was recorded during the N.C.C/B.S.B.I. arable weed survey between 1986 and 1989 (A.Smith, pers. comm). Edaphic and climatic preferences and crop correlations are from survey data (Chapter 2). Crop correlations are either positive or negative. Preferred crops and drilling dates, germination periodicity and herbicide sensitivity are from the experimental results described in Chapters 7, 5, and 4.

Adonis annua.

Geographical distribution: Figure 1.
Decrease, 10km. squares 1930-60, 30 ; 1988, 10.

Edaphic preferences: high pH, high Ca^{2+}content.
Climate: Low summer rainfall.
Crop correlations: + Winter barley, - root crops, + grass

Optimum crop & sowing date: Winter wheat, Nov. to Dec.
Germination periodicity: Mainly initial (42.3%).

Seed weight per 1000 seed: 7.9g

Herbicide sensitivity: Not known.

It has been suggested that the decline of this species began in the last century, partly in response to improved seed cleaning methods (Salisbury, 1961) and partly as a result of climatic change in the 1880s (Smith, 1986). Due to difficulties in producing enough seed for experimental use, little information was gained from this study on the response of this species to herbicides or competition from the crop in response to high levels of applied nitrogen. Silverside (1977) believes both of these factors to have been important in its decline.

Only 12 sites are known for this species, (Wiltshire, 4; Hampshire, 4; Dorset, 1; Gloucestershire, 1; Sussex, 1; Berkshire, 1). Eight of these were surveyed. It was found only on loamy soils derived from chalk or oolitic limestone, and occurs no further north than Berkshire. In all of its remaining sites, it is part of a species-rich community, referred by Silverside (1976) to the *Adonido autumnalis-Iberidetum amarae*, although his arguments appeared unconvincing with regard to the sites recorded here. Uncommon species that were particularly frequently associated with A. annua were Papaver hybridum and Petroselinum segetum. It was recorded mainly from winter cereals and rape, and was found experimentally to grow best in a late drilled crop of winter wheat. It has been suggested that this species can exhibit considerable persistence in the soil (Salisbury, 1961; Horton et al, 1972), although in the experiment described in Chapter 5, the germination that occurred was almost entirely initial, possibly due to seed storage conditions. This species appeared to be able to survive in the soil under a grass ley for several years at a number of sites.

Seed production was observed in two experiments (Chapters 6 & 7), and was in general rather small. Salisbury (1961) also recorded low numbers of seed, and considered that improved crop seed cleaning had contributed to its decline.

In view of its low seed productivity and restricted period of germination, it is probable that any adverse changes in farming practices will have had rapid and profound effects on populations of this species (Salisbury, 1961; Smith, 1986). The only factor that was shown to be unfavourable experimentally, was the trend towards earlier crop drilling, although it is probable that increased use of herbicides and fertiliser have also played a part.

Chrysanthemum segetum.

Decrease: unknown.

Edaphic preferences: low pH, low Ca2+content, light soils.
Climate: High summer rainfall, high winter air temperature.
Crop correlations: + Spring barley, + root crops.

Optimum crop & sowing date: Spring barley, March.
Germination periodicity: March-May, August-October.

Seed weight per 1000 seed: 1.8g

Herbicide sensitivity: MCPA, Resistant ;
Mecoprop, Resistant ;
Dicurane, Susceptible ;
Ioxynil/Bromoxynil, Susceptible.

Although Salisbury (1961) described this species as having decreased, it is still regarded as a problem to agriculture in some areas of Britain, in particular Ireland and Scotland. This species is believed to have decreased within the last ten years, although it has not been possible to quantify this. It is known to be resistant to a wide range of herbicides (Flint, 1987), and of the early chemicals developed, only the highly toxic Dinoseb and DNOC were effective against this species (Woodford & Evans, 1963). Neither of these herbicides is now approved for use in arable farming. The development of more effective herbicides in recent years seems to have been at least partially responsible for the decline of this species. Salisbury (1961) attributes some of the longer-term decline of this species to improvements in seed cleaning.

The periodicity of germination of this species has meant that it is largely restricted to growing in spring sown crops, as has been known for many years (Brenchley, 1920). *C. segetum* can also germinate in early autumn, and was present in experimental plots of winter barley sown in September, and was recorded from an area of habitually early-sown winter cereals in mid-Norfolk. The tendency towards the replacement of spring crops by winter cereals, has probably been another factor in the decline of this species, although in the areas where *C. segetum* is still relatively widespread, this tendency has been less marked (M.A.F.F., 1965 & 1989).

This species is characteristically restricted to freely-draining soils with a high sand fraction. The waxy cuticle that covers the leaves of this plant and prevents the penetration of many herbicides, may be an adaptation to reduce water loss. The restriction of this species to such soils was noted by Brenchley (1920), and Salisbury (1961) suggested that it was further restricted to soils of low pH, and low $CaCO_3$ content. This was largely confirmed by the results of this project, although the largest populations recorded, were on soils with both high pH and $CaCO_3$ content due to substantial inputs of calcareous sand. *C. segetum* grew on almost pure chalk at one survey site.

The emergence of *C. segetum* in the experiment described in Chapter 5, implied that this species can persist in the soil seed-bank, and that dormancy mechanisms are complex.

C. segetum competed well with a spring barley crop when high levels of nitrogen were applied (Chapter 6). The competitiveness of this species has been noted by other workers (Courtney & Johnston, 1988). Seed production can be very high, especially under low competitive pressure and high nitrogen level.

This species is very restricted edaphically, and only grows well in spring crops. The transition from spring barley to winter crops has probably been responsible for much of the decline of this species, and the introduction of effective herbicides has exacerbated the situation where spring barley is still widely grown.

Buglossoides arvensis.

Decrease: 10km squares 1930-60, 310; 1988, 42.

Edaphic preferences: High pH, no stones, clay.
Climate: Low winter rainfall.
Crop rotations: - root vegetables, + winter crops.

Optimum crop & sowing date: Winter crops; Oct., early Nov.
Germination periodicity: October-December, March-April.

Seed weight per 1000 seeds: 5.95g

Herbicide sensitivity: MCPA, Resistant ;
Mecoprop, Moderately resistant ;
Dicurane, Moderately susceptible ;
Ioxynil/Bromoxynil, susceptible .

This is another species which is still considered a problem in some areas (G. Cussans, pers.comm.; G. Collini, pers. comm.). As described in Chapter 2, *B. arvensis* seems to occur in two situations. Most sites were on chalky soils with high pH and high $CaCO_3$ content, in fields bearing a mixture of crops and species-rich weed floras. There was however, a group of sites from much heavier clay soils in Suffolk and the South Midlands, at which mainly winter cereals were grown, and with relatively species-poor weed communities. These weed communities may represent degraded remnants of formerly richer floras, which have deteriorated in response to intensified farming methods.

There is evidence that some inter-site transport of *B. arvensis* seed may occur. A local infestation of this species in Northamptonshire was connected with the use of contaminated farmyard manure (G. Collini, pers.comm.), and seed contamination was blamed for its occurrence in one site in Bedfordshire (C. Merritt, pers. comm.). The presence of *B. arvensis* at two non-arable sites in the Suffolk Brecklands was thought to be due to the feeding of stock on straw containing this species (P.J.O. Trist, pers. comm.). Seed cleaning may have had some effect on the abundance of this species, as it has seed of similar dimensions to those of cereals (Salisbury, 1961).

B. arvensis is quite resistant to some commonly used herbicides (Chapter 4; Flint, 1987), and it is possible that this species owes its persistence in some areas to difficulties in eradication by herbicide use alone. *B. arvensis* appears to grow and produce seed better in winter crops sown in October and November, and will be favoured by the continual growing of winter cereals if sown at this time. However, the prevailing recent trend has been towards drilling crops early in the autumn, which does not favour this species. *B. arvensis* can grow well in spring crops, but does not produce so much seed as in winter cereals (Chapter 7).

B. arvensis has been found to be very competitive in relation to cereal crops (Wells, 1979; Wilson, 1986). The results of the experiment described in Chapter 6 supported these findings, and it appears that *B. arvensis* responds well to nitrogenous fertilisers, especially in winter cereals. Seed production can be high, and can exceed that of the other rare species examined when in a fully fertilised crop of winter cereal drilled in October.

Most germination of this species in the experiment described in Chapter 5 occurred initially, although some germination was recorded throughout the course of the experiment. The persistence of seed in the soil may therefore be less than that of some other species, although is probably greater than that of Scandix pecten-veneris and Ranunculus arvensis. This species is relatively adaptable, and seems to be well suited to many of the trends in modern arable farming, apart from the trend towards earlier sowing of autumn sown cereals, and it is also very susceptible to some recently introduced herbicides (Flint, 1987).

Misopates orontium.

Decrease: 10km squares 1930-1960, 197; 1988, 59.

Edaphic preferences: low pH, sand, siliceous stones.
Climate: High summer rainfall, high summer sunshine, high winter air temperature.
Crop correlations: + Spring barley, + root crops.

Optimum crop & sowing date: Spring barley, late sown.
Germination periodicity: March-September

Seed weight per 1000 seeds: 0.187g

Herbicide sensitivity: MCPA Moderately resistant ;
Mecoprop Moderately susceptible ;
Dicurane not tested ;
Ioxynil/Bromoxynil Susceptible .

Misopates orontium is similar in its general ecological requirements to Chrysanthemum segetum, although much more restricted in geographical range to the south and west of Britain. It appears to have gone from most of the sites in central and Eastern England from which it was recorded between 1930 and 1960 (Perring & Walters, 1976), although it is still quite frequent around the coasts of Cornwall, and more locally on gravelly soils in the Hampshire Basin. It prefers sandy, stony soils of low pH, although it grows also on stony acidic clay soils in mid-Devon.

This species germinates almost exclusively in spring and summer months, and is therefore found mainly in spring sown crops, in particular root crops, and in some areas, market gardens. It is probable that the decline in area sown to these crops (Table 49) has contributed to the decline of this species.

No plants survived to produce seed in crops supplied with high levels of nitrogen in the experiment described in Chapter 6. It is probable that the increased quantities of nitrogen supplied to cereal crops have contributed to the decline of this species. It was also susceptible to all of the herbicides tested.

In the experiment described in Chapter 5, seed of M. orontium was still germinating at the end of the experiment, and it is possible that this species exhibits considerable longevity in the seed-bank. One site at which this species was recorded had been under grass for at least eight years before the year of the survey.

Herbicides, fertiliser use and changes in crop types and sowing dates are all thought to have contributed to the decline of this species, although it still seems to persist in areas where conditions are still suitable.

Papaver hybridum.

Decrease: 1930-1960, 77; 1988, 44.

Edaphic preferences: high pH, high $CaCO_3$, light soils.
Climate: High summer sunshine, low summer rainfall, high winter air temperature.
Crop correlations: + Spring barley, - root crops, + winter barley.

Preferred crop & sowing date: Winter wheat, late Nov.; also spring barley
Germination periodicity: February-April, October-December.

Seed weight per 1000 seed: 0.12g

Herbicide sensitivity: MCPA Moderately resistant ;
Mecoprop Moderately susceptible ;
Chlortoluron Susceptible ;
Ioxynil/Bromoxynil Susceptible .

Papaver hybridum is still locally frequent in some parts of southern England, but unlike Chrysanthemum segetum or Buglossoides arvensis has never been present in sufficient quantities to be considered a problem. Its geographical range is restricted, being a characteristic species of fields with light, chalky soils from Wiltshire to Cambridgeshire and to Kent, with outlying sites in Norfolk, Northamptonshire, Dorset and Cornwall. It appears to have gone from most of its former sites outside the climatically and edaphically favourable limits of this range.

In the survey described in Chapter 2, it was found mainly as a part of fairly species-rich communities, most of which can be included within the alliance *Caucalidion lappulae* (Silverside, 1977). Some sites were species poor, and probably of relic status, with species such as Bromus sterilis and Galium aparine.

P. hybridum was competitively disadvantaged in the presence of crops by high levels of nitrogen (Chapter 6), and was susceptible to all of the herbicides tested. It grew best and produced most seed in a late-November drilled wheat crop, although also performing well in spring sown crops. In the field, it was found mostly in crops of spring barley.

This species was restricted to the extreme edge of the cultivated area of a number of fields surveyed (Wilson, 1989; Chapter 3), and it is possible that it can survive in such positions only because of the relatively low levels of agrochemical and fertiliser inputs.

In common with other species of Papaver (Roberts & Boddrell, 1984), P. hybridum is thought to have a dormancy mechanism which enables the seed to exhibit considerable longevity in the soil. This species was sown twice in the experiment described in Chapter 5, and seedlings were still emerging at the end of the experiment. Despite the susceptibility of this species to the increase of fertiliser and herbicide use and to changes in crop sowing times, it is still capable of persisting in areas where suitable crops are grown, and can survive periods of adverse conditions in the seed-bank.

Ranunculus arvensis.

Decrease: 10km squares 1930-1960, 432; 1988, 26

Edaphic preferences: Clay, no chalk or limestone.

Climate: Low summer air temperature.
Crop correlations: + Winter crops, - winter barley.

Preferred crop & sowing date: Winter cereals; Oct., Nov.
Germination periodicity: October-December.

Seed weight per 1000: 10.5g

Herbicide sensitivity: MCPA, not tested ;
Mecoprop, Susceptible ;
Chlortoluron, Susceptible ;
Ioxynil/Bromoxynil, not tested.

Although this species was always rather unpredictable in its occurrence and abundance from year to year at any one site (Thurston 1964; Salisbury, 1961), and despite the lack of comparability between the times over which the distributions are compared, it is thought that this species has experienced the greatest and most rapid decline of any in the British flora. Many of the more recent records are of single plants which did not persist for more than one year, and which may represent relics of a once larger seed-bank.

Only four sites were visited at which this plant could be considered to have good and reliable populations, although it is possible that there are additional sites that may still be viable, given the known instability of population sizes from year to year. At several former sites, the species could not be refound, and at others populations were very small. The main centre of distribution is on the heavy, non-calcareous clay soils of Worcestershire and Warwickshire, although populations exist on similar soils in other parts of the country.

The heavy soils which this species favours are now normally sown to winter wheat or rape, crops whose phenologies coincide with that of this species (Chapter 7). R. arvensis performed poorly in winter barley when sown in September, possibly due to the density and competitiveness of the crop, and R. arvensis was found to perform badly in competition with wheat crops at high levels of nitrogen supply (Chapter 6). Two of the best field populations were found in very gappy and uncompetitive crops of rape, a characteristically early sown crop.

Seed production by this species is very small compared with that of species such as Papaver spp., Silene noctiflora, Misopates orontium or Buglossoides arvensis, even when grown under optimum conditions.

R. arvensis was still common in the early 1950s when herbicides were first used widely, and some information exists on its susceptibility to some of the early herbicides. It is known to be highly sensitive to most of the commonly used compounds (Chapter 5; Flint, 1987). Thurston (1964) attributed the decline of this species on Broadbalk to the introduction of herbicides.

Most of the germination of this species was found to occur initially (Chapter 5), although a few seedlings did emerge throughout the course of the experiment. If this pattern of germination is exhibited in the field, then the fluctuations in population size, its rapid decline, and the occasional records of isolated plants can be easily explained, if considered in context of its sensitivity to changes in farming practice and its poor seed production.

The best sites for this species included other rare species such as Euphorbia platyphyllos, Scandix pecten-veneris, Torilis arvensis, and Valerianella rimosa and are among the most important sites for arable weed conservation in the country.

Scandix pecten-veneris.

Geographical distribution: Figure 1.
Decrease: 10km squares 1930-1960, 426; 1988, 25.

Edaphic preferences: high pH, clay.
Climate: Low winter air temperature, low summer rainfall.
Crop correlations: + Winter crops, - winter barley,
- root crops.

Optimum crop & sowing date: Winter cereals, Oct., Nov.
Germination periodicity: Mainly initial, November-December.

Seed weight per 1000 seed: 21.5g

Herbicide sensitivity: MCPA Moderately susceptible ;
Mecoprop Moderately susceptible ;
Chlortoluron Susceptible ;
Ioxynil/
Bromoxynil Moderately susceptible.

This was once a very common species, regarded as a serious pest, over much of the country, until the early 1950s. The rate and extent of the decline is very similar to that of Ranunculus arvensis, although it has not been quite so great or rapid. It is now found only in a few scattered arable sites from Somerset to East Suffolk, and in three sub-maritime ruderal sites at which it almost certainly spread from neighbouring arable land. It is most frequent in a small area of West Suffolk, where it occurs in about six localities within 10 miles of each other. It is known from three other sites in Suffolk, two in each of Cambridgeshire, Kent, Hampshire and Warwickshire, and one in each of Sussex, Somerset, Worcestershire, Buckinghamshire, and Hertfordshire. At some of these sites it may be found in great abundance.

Others have stated that this species is much more common on chalky soils (Salisbury, 1961; Smith, 1986), and Brenchley found that it showed different soil preferences in different areas of the country (Brenchley, 1920 and unpublished data), but commented that this simply reflected the distribution of soil types. The survey described in Chapter 2 recorded S. pecten-veneris mainly from heavy clay soils, usually overlying calcareous substrata. In common with R. arvensis, the relationship with soil type is a reflection of the types of crops that tend to be grown. In the experiment described in Chapter 7, this species grew best in winter crops sown in October and November, and at most sites where it is still common, winter cereals are grown more or less continuously. In the field, it was observed that this species could germinate and produce seed in spring barley crops, but plants tended to be fewer and much smaller than in winter crops, and seed production poorer.

In the experimental investigation of germination periodicity (Chapter 5), this species was sown twice. In one of these sowings, almost all seed had germinated within six months of sowing. In the other, although most germination was initial, small numbers of seed were still germinating at the end of the experiment, and there was a tendency towards a mainly autumnal periodicity. When attempts were made to store quantities of seed buried in the soil for spring sowing in the experiments described in Chapters 6 & 7, a considerable proportion was observed to germinate in the soil. This evidence implies that *S. pecten-veneris* exhibits relatively little dormancy in the soil, germinating mainly in the autumn after production, although some seed can persist for longer periods (Brenchley & Warington, 1930; Grieg, in press).

S. pecten-veneris is susceptible to many herbicides, (Flint, 1987; Chapter 4), and its decline on the Broadbalk experimental field has been attributed to the introduction of herbicide use in 1957 (Thurston, 1968; Chapter 4). Most of the sites at which this species still flourished, have a history of either low herbicide use or herbicide treatments that concentrated mainly on grass-weed control.

It was found that increased supplies of nitrogen had little effect on the growth or productivity of this species within crops (Chapter 6). This was consistent with field observations, which showed that, in the absence of efficient weed control, this species could compete well with crops of both winter wheat and rape. In the experiments described in Chapters 6 & 7, seed production was much lower than that recorded for species such as

Papaver spp., Silene noctiflora or Misopates orontium.

The decline of this species can probably be attributed to its sensitivity to herbicides and the tendency towards drilling crops early in the autumn, in conjunction with short lived persistence of seed in the soil, and low seed production.

Silene noctiflora.

Decrease: 10km squares 1930-1960, 303; 1988, <82.

Edaphic preferences: low pH, light, stony soils.
Climate: --
Crop correlations: + root crops, + spring crops, + winter barley.

Preferred crop & sowing date: Spring barley, Late March.
Germination periodicity: March-April, August-September.

Seed weight per 1000 seed: 1.22g.

Herbicide sensitivity: MCPA Moderately resistant ;
Mecoprop Moderately susceptible ;
Chlortoluron Susceptible ;
Ioxynil/Bromoxynil Susceptible .

Silene noctiflora is still relatively widespread in East Anglia and on the chalk of Hampshire and Wiltshire. It appears to have retreated from much of the rest of the country, but has isolated sites on soils derived from oolitic limestones from Gloucestershire to Yorkshire. The existence of three sites in North Yorkshire is remarkable, and it occurs there in species-rich communities, representing the northernmost localities for a number of species. It tends to be associated with light soils, frequently sandy in Norfolk, and calcareous silty loams in the rest of the country.

This species is known to be chiefly spring germinating (Chapter 5), and in the experiment described in Chapter 7, was found mainly in the spring barley plots sown in March and April, in which it also produced more seed. In the field, it was found mainly in spring barley and sugar beet, with plants generally seeming to do better in the relatively less competitive root crops. It was however also observed in winter wheat at a few sites. This species produced some seed in stubbles after harvest, although the amounts produced were small.

S. noctiflora performed poorly in crops at higher levels of nitrogen application, although many plants still survived to produce seed (Chapter 6). It was also susceptible to most of the herbicides tested in Chapter 4.

Seedlings of S. noctiflora were still germinating nearly three years after sowing (Chapter 5), and the seed is believed to be quite long-lived in the seed-bank. Seed production can also be high, especially under conditions of low competition but high nitrogen supply as might be experienced in a root crop.

The decline of this species is probably related to its susceptibility to changes in crop type, herbicide use and poor competitivity in relation to the crop. However, it is well adapted to growing in spring barley and root crops and this species seems to have become restricted to those areas in which such crops are frequently grown.

CHAPTER 10.

MANAGEMENT RECOMMENDATIONS FOR THE CONSERVATION OF POPULATIONS OF UNCOMMON ANNUAL WEED SPECIES.

The potential roles of a number of changing agricultural practices in the decline of a number of arable weed species have been discussed above. It is now necessary to consider how farming practices may be modified in order to conserve populations of these and other rare species.

The nature of any proposed management guidelines will vary according to the characteristics of the site, and the species present. In many cases, some aspects of the existing management of a rare weed site will be suitable for the species, and will require relatively little alteration. In particular, the presence of some weed species has been demonstrated to be closely related to the types of crops grown (Chapter 7). At other sites, rare species occur in small relic populations which are probably still declining, and alterations to existing farming practices will be necessary if these small populations are to be conserved. It is intended that all of these guidelines will be applicable within the context of normal arable farming, so that the amount of additional management or modification of existing practice will be as little as possible.

A general set of recommendations may be proposed for use in the wider countryside where, although no particular botanical interest may be known, the general benefit to the arable weed flora and associated fauna and the environment in general will be felt. These will also act as a basis for more detailed guidelines for specific sites and species. These guidelines are based on those produced for "Conservation Headlands" by The Game Conservancy's Cereals and Gamebirds Research Project, which have the advantages of having been thoroughly researched (Rands, 1985; Boatman *et al*; 1988; Boatman & Sotherton, 1988) and accepted by farmers as effective for increasing populations of grey partridges (*Perdix perdix*). They are modified here to be of particular value to populations of uncommon weeds. The benefits to other groups of farmland organisms which have been shown for "Conservation Headlands" (Sotherton & Rands, 1987; Tew, 1987; Dover, 1989) should still accrue to these weed conservation areas, and may be enhanced, as many of these benefits depend on the quantity of weed growth present. The current guidelines for "Conservation Headlands" are included as Appendix 4.

The degree to which a farmer is prepared to modify farming practice will vary. Some will be extremely keen, and will be prepared to carry out any suggestion that might be made, while others will be less enthusiastic, and may require financial inducement before they are prepared to do anything. Any recommendation must therefore be flexible, and must be able to be modified according to the requirements of the farmer. At sites which are known to be of particular interest, it will probably be necessary to construct a customised management regime on the basis of the species present, the existing crop rotation, the willingness of the farmer, and general characteristics of the site.

It is important to consider the management of arable fields in relation to the conservation management of the rest of the farm. Quite apart from the general aesthetic and philosophical questions of integrated sustainable farm management, on a purely practical level it is essential to ensure that field boundary management will not encourage the ingress of invasive species such as *Galium aparine* and *Bromus sterilis* into the cultivated field. It is also essential to ensure that the management of a well-established hedge or fence bottom is consistent with the conservation of the field margin seed-bank. The benefits of well managed hedge bottoms have also been demonstrated for populations of gamebirds (Rands, 1986) and predatory insects (Sotherton, 1988 ; Thomas, 1990).

The extreme edge of the arable field is frequently the subject of different management regimes to the rest of the field. The use of a chemically applied or cultivated "sterile strip" between the crop and the field boundary to prevent the ingress of weeds from the field boundary into the field, is a popular current practice in modern farming (Fielder, 1987). While it is preferable to complete eradication of hedge-bottom vegetation, it is frequently unnecessary, and serves a purely cosmetic purpose. Various options for the outer 15 metre wide strip around arable fields have been included in the recommendations for arable "set-aside" (Anon, 1988). These measures will have detrimental effects on small seed-banks of rare species confined to the extreme edges of the fields, and should not be practised in areas of fields where the conservation of the arable flora is a priority.

Site location and assessment.

The location of a site at which conservation management is to be attempted will ideally be on the basis of the presence of one or more uncommon arable weed species, although the management suggestions will also be of more general environmental benefit.

The probability of a field containing a rich weed flora is higher if the field has had a long history of arable farming. Fields ploughed from permanent habitats in recent years tend to have relatively poor weed floras. Sites which are heavily shaded should also be avoided, as the majority of annual species tend to grow better when light is not restricted (Goldberg & Miller, 1990). The selection of a site cannot be made on the basis of soil type, as all soil types are known to support their own particular assemblage of uncommon weed species.

Once the site has been located, an assessment of the status of both rare and potentially troublesome weed species is desirable. Determination of the true status of weed populations is difficult (Chapter 3). To obtain an ideal picture, a programme of soil seed-bank sampling should be undertaken but this is usually impracticable, and a good asessment of the weed flora that develops after a particular time and type of cultivation, can usually be obtained by a count of seedlings before herbicide application.

Ideally the success or otherwise of management should be assessed by an experienced observer. However it should also be possible for a site manager or farmer to be able to assess the success of any conservation management carried out. The simplest method would be to count the number of species present in the area in question before management commences, and to compare this with the number of species present in the area when under the management regime. A comparison of the abundances of the species present before and after implementation of the management regime would also be of interest.

The greatest abundance and diversity of weed species is to be found within four metres of the field edge (Wilson, 1989; Chapter 3). In most cases, this headland strip is the area to which management recommendations should be applied. At some sites, rare weed populations show distributions across wider areas of the field, and where possible, the areas of greatest botanical interest at any site should be located by survey.

Reduction of herbicide use.

The first requirement for the conservation of rare arable weed species is a reduction of herbicide use. In view of our limited knowledge of the susceptibilities of most annual species, herbicides should ideally be eliminated entirely.

The possible responses of pernicious weed species to the reduction of herbicide use must be considered. These species include some that have increased in response to modern agricultural practice, such as Bromus sterilis, B. commutatus, Alopecurus myosuroides, Poa trivialis and Galium aparine (Orson, 1987), and others that have presented more long term problems such as Elymus repens, Cirsium arvense and Avena spp. (Thurston, 1959; Fryer & Chancellor, 1970). It is possible that the competitive effects of some of these weeds may be detrimental to uncommon species if herbicides are totally eliminated, although reduction of fertiliser inputs as suggested below, may reduce the competitivity of such species to an extent to which they will no longer present significant problems.

Within a sustainable or "organic" system, balanced crop rotations and fallows are designed to prevent the establishment of pernicious weed species (Widdowson, 1987). The effects of "organic" regimes on the populations of rare weeds are unknown, although experience in Denmark indicates that they may be beneficial to some species (Hald & Reddersen, 1990). It is unlikely that a farmer will adopt organic methods solely for the conservation of rare weeds.

Different herbicides have different ranges of phytotoxicity, and some chemicals may prove useful in limited circumstances where particular intractable weed problems are unresponsive to non-chemical management, and where farming considerations are paramount. The "Conservation Headland" guidelines (Game Conservancy, 1989, Appendix 4) permit the use of a limited range of selective herbicides for the control of some weed species (Table 61).

Table 61. Herbicides recommended for use as part of The Game Conservancy's "Conservation Headland" technique (Game Conservancy, 1989). Data from Boatman (1989) and Flint (1987).

Herbicide	Target	Additional species affected
Tri-allate	*Alopecurus myosuroides* *Avena* spp. *Galium aparine*	*Anagallis arvensis*, *Veronica* spp. *Stellaria media*, *Fumaria* spp. *Myosotis arvensis*.
Difenzoquat	*Avena* spp.	None as far as known
Flamprop-m-isopropyl	*Avena* spp. *Alopecurus myosuroides* *Arrhenatherum elatius*	Other weed grasses
Diclofop-methyl	*Alopecurus myosuroides* *Avena* spp. *Poa trivialis* *Lolium* spp.	Other weed grasses
Fenoxaprop-ethyl	*Alopecurus myosuroides* *Avena* spp.	Other grass species.
Glyphosate	[illegible] *repens* *Cirsium arvense*	Very broad spectrum. (Pre-harvest use only)
Fluroxypyr	*Galium aparine*	Many dicotyledons
Atrazine	Sterile strips.	Very broad spectrum.

It may be seen from Table 61, that a number of these chemicals have an activity spectrum that will render them unacceptable in a situation where the conservation of arable weed floras is the aim. Some of the Alopecurus myosuroides and Avena spp. specific chemicals have such a limited action on non-target species however, that their use may be permissible if absolutely neccessary. These chemicals may however affect rare annual grass species such as Briza minor, Gastridium ventricosum, Apera interrupta, Bromus arvensis, and Bromus secalinus, and their use should be avoided in areas where these species occur. Avena spp. are frequently controlled by hand pulling in the summer, a method which is totally selective, but which is only possible where populations are small.

For other problem weeds, an approach must be adopted by which undesirable species may be controlled without affecting the other components of the flora, in particular, the rarer ones. Species such as Bromus sterilis, B. commutatus and Galium aparine have become more frequent in recent years in response to changes in modern farming (Cussans, 1976; Chancellor & Froud-Williams, 1986) and species which have become rarer in recent years have become so in response to the very same changes. In many cases where populations of rare species still persist, farming practices have remained relatively unintensive, and few problems with grass weeds or Galium aparine were recorded. The exceptions largely involved Avena spp., and in a few winter cereal crops, A. myosuroides. The highly selective herbicides listed in Table 61. could be employed in such cases. Some relic populations of rare species did occur in association with B. sterilis and G. aparine, and some degraded communities including Buglossoides arvensis were particularly badly affected. In such cases, if conservation of these relic communities is to be attempted, problem weeds could be controlled by the introduction of spring-sown break crops, G. aparine and B. sterilis, being in particular winter-germinating and with little seed-dormancy, efficient ploughing, and spot-treatment of G. aparine with herbicide (Boatman & Sotherton, 1988). Introduction of spring-sown crops is not compatible with the conservation of rare species such as Scandix pecten-veneris.

Elymus repens can pose particular problems, being a perennial species which can regenerate after the above-ground parts have been removed by contact herbicides or cutting. There are two possible remedies for infestations with this species. The more drastic one is to sow pasture grass in the affected field for a few years, and to allow the continual grazing by stock and the competitive effect of the sown sward to control the weed (Widdowson, 1987). This method will not be suitable for sites containing populations of species with relatively short-lived seed, such as Scandix pecten-veneris or Ranunculus arvensis, and is not practicable in most arable farming situations. The alternative is to treat the affected area with the systemic herbicide Glyphosate, as late as possible in the season, to avoid damage to any of the other species. Only one application of this chemical may be necessary for effective control of *E.repens*.

Reduction of nitrogen supply.

The second important agricultural input which has been shown to have a considerable effect on the growth of weed plants is nitrogenous fertiliser (Chapter 6). The high levels of nitrogen applied to cereals in modern agriculture can have an effect on the survival and productivity of many weed species similar to that of a broad-spectrum herbicide application.

The reduction of the amount of applied nitrogen is an easily achieved method for decreasing the competitive ability of the crop with respect to that of the associated weeds (Chapter 6). The effects of nitrogen application may vary according to the soil type, probably depending on the soil texture and the rate at which the fertiliser is leached out before it can be used by the plant. The interaction between soil type and crop/weed competition was not investigated here. German recommendations for rare weed conservation specify nitrogen reduction on poor quality sandy soils, and very productive clay soils (Schumacher, 1987).

Many of the more problematic weed species are highly responsive to nitrogen supply, in some cases more so than the crop. These species include Avena spp. (Thurston, 1959), G. aparine, Stellaria media (Mahn, 1984), A. myosuroides (Pulcher-Haussling & Hurle, 1986), and B. sterilis (Orson, 1987). If the supply of nitrogen to fields in which populations of these species coexist with less nitrogen-responsive species is reduced, or ideally, eliminated altogether, then the competitive balance will be altered in favour of those that are less competitive. Problems due to large numbers of highly competitive weeds will therefore be reduced, and it is possible that the need for the selective control of such species will be obviated.

The reduction of nitrogen use has been included in conservation packages for arable weeds in Germany (Eggers, 1984a; Schumacher, 1987). The reduction of nitrogen inputs has been approached in relation to the eutrophication of ground-water in nitrogen-sensitive areas in Britain, and it is possible that it may also be included as part of a government funded cereal extensification programme. Any reduction of nitrogen inputs, especially to the edges of fields, will have an additional effect in reducing the eutrophication of adjoining habitats.

Additional measures for reducing the competitivity of the crop may include reducing the quantity of seed sown per hectare, and increasing the row spacing of the crop. While these measures may decrease crop competitivity, this has not been demonstrated here, and it is possible that the response of crop plants to decreased density will simply result in a greater degree of tillering.

Post-harvest practices.

The leaving of a stubble after the harvesting of the crop, was not shown experimentally to be important to more than a very few species (Chapter 7). Other observations however have indicated that many species, especially those that are prostrate in growth form, are probably reliant on a post-harvest stubble in order to set seed. It is therefore desirable that cultivation of the stubble is postponed for as long as possible within the constraints of the crop rotation.

Responses of uncommon weed species to stubble burning were not investigated, but as this practice is to be prohibited after 1992 except in special circumstances, it is not necessary to consider it further.

Times of cultivation and crop drilling.

Species-specific measures can be based on the reductions of herbicide and nitrogen inputs outlined above. These measures may however be modified according to the individual ecology of each species, paying particular attention to their germination behaviour and phenology (Chapters 5 & 7). The best times of crop drilling for some species are listed in Chapter 7, Table 59 .

Alteration of a farm cropping pattern will entail considerable disruption to farming practices. It will therefore not be realistic at many sites, other than where some financial inducement is available, for instance as part of an S.S.S.I. agreement, or where a farmer is particularly enthusiastic. However, as described above, weed communities are frequently adapted to the prevailing crop rotations, and often alterations will only be needed when small relic populations are present and the proposed future cropping regime is unsuitable. Even in these cases, it may only be necessary to consider changing the crop sown on the particular area of the field where the rare species occurs.

A summarised set of general management recommendations is produced below in a format that might be suitable for public distribution.

ENDANGERED ARABLE WEEDS: SUGGESTIONS FOR THEIR CONSERVATION

The weeds which now pose the most serious problems to the arable farmer are very different to those of forty years ago. A field of poppies or corn marigolds is now a rare site, and the appearance of a single plant of cornflower or corn cockle would cause great surprise. In contrast, sterile brome and cleavers were almost unheard of as arable weeds, but are now almost ubiquitous especially where continuous winter crops are grown. The traditionally occurring species are now easy to control with herbicides, whereas the new problem species tend to be resistant and well suited to modern methods of cereal growing. As well as the more obvious losses from the countryside, many less conspicuous species have also become rarer (Table a).

Table a. Declines of some arable weed species expressed in terms of the number of 10 km. squares in which they are found.

Species.	No. of $10km.^2$ grid squares.			
	1930-1960	1960-1975	1976-1985	1989
Pheasant's eye	36	34	13	11
Corn cockle	>150	14	17	0
Thorowax	17	8	1	0
Cornflower	264	<100	<50	2
Corn cleavers	77	16	7	2
Corn buttercup	432	169	71	22
Shepherd's needle	426	86	<20	21
Spreading hedge-parsley	136	35	16	10
Broad-fruited corn-salad	60	17	11	5

In addition to herbicide use, it is also believed that the development of cereal varieties responsive to the increased use of nitrogen, the tendency to drill crops earlier in the autumn, and the adoption of minimum cultivation methods have also had a considerable effect on the status of many arable weed species. The conservation of the remaining populations of these less common species will not only prevent their final disappearance, but will also introduce some additional beauty and variety to the countryside, at little inconvenience or cost to the farmer.

The work of The Game Conservancy's Cereals and Gamebirds Research Project has shown that the "Conservation Headland", which relies on the enhanced growth of weeds following the omission of herbicides from cereal headlands, has considerable benefits for populations of butterflies, predatory insects and gamebirds. It has been implemented by many farmers with considerable success. The management programme suggested here for arable weed conservation is based on the "Conservation Headland", although modified in the light of three years of research, and measures taken to conserve rare weeds in Germany.

1. SELECT THE SITE. The site should be selected in the previous year before trying any conservation management. The obvious site is one in which unusual weed species have been found in the past. A list of particularly interesting species is shown in Table b., with a guide to the region of the country and the soil type on which they are mostly to be found. Some of these species are still relatively frequent in parts of the country. If none of these species is thought to be present, considerable aesthetic interest

can be created by the presence of some common weeds, and many such species have been shown to benefit a wide range of useful predatory insects.

The occurrence of an interesting weed flora is more likely in a field which is known to have been in cultivation for a long period of time. Fields ploughed up from permanent grassland or woodland since the last World War, tend to support only the more common species.

The richest communities of weeds are usually found within four metres of the ploughed edge of the field. In most cases, this will be the area on which any conservation management should be carried out. It is also unfortunately the area which tends to have the most serious problems with pernicious weed species. Areas to avoid are those with bad infestations of sterile brome or cleavers. Also to be avoided are areas which are heavily shaded by overhanging trees or bushes.

2. ASSESS THE SITE. Make a record of all of the weed species present in the area chosen, and their approximate abundances, paying particular attention to those species listed in Table 2.

3. MANAGEMENT RECOMMENDATIONS.

a. Drill winter cereals in October rather than September, and spring cereals in March rather than February.

b. Apply no nitrogen to the area in question (usually the outer six metres of the ploughed area of the field, but depending on the size of the farm machinery).

c. Apply no herbicide. Some exceptions are listed in Table c, but these should only be used if essential, and should be avoided if rare grasses are present.

Table c. Herbicides permissible in rare weed conservation areas.

Herbicide	Trade name	Target	Other species affected
Difenzoquat	Avenge	Wild oats	None
Flamprop-m-isopropyl	Commando	Wild oats Onion couch	Other weed grasses.
Diclofop-methyl	Hoegrass	Black-grass Wild oats Rye-grasses	Other weed grasses.
Fenoxaprop-ethyl	Cheetah	Black-grass Wild oats Meadow-grass	None as far as known.
Glyphosate	Round-up	Couch Creeping thistle	Very broad spectrum.

d. Do not spray or rotovate a "sterile strip"

e. Leave stubble for as long as is possible after harvest.

4. HAVE YOU SUCCEEDED ? Record the the weed species present and their abundances in the same way as before (Section 2), and compare the lists. It is hoped that there will be an increase in the number of species present and in the abundance of any rarer species, without any increase of the "problem" species.

Table b. Uncommon arable weed species, main soil type and region.

Common name	Soil type	Region
	Extremely rare.	
Pheasant's eye	Chalk/brash	S.E.England
Blue pimpernel	"	S.E.England
Loose-flowered silky-bent	Sand	E.Anglia
Broad-leaved cudweed	Chalk/Sand	S.England
Western fumitory	Sand/loam	Cornwall
Corn Buttercup	Clay	S.W.Midlands
Shepherd's needle	"	E.Anglia
Small-flowered catchfly	Sand/gravel	S.W.England
Spreading hedge-parsley	Clay/loam	S.England
Broad-fruited corn-salad	Clay/chalk	S.England
	Rare.	
Lesser quaking-grass	Sand/gravel	S.W.Britain
Rye-brome	Clay	S.England
Fig-leaved goosefoot	Clay/peat	S.England
Broad-leaved spurge	Chalk/clay	S.England
Dense-flowered fumitory	Chalk	S.E.England
Small-flowered fumitory	"	S.E.England
Vaillants fumitory	"	S.E.England
Long-stalked cranesbill	"	S.E.England
Mouse-tail	Clay	S.Midlands
Rough-headed poppy	Chalk	S.E.England
Corn parsley	Chalk/clay	S.England
Small-flowered buttercup	Clay	S.W.England
Slender tare	Clay/brash	S.England
	Uncommon.	
Corn Marigold	Sand/gravel	All Britain
Narrow-leaved hemp-nettle	Chalk	S.E.England
Corn gromwell	Chalk/clay	S.England
Weasel's snout	Sand/loam	S.W.Britain
Long-headed prickly poppy	Sand/Chalk	S.E.England
Night-flowering catchfly	All soils	E.England
Narrow-fruited corn-salad	Chalk/clay	S.E.England
Green field speedwell	Sand/loam	S.W.England
	Decreasing	
Bugloss	Sand	All Britain
Treacle mustard	Sand	E.England
Catmint	Chalk	S.E.England
Stinking mayweed	All soils	S.England
Dwarf spurge	All soils	S.England
Babington's poppy	Clay	S.Midlands
Bur-parsley	Sand	E.England

Small-flowered cranesbill	Sand	S.England
Stone parsley	Clay	S.England
Thale-cress	Sand/clay	All Britain
Sharp-leaved fluellen	All soils	S.Britain
Field woundwort	Sand/gravel	S.W.Britain
Thyme-leaved sandwort	All soils	All Britain
Round-leaved fluellen	Chalk/clay	S.E.England
Knotted hedge-parsley	Chalk/clay	S.England
Small toadflax	Chalk	S.E.England
Henbit	Chalk	S.England
Grey speedwell	Chalk	S.E.England
Cut-leaved dead-nettle	Clay/sand	E.Anglia
Flixweed	Sand	E.Anglia
Venus' looking-glass	Clay/chalk	S.E.England
Wall rocket	Chalk	S.E.England
Field cress	Clay	S.Midlands
Common storksbill	Sand	All Britain
Dwarf mallow	Sand	S.England

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Appendix 1.

Survey of rare arable weed sites. Site locations, ordinations derived from DECORANA, soil and climatic data, and recent cropping history.

Soil variables.

[1] Soil Calcium Carbonate content, determined by the Soil Survey standard method (Avery and Bascomb, 1974)

5 > 10%	4 = 5-10%
3 = 3-5%	2 = 1-3%
1 = <1%	

[2] Subjective estimate of soil stoniness:

0 = few stones
1 = high proportion of calcareous stones, chalk or oolitic or lias limestones
2 = high proportion of silicious stones, mainly flints or slate fragments.

[3] Soil texture, determined by ADAS standard method (Holloway & Sneesby, 1981).

1 Loamy coarse sand	9 Loam
2 Loamy sand	10 Silty loam
3 Loamy fine sand	11 Sandy clay loam
4 Loamy very fine sand	12 Silty clay loam
5 Coarse sandy loam	13 Clay loam
6 Sandy loam	14 Clay
7 Fine sandy loam	
8 Very fine sandy loam	

[4] Climatic data derived from White & Smith (1982).

1 Mean air temp. Jan-March; 1=2-4°C, 2=4-6°C, 3=>6°C
2 Mean air temp. Apr-June; 1=10-12°C, 2=>12°C
3 Mean rainfall(cm/day); Apr-June; 1=<0.15, 2=0.15-0.2, 3=0.2-0.25, 4=0.25-0.3, 5=0.3-0.4
4 Mean duration of bright sunshine(hours/day). Apr.-June. 1=5.3-5.6, 2=5.6-5.9, 3=5.9-6.2, 4=>6.2

Crop data.

[5] I = Crop Index (See text). I < 15 Mainly winter crops;
I > 15 Mainly spring crops.

[6] Crop recorded in the year of survey.
G = grass, WR = winter rape, WB = winter barley or oats, WW = winter wheat, rye or triticale (also including winter beans), SB = spring barley or wheat(also including spring beans and linseed), P = peas or maize, V = root vegetables(including sugar beet and potatoes).

[7] "Rarity index" (see Table 7).

[8] Selected species occuring in field. A *Adonis annua*, C *Chrysanthemum segetum*, L *Lithospermum arvense*, M *Misopates orontium*, P *Papaver hybridum*, R *Ranunculus arvensis*, Sc *Scandix pecten-veneris*, Si *Silene noctiflora*.

	Decorana axes				Soil			Climate				Crops			
					1	2	3	4				5	6	7	8
	1	2	3	pH	Ca CO_3	G	T	1	2	3	4	I	C	R	S. Sp.
2Oxford	199	230	128	7.6	4	0	13	1	2	2	2	*	WW	0	-
3Durnford	140	110	111	7.3	5	1	12	1	2	3	3	10	WW	10	AP
4 "	87	106	63	7.1	5	1	12	1	2	3	3	7	WB	0	-
5 "	140	169	103	7.3	5	1	12	1	2	3	3	17	WW	1	-
6Hamptworth	292	110	141	5.1	1	2	3	2	2	2	4	*	V	8	CM
7 "	305	154	169	5.4	1	0	3	2	2	2	4	*	P	2	C
9Whichford	165	196	120	6.8	1	0	13	1	1	3	2	2	WR	0	-
10 "	146	172	100	7.5	2	0	13	1	1	3	2	1	WW	4	R
11Bishampton	162	180	148	7.6	2	0	13	2	2	2	2	6	WR	7	R
13Burmington	111	187	119	7.4	3	0	13	1	1	2	2	7	WW	7	R
14 "	140	221	135	7.2	1	0	13	1	1	2	2	6	WR	9	RSp
15 "	160	208	126	6.9	5	0	13	1	1	2	2	6	WW	5	R
17Fivehead	80	193	155	7.5	4	0	13	2	2	2	3	*	G	29	SpR
18 "	89	174	173	7.4	5	1	13	2	2	2	3	*	WW	25	SpR
19 "	81	182	183	7.4	5	1	13	2	2	2	3	*	WW	25	Sp
20Woodyates	130	87	164	7.7	5	1	12	2	2	3	3	*	SB	10	LP
21Woodyates	131	80	188	7.3	5	1	10	2	2	3	3	*	SB	11	-
22Tidpit	101	48	140	7.9	5	1	10	2	2	3	3	*	WW	12	LP
23Downton	156	95	134	*	5	0	12	2	2	3	3	19	SB	8	P
24 "	145	66	124	7.5	5	1	12	2	2	3	3	12	SB	9	P
25 "	181	51	112	7.2	5	1	10	2	2	3	3	13	SB	6	P
26 "	194	89	87	7.1	5	1	12	2	2	3	3	13	SB	1	-
27Beeding	153	81	164	7.6	4	0	12	2	2	2	4	*	P	10	P
28 "	129	82	131	7.4	5	1	10	2	2	2	4	*	WW	12	LP
29Alresford	159	82	146	7.4	5	1	12	1	1	2	3	*	SB	11	P
30 "	150	80	126	7.6	5	1	10	1	1	2	3	*	WW	10	P
31Gt.Snoring	227	89	124	6.2	2	0	11	1	2	2	3	15	SB	3	Sn
32 "	213	120	125	5.9	2	0	7	1	2	2	3	13	SB	1	-
34Ringstead	205	53	63	7.1	4	0	7	1	2	2	3	23	V	6	P
35 "	194	0	67	7.2	3	0	3	1	2	2	3	23	SB	7	Sn
36Hockering	243	69	127	6.5	1	0	3	1	2	2	2	11	V	2	C
37 "	269	67	88	6.4	1	0	6	1	2	2	2	8	WB	6	C
38 "	251	88	107	6.8	1	2	6	1	2	2	2	*	V	4	C
39 "	215	108	121	6.1	1	2	7	1	2	2	2	9	WW	2	C
40 "	208	151	104	7.5	3	0	6	1	2	2	2	8	WB	2	C
41 "	195	134	122	6.2	1	0	7	1	2	2	2	12	WW	2	-
42Gt.Snoring	235	88	120	7.2	2	2	11	1	2	2	3	*	SB	1	-
43 "	266	61	123	7.2	2	2	11	1	2	2	3	*	V	2	-
44 "	244	101	133	6.5	1	0	6	1	2	2	3	*	SB	2	C
45Laverstoke	112	107	144	7.3	4	2	12	1	2	2	3	7	WR	14	AP
46 "	153	127	124	7.2	4	2	12	1	2	2	3	1	WW	4	-
47 "	107	108	153	7.3	5	1	12	1	2	2	3	6	WW	13	P
48Alderholt	284	130	178	6.1	1	2	7	2	2	3	4	*	SB	4	CM
49 "	241	149	150	5.7	1	0	8	2	2	3	4	*	WW	0	-
50Sandford	291	150	143	6.5	2	2	11	2	2	3	3	21	V	3	M
51 "	272	137	150	7.1	3	2	12	2	2	3	3	18	V	7	M
52 "	285	151	176	6.2	2	2	11	2	2	3	3	19	P	3	M
53Burrington	257	110	186	6.0	1	2	12	2	1	4	4	20	SB	7	M
54 "	176	162	167	6.5	1	2	12	2	1	4	4	*	WW	0	-
55Blue Anchor	169	138	167	6.5	4	1	12	2	1	4	3	*	WW	12	M

	Decorana axes				Soil			Climate				Crops			
					[1]	[2]	[3]	[4]				[5]	[6]	[7]	[8]
	1	2	3	pH	Ca CO3	G	T	1	2	3	4	I	C	R	S. Sp.
56 "	176	180	119	7.5	4	1	12	2	1	4	3	*	WW	0	
57Crediton	287	150	150	6.3	1	2	13	2	2	3	3	19	V	0	-
58 "	274	135	119	6.1	1	2	13	2	2	3	3	19	P	0	-
59Basingstoke	137	61	130	*	*	1	12	1	2	2	3	*	SB	14	SnP
60 "	135	53	133	*	*	1	12	1	2	2	3	*	SB	10	P
61 "	129	150	75	*	*	1	12	1	2	2	3	*	WW	0	-
62Bix	230	144	100	5.9	*	2	6	1	1	3	3	12	WW	5	CM
63 "	209	138	81	6.4	*	2	6	1	1	3	3	12	WW	1	-
64Bishop's	193	204	152	7.3	2	0	11	1	2	2	2	*	WR	8	R
65 Tachbrook	240	132	142	7.3	1	0	11	1	2	2	2	*	WW	1	-
66Pershore	280	177	85	*	*	*	*	2	2	2	2	*	WW	1	-
67 "	209	142	123	*	*	*	*	2	2	2	2	*	WW	1	-
68 "	151	209	71	6.4	2	0	11	2	2	2	2	*	WW	1	-
69 "	164	179	152	6.8	1	2	11	2	2	2	2	*	WW	10	R
70Idlicote	96	218	94	*	*	*	13	1	2	3	1	*	SB	3	L
71 "		201	152	*	*	*	13	1	2	3	1	*	SB	3	L
72	100	206	101	7.3	4	0	13	1	2	2	2	7	WW	0	-
73	86	206	128	7.5	4	0	13	1	2	2	2	5	WB	3	L
74Bishmpton	132	184	98	7.8	4	0	13	2	2	2	2	5	WW	2	-
75	202	153	137	*	*	*	13	1	2	2	2	*	WB	1	-
76Strethall	123	82	119	7.3	5	1	10	1	1	2	2	*	WW	10	P
77 "	132	88	130	7.3	5	1	10	1	1	2	2	*	SB	9	PL
78Hawkedon	166	131	169	*	*	*	*	1	2	2	2	*	SB	4	-
79 "	100	172	165	7.4	4	0	13	1	2	2	2	5	WR	5	Sp
80 "	101	196	105	7.2	3	0	12	1	2	2	2	*	WB	0	-
81 "	117	193	150	7.4	5	0	13	1	2	2	2	15	WW	2	-
82 "	127	216	167	7.3	3	0	13	1	2	2	2	8	WW	1	-
83Cavendish	94	211	134	7.3	4	0	13	1	2	2	2	9	WW	4	Sp
84 "	148	203	102	7.4	3	0	13	1	2	2	2	6	WW	2	-
85Clare	86	194	173	7.2	4	0	13	1	2	2	2	8	WW	7	Sp
86Gt.Thurlow	215	149	162	7.3	5	2	12	1	2	2	2	*	V	4	Sn
87 "	120	230	140	7.2	1	2	13	1	2	2	2	*	WW	5	-
88Snailwell	205	60	105	7.2	5	0	7	1	2	2	2	*	SB	5	P
89 "	157	82	91	7.3	4	0	7	1	2	2	2	*	WW	4	P
90Wickhambrook	89	186	151	7.3	4	0	13	1	2	2	2	7	WR	3	L
91 "	163	183	156	7.3	5	0	12	1	2	2	2	7	WR	2	-
92 "	154	163	176	7.2	5	0	12	1	2	2	2	12	WW	9	LSn
93Hartest	112	180	199	7.3	4	0	12	1	2	2	2	5	SB	8	Sp
94 "	153	177	154	7.2	4	0	13	1	2	2	2	*	WB	4	-
95Somerton	84	237	141	7.4	4	1	13	1	2	2	2	5	WW	4	Sp
96 "	132	183	157	7.3	3	0	13	1	2	2	2	8	SB	6	Sp
97 "	65	217	180	7.4	5	1	13	1	2	2	2	*	WB	6	Sp
98 "	148	171	166	7.3	5	0	13	1	2	2	2	3	WW	5	Sp
99 "	150	193	148	7.4	5	1	13	1	2	2	2	6	WB	0	-
102Odstock	118	86	127	7.3	5	1	10	2	2	3	4	15	G	15	AP
103 "	145	51	143	7.2	5	1	12	2	2	3	4	16	SB	16	PSn
104 "	209	120	127	*	*	*	13	2	2	3	4	15	WW	2	-
105Brickworth	127	135	123	7.4	5	2	12	1	2	3	3	*	WW	9	A
106 "	131	146	138	7.3	5	0	10	1	2	3	3	*	WW	1	-
107 "	108	38	126	7.4	5	1	9	1	2	2	4	15	SB	20	LPSn

	Decorana axes			Soil				Climate [4]				Crops			
	1	2	3	pH	Ca CO_3 [1]	G [2]	T [3]	1	2	3	4	I [5]	C [6]	R [7]	S. Sp. [8]
108 "	137	99	151	7.7	5	1	10	1	2	2	4	13	SB	3	-
109Thornton Dale	290	53	113	7.1	1	0	3	1	1	2	1	20	SB	6	CSn
110 "	216	71	154	7.2	4	1	12	1	1	2	1	20	V	3	-
111 "	251	96	136	7.1	3	0	7	1	1	2	1	20	SB	3	Cs
112 "	227	45	111	7.1	2	0	11	1	1	2	1	21	V	4	Sn
113Hackness	303	90	154	6.9	1	0	3	1	1	3	2	19	V	6	SnC
114N.Thoresby	143	174	155	*	*	*	*	2	1	2	2	*	WR	3	L
115 "	144	179	105	*	*	*	*	2	1	2	2	*	WW	0	-
116 "	114	201	131	*	*	*	*	2	1	2	2	*	WW	0	-
117Coningsby	279	86	123	7.3	1	0	7	1	2	2	2	31	V	7	C
118 "	253	59	106	7.3	3	0	3	1	2	2	2	31	V	6	C
119Romsey	242	157	163	6.5	1	2	6	2	2	3	4	*	WB	4	CM
120Cadnam	308	125	170	6.4	1	0	3	2	2	3	4	*	V	8	CM
121Ower	285	123	171	6.7	1	2	6	2	2	3	4	17	V	12	CM
122 "	311	148	166	5.7	1	0	3	2	2	3	4	17	V	0	-
123Romsey	231	134	151	6.3	1	2	8	2	2	3	4	*	WW	3	M
124 "	281	109	145	6.2	1	2	7	2	2	3	4	*	WW	5	C
125 "	237	154	173	6.5	1	2	8	2	2	3	4	*	WW	8	M
126 "	211	122	160	6.3	2	2	8	2	2	3	4	*	WW	7	CM
127Fontmell	187	92	139	7.8	5	1	10	2	2	3	4	15	SB	2	C
128Chilworth	246	125	159	6.5	1	0	8	2	2	3	4	23	SB	3	C
129 "	246	142	167	6.2	1	0	8	2	2	3	4	23	SB	4	C
131Cambridge	202	171	144	7.8	3	2	13	1	2	2	2	13	SB	6	Sp
133Wilmington	92	190	171	*	*	*	*	2	2	2	4	*	SB	3	-
134Folkington	161	107	133	7.6	5	1	10	2	2	2	4	*	WW	17	PL
135W.Sandford	278	102	113	6.8	1	2	13	2	2	3	3	*	G	3	M
136 "	218	98	125	6.8	1	2	13	2	2	3	3	*	WB	0	-
137 "	194	159	131	6.9	1	2	13	2	2	3	3	*	WW	0	-
138Boscastle	275	101	160	6.4	1	2	12	2	1	5	4	20	SB	7	CM
139Porth Joke	221	95	153	7.7	4	2	11	3	2	4	4	24	P	5	CP
140 "	214	95	183	7.9	5	2	11	3	2	4	4	23	SB	9	CP
141 "	180	87	184	7.6	3	2	9	3	2	4	4	23	SB	9	CPM
142 "	261	139	192	5.7	1	2	12	3	2	4	4	23	SB	10	CP
143 "	215	111	193	6.5	1	2	12	3	2	4	4	24	P	9	CP
144 "	184	113	181	7.7	4	2	12	3	2	4	4	23	SB	6	CP
145 "	242	117	188	7.8	5	2	11	3	2	4	4	23	SB	7	CP
146 "	199	93	153	7.6	3	2	12	3	2	4	4	23	SB	7	P
147 "	191	105	153	7.6	3	2	12	3	2	4	4	20	WW	5	P
148Lizard	310	88	100	6.8	1	2	12	3	1	4	4	31	V	0	-
149 "	296	101	138	*	*	*	*	3	1	4	4	31	V	0	-
150 "	294	111	157	7.1	1	2	12	3	1	4	4	31	V	4	M
151 "	310	49	96	7.6	2	0	9	3	1	4	4	31	V	4	-
152Amberley	135	98	112	7.8	5	1	10	1	1	3	4	23	SB	8	L
153 "	127	92	122	7.7	5	1	12	1	1	3	4	24	SB	8	L
154 "	207	93	146	7.6	5	0	10	1	1	3	4	11	SB	0	-
155Damerham	134	65	152	7.9	5	1	12	2	2	2	3	*	WW	18	A
156 "	137	42	119	7.7	5	1	12	2	2	2	3	*	WB	13	PSn
157 "	135	54	139	7.8	5	1	12	2	2	2	3	*	WW	3	-
158 "	142	11	102	*	*	*	12	2	2	2	3	*	WW	2	-
159 "	262	69	129	7.7	3	2	11	2	2	2	3	*	SB	1	-

	Decorana axes				Soil			Climate				Crops			
	1	2	3	pH	Ca CO3 [1]	G [2]	T [3]	1	2 [4]	3	4	I [5]	C [6]	R [7]	S. Sp. [8]
160 "	178	85	136	7.8	5	2	12	2	2	2	3	*	WW	10	A
161 "	131	77	148	7.8	5	0	13	2	2	2	3	*	WB	8	-
162 N.Baddesley	285	145	200	6.2	1	2	8	2	2	3	4	19	SB	4	C
163 "	230	157	133	6.9	1	2	8	2	2	3	4	14	WW	2	C
164 "	247	123	164	7.6	2	0	8	2	2	3	4	19	SB	5	C
165 "	284	138	189	4.9	1	0	8	2	2	3	4	19	SB	3	C
166 Sparsholt	193	43	124	*	*	1	12	1	2	3	3	*	V	9	P
167 Overton	112	101	117	7.8	5	1	12	2	2	3	3	15	SB	11	A
168 "	77	126	106	7.7	5	1	12	2	2	3	3	12	WB	6	-
169 "	132	47	144	*	*	*	*	2	2	3	3	15	SB	6	-
170 Glynde	122	102	164	7.6	5	1	12	2	2	2	4	*	SB	12	P
171 Firle	189	70	167	7.6	5	1	10	2	2	2	4	*	SB	3	Sn
172 "	200	85	137	*	*	*	*	2	2	2	4	*	SB	2	-
173 "	140	42	280	*	*	*	*	2	2	2	4	*	SB	6	Sn
174 "	104	143	54	7.7	5	0	12	2	2	2	4	*	WW	3	P
175 Balsdean	74	67	134	7.6	4	1	10	2	2	2	4	*	WB	9	P
176 "	99	66	178	*	*	*	*	2	2	2	4	*	SB	6	-
177 Stapleford	172	64	166	7.8	5	0	10	1	2	2	2	20	WB	0	-
178 "	178	109	107	7.7	3	0	10	1	2	2	2	24	WW	0	-
179 "	120	74	112	7.8	4	1	10	1	2	2	2	24	SB	9	PL
181 Newmarket	157	55	121	7.7	5	1	12	1	2	2	2	13	P	9	Sn
182 Brampton	0	273	180	7.7	3	0	14	2	2	2	3	7	WW	4	Sp
183 "	177	224	173	7.7	3	0	13	2	2	2	3	5	WW	2	-
184 Cookley	150	67	121	7.6	1	2	7	1	2	2	2	*	WW	5	-
185 "	167	185	154	6.9	1	0	11	1	2	2	2	*	WR	5	Sp
186 "	121	217	183	7.5	3	0	11	1	2	2	2	*	WW	8	Sp
187 "	106	177	172	7.6	2	0	13	1	2	2	2	*	SB	7	Sp
188 Gt.Wilbraham	144	67	131	7.7	5	1	11	1	2	2	2	*	P	10	PLSn
200 "	129	46	92	7.7	5	1	11	1	2	2	2	*	SB	4	Sn
189 "	147	96	83	7.9	5	1	11	1	2	2	2	*	P	0	-
190 "	110	79	124	7.9	5	0	10	1	2	2	2	*	WW	11	PL
191 Romsey	232	146	179	7.8	2	2	8	2	2	2	3	*	SB	10	CM
192 "	235	147	183	6.7	1	2	8	2	2	2	3	*	SB	11	CM
193 "	230	131	160	5.7	1	2	8	2	2	2	3	*	WW	5	CM
194 Tidpit	127	37	133	7.8	4	2	12	2	2	2	4	*	WW	23	PL
195 Martin	107	43	146	7.8	5	1	10	2	2	2	4	*	WW	16	L
196 Ixworth	228	97	118	7.3	2	0	7	1	2	2	2	15	SB	7	Sn
197 Thorpe	204	172	128	7.3	3	0	13	1	2	2	2	19	SB	3	-
198 Bardwell	256	46	88	7.1	3	0	6	1	2	2	2	24	WW	1	-
199 "	270	56	78	7.5	5	0	8	1	2	2	2	27	SB	5	Sn
201 "	234	27	76	7.3	4	0	6	1	2	2	2	21	V	3	Sn
202 Ixworth	229	172	131	7.2	4	0	11	1	2	2	2	14	WW	1	-
203 Thorpe	206	19	54	7.1	1	2	3	1	2	2	2	*	WW	7	-
204 Westmancote	165	169	130	7.6	4	0	13	2	2	2	2	13	SB	4	-
205 "	131	241	138	7.4	4	0	13	2	2	2	2	11	WW	5	R
206 "	177	175	143	7.0	1	0	13	2	2	2	2	11	WW	7	R
207 "	103	246	119	6.8	1	0	13	2	2	2	2	10	WW	1	-
208 Bintree	199	99	136	6.8	1	0	6	1	2	2	2	7	WB	4	Sn
209 "	236	109	140	6.2	1	0	7	1	2	2	2	5	WW	6	Sn
210 Micheldever	138	57	124	*	*	1	10	1	2	2	3	8	P	18	P

	Decorana axes 1	Decorana axes 2	Decorana axes 3	pH	Soil [1] Ca CO3	Soil [2] G	Soil [3] T	Climate [4] 1	Climate 2	Climate 3	Climate 4	Climate [5] I	Crops [6] C	Crops [7] R	Crops [8] S. Sp.
211 "	160	63	156	*	*	1	12	2	2	3	3	12	P	7	P
212 "	116	5	153	7.9	5	1	10	1	2	3	3	8	WB	8	P
213 "	183	70	154	7.8	5	1	10	1	2	3	3	13	WW	11	PSn
220 "	108	14	108	7.6	4	1	12	2	2	3	3	18	SB	12	PSn
214 "	180	70	126	*	*	1	10	2	2	3	3	13	SB	8	P
215 "	119	47	160	*	*	1	10	2	2	2	3	13	SB	18	P
216 "	143	47	127	*	*	1	10	2	2	3	3	13	SB	10	P
217 "	134	59	148	*	*	1	10	2	2	3	3	11	SB	10	P
218 "	113	70	151	*	*	0	12	2	2	2	3	14	WW	6	-
219 "	192	107	199	*	*	0	12	2	2	2	3	14	WW	4	-
221 Longparish	107	42	153	7.8	5	1	12	2	2	2	3	15	SB	39	PSpA
222 "	141	39	151	7.7	5	1	12	2	2	2	3	13	WB	24	PA
223 "	108	61	123	7.8	5	1	12	2	2	2	3	*	WB	18	PA
224 "	156	102	153	7.9	5	0	12	2	2	2	3	*	WW	3	-
225 "	138	87	112	7.7	5	1	12	2	2	2	3	*	WW	0	-
226 "	180	91	138	7.4	5	1	10	2	2	2	3	*	WB	0	-
227 "	154	57	126	7.8	5	0	10	2	2	2	3	*	SB	9	P
228 "	154	84	187	*	*	0	12	2	2	2	3	*	WW	6	-
229 "	148	78	159	*	*	0	12	2	2	2	3	*	WW	4	P
230 Worting	144	57	138	7.4	5	1	10	1	2	3	3	16	WB	12	P
235 "	172	88	136	*	*	2	13	1	2	3	3	18	WW	2	-
236 "	183	65	143	*	*	1	10	1	2	3	3	23	SB	9	P
237 "	151	40	156	7.8	5	1	10	1	2	3	3	24	SB	20	PSn
239 "	130	40	150	7.8	5	1	10	1	2	3	3	18	SB	23	PL
240 "	143	86	151	7.8	3	0	12	1	2	3	3	21	SB	22	PSpL
231 Basingstoke	140	96	136	*	*	1	12	1	2	3	3	4	WB	10	-
241 "	198	135	128	*	*	0	13	1	2	3	3	12	WW	5	-
242 "	232	120	167	*	*	2	12	1	2	3	3	14	WW	3	-
244 "	155	58	129	*	*	0	13	1	2	3	3	12	WW	0	-
245 "	140	103	113	*	*	1	12	1	2	3	3	4	WW	5	-
232 Oakley	163	72	150	*	*	0	12	1	2	3	3	19	SB	2	-
233 "	188	123	152	*	*	0	13	1	2	3	3	16	SB	2	-
234 "	207	139	180	*	*	2	12	1	2	3	3	18	SB	4	-
238 "	223	113	160	*	*	0	*	1	2	3	3	20	SB	4	-
243 "	214	133	162	*	*	0	13	1	2	3	3	7	SB	1	-
246 "	243	122	141	*	*	0	12	1	2	3	3	16	P	3	-
247 Pirton	86	144	110	7.7	5	0	13	1	1	2	2	*	WB	12	L
248 Sonning	97	117	47	8.0	5	1	12	1	2	2	3	2	WR	12	AL
249 "	133	104	87	7.8	5	1	13	1	2	2	3	2	WR	3	-
250 "	120	99	110	*	*	1	*	1	2	2	3	*	P	6	-
252 "	141	87	87	*	*	1	12	1	2	2	3	*	WR	1	-
253 Ivinghoe	70	218	181	7.7	5	1	13	1	1	2	2	10	WW	6	Sp
254 Aston	61	208	50	7.8	5	1	13	1	1	2	2	10	WW	0	-
255 Sompting	152	96	134	7.1	5	1	10	2	2	2	4	1	WR	12	PL
256 "	132	115	120	7.5	*	2	12	2	2	2	4	*	WB	5	L
257 Lancing	159	80	121	7.3	5	1	12	2	2	2	4	15	SB	4	L
258 "	140	142	79	7.5	*	1	*	2	2	2	4	15	WB	0	-
259 Burpham	84	48	122	*	*	*	*	1	1	3	4	10	WW	10	-
260 "	131	81	102	*	*	*	*	1	1	3	4	7	SB	4	-
261 "	137	146	87	7.2	2	2	12	1	2	2	4	10	WW	2	-

	Decorana axes				Soil			Climate				Crops			
					1	2	3	4				5	6	7	8
	1	2	3	pH	Ca CO_3	G	T	1	2	3	4	I	C	R	S. Sp.
262Findon	152	188	29	7.3	5	1	10	1	1	3	4	11	WW	4	-
263 "	208	165	71	6.5	1	2	13	2	2	2	4	12	WW	1	-
264 "	199	148	0	7.5	5	1	10	2	2	2	4	12	WW	0	-
265 "	146	126	68	6.1	*	2	*	2	2	2	4	12	WW	1	-
266 "	176	123	22	7.3	*	2	13	2	2	2	4	10	WW	1	-
267Sompting	139	109	117	*	*	*	*	2	2	2	4	7	WW	0	-
268 "	35	147	18	*	*	1	9	2	2	2	4	8	WW	1	-
269Steyning	90	46	53	*	*	*	*	1	2	2	4	*	WW	1	-
270 "	201	84	125	7.1	*	1	*	1	2	2	4	12	SB	4	-
271Cuxton	124	40	140	7.7	5	1	12	2	2	2	4	*	SB	24	PSn
272Deal	138	94	116	7.7	5	1	12	1	2	2	4	7	WR	19	PSp
273	126	62	98	7.7	5	1	12	1	2	2	4	*	WB	6	P
274	152	73	129	7.7	5	1	12	1	2	2	4	*	WW	7	P
275	101	29	154	7.7	5	1	12	1	2	2	4	*	WB	9	P
276Collyweston	214	99	195	7.6	3	1	10	1	2	2	2	25	SB	5	C
277 "	88	157	53	7.6	3	1	10	1	2	2	2	25	SB	0	-
278 "	178	62	151	7.7	3	1	10	1	2	2	2	25	SB	10	CS
279 "	122	59	139	7.7	3	1	12	1	2	2	2	*	WB	6	P
280Raunds	56	198	111	7.7	4	0	13	1	2	2	1	3	WW	3	L
281 "	24	220	85	7.5	2	0	13	1	2	2	1	3	WW	3	L
282Fleam Dyke	136	63	133	7.8	5	1	12	1	2	2	2	*	WW	12	PSn
283 "	124	11	161	7.8	5	1	12	1	2	2	2	*	WW	9	Sn
284 "	131	80	117	7.8	5	1	12	1	2	2	2	*	WB	11	P
285Balsham	150	136	136	*	*	*	13	1	1	2	2	*	WW	8	P
286 "	113	148	105	7.8	3	0	13	1	1	2	2	*	WW	3	P
287 "	131	174	91	*	*	*	13	1	1	2	2	*	WW	0	-
288 "	182	88	137	7.8	4	0	12	1	1	2	2	*	WW	6	PSn
289 "	133	97	111	*	*	*	13	1	1	2	2	*	WW	4	P
290Headbourne	145	117	108	*	*	*	*	2	2	2	3	*	WW	6	P
291 Worthy	180	108	135	7.7	4	1	10	2	2	2	3	*	SB	9	P
292 "	143	75	201	7.6	3	1	10	2	2	2	3	*	SB	1	-
293 "	176	55	160	7.7	5	1	*	2	2	2	3	*	SB	3	-
294 "	236	119	152	7.7	5	1	10	2	2	2	3	*	SB	0	-
295 "	172	60	135	*	*	*	*	2	2	2	3	*	SB	8	P
296Oxford	154	206	127	7.0	4	0	13	1	2	2	2	*	WW	6	R
297Lt.Wolford	171	176	138	6.7	1	0	13	1	1	3	2	7	WW	4	R
298 "	154	199	130	7.3	1	0	11	1	2	2	1	4	WR	5	R
299Worting	145	70	143	*	*	0	12	1	2	2	3	12	WW	12	P
300Oakley	1 5	70	147	*	*	1	12	1	2	2	3	10	WW	11	P
301Basingstoke	185	86	154	*	*	1	13	1	2	2	3	11	WW	8	-
302Oakley	182	133	143	*	*	0	13	1	2	2	3	10	SB	0	-
303Basingstoke	178	85	158	*	*	0	*	1	2	2	3	23	SB	4	-
304 "	212	133	142	*	*	2	13	1	2	2	3	15	WW	2	-
305 "	207	139	131	*	*	2	13	1	2	2	3	9	WW	4	-
306Ringstead	174	56	96	6.9	1	0	3	1	2	2	3	17	SB	10	CSnP
307Harpenden	110	132	140	*	*	2	13	1	1	2	2	7	WW	20	SpR

Appendix 2.

Sites contained in each of the final groups detected by classification of surveyed rare weed sites by TWINSPAN (Chapter 2). Site numbers refer to Appendix 1. Selected rare species present: Aa *Adonis annua*, Cs *Chrysanthemum segetum*, Ba *Buglossoides arvensis*, Mo *Misopates orontium*, Ph *Papaver hybridum*, Ra *Ranunculus arvensis*, Sn *Silene noctiflora*, Sp-v *Scandix pecten-veneris*.

Final group.	
0 - 7.	162 Cs, 163 Cs, 165 Cs.
8.	148, 151.
9.	36 Cs, 41 Cs, 139 Cs Ph.
10.	31 Sn, 32, 149, 196 Sn, 197, 198, 199 Sn, 201 Sn.
11.	37 Cs, 42, 43, 44 Cs, 111 Cs, 112 Sn, 113 Sn Cs, 118 Cs.
12.	53 Mo, 62 Cs Mo, 65, 67, 119 Cs Mo, 123 Mo, 125 Mo, 126 Cs Mo, 140 Cs Ph, 150 Mo, 154,159, 164 Cs, 191 Cs Mo, 202, 208 Sn, 209 Sn, 234, 238, 242, 243, 246, 304, 305.
13.	6 Cs Mo, 39 Cs, 40 Cs, 48 Cs Mo, 49, 104, 117, 121 Cs Mo, 122, 124 Cs, 127 Cs, 128 Cs, 129 Cs, 138 Cs Mo, 142 Cs Ph, 146 Ph, 192 Cs Mo, 263.
14.	7 Cs, 50 Mo, 51 Mo, 52 Mo, 57, 58, 66, 120 Cs Mo.
15.	86 Sn.
16.	3 Aa, 5, 11 Ra, 23 Ph, 26, 34 Ph, 35 Sn, 37 Ph Ba, 88 Ph, 102 Aa Ph, 103 Ph Sn, 106, 141 Cs Ph Mo, 144 Cs Ph, 147 Ph, 172, 175 Ph, 179 Ph Ba, 188 Ph Ba Sn, 200 Sn, 217 Ph, 223 Ph Aa, 224, 225, 226, 247 Ba, 250, 265, 267, 274 Ph, 276 Cs, 286 Ph, 288 Ph Sn, 290 Ph, 292, 294, 306 Ph Cs Sn.
17.	24 Ph, 25 Ph, 30 Ph, 63, 110, 166 Ph, 171 Sn, 178, 180 Ph Sn, 181 Sn, 203, 211 Ph, 212 Ph, 214 Ph, 216 Ph, 227 Ph, 232, 233, 235, 236 Ph, 237 Ph Sn, 241, 244, 245, 252, 256 Ba, 257 Ba, 260, 270, 278 Cs Sn, 279 Ph, 283 Sn, 284 Ph, 291 Ph, 293, 295 Ph, 299 Ph, 300 Ph, 301, 303.

18. 21, 22 Ba Ph, 27 Ph, 28 Ba Ph, 29 Ph, 45 Aa Ph, 46, 47 Ph, 55, 59 Sn Ph, 60 Ph, 76 Ph, 105 Aa, 134 Ph Ba, 152 Ba, 155 Aa, 160 Aa, 161, 167 Aa, 170 Ph, 176, 190 Ph Ba, 195 Ba, 210 Ph, 213 Ph Sn, 218, 219, 221 Ph Sp-v Aa, 222 Ph Aa, 228, 229 Ph, 275 Ph.

19. 107 Ba Ph Sn, 153 Ba, 156 Ph Sn, 157, 158 Sn, 169, 184, 194 Ph Ba, 220 Ph Sn, 230 Ph, 234, 239 Ph Ba, 240 Ph Sp-v Ba, 249, 255 Ph Ba, 259, 271 Ph Sn, 272 Ph Sp-v, 282 Ph Sn, 285 Ph, 307 Ra Sp-v.

20-21. 189, 248, 249 Ph.

22. 4, 89 Ph, 261.

23. 174 Ph, 269, 273 Ph.

24. 13 Ra, 14 Ra Sp-v, 64 Ra, 69 Ra, 74 Ra, 296 Ra, 297 Ra, 298 Ra

25. 78, 91, 92 Ba Sn, 94, 131 Sp-v, 183, 186 Sp-v, 204, 206 Ra.

26. 79 Sp-v, 81, 82, 87, 90 Ba, 95 Sp-v, 96 Sp-v, 97 Sp-v, 98 Sp-v, 114 Ba, 168, 185 Sp-v, 205 Ra.

27. 17 Ra Sp-v, 18 Ra Sp-v, 19 Ra Sp-v, 85 Sp-v, 93 Sp-v, 187 Sp-v,

28. 9, 54, 56, 61, 115, 116, 133, 302.

29. 68, 84, 262, 264, 287.

30. 70 Ba, 71 Ba, 72, 73 Ba, 80, 83 Sp-v, 182 Sp-v, 253 Sp-v, 254, 281 Ba.

31. 207, 258, 268, 277, 280 Ba.

Appendix 3. Full result tables for Chapter 6.

Table i. Performance of two cereal types in an experiment in which they were sown in $4m^2$ plots at two densities, and at three levels of nitrogenous fertiliser application. Analysis performed on square-root transformed data (in brackets) for numbers of ears, and numbers of plants, and on $log_{10}(n+1)$ transformed data for crop dry weight. Crop height was untransformed. Crop type(C). B = Spring barley; W = Winter wheat.

a. CHILWORTH.

		Crop sowing density (kg/ha) S						
		150	75	150	75	150	75	
		Nitrogen level (kg/ha) N						
		0	0	75	75	150	150	s.e.m.
Number of ears/m^2.	W	222.6	203.3	220.2	163.1	221.7	184.4	C 0.40
		(14.9	14.3	14.8	12.8	14.9	13.6)	D 0.40
	B	156.5	201.6	134.1	141.3	130.9	97.4	N 0.49
		12.5	14.2	11.6	11.9	11.4	9.9	
Number of plants/m^2.	W	215.5	154.8	223.8	149.6	233.2	139.2	C 0.21
		(14.7	12.4	15	12.2	15.3	11.8)	D 0.21
	B	39.6	48.3	43.4	36.1	24.5	31.8	N 0.26
		6.3	7	6.6	6.0	5	5.6	
Mean dry wt. of crop. g/m^2.	W	10.48	12.27	35.64	21.65	46.86	30.7	C 0.04
		(1.06	1.12	1.56	1.36	1.68	1.50)	D 0.04
	B	1.28	1.89	4.61	6.71	4.92	4.93	N 0.05
		(0.3	0.45	0.75	0.89	0.77	0.77)	

b.MANYDOWN.

Number of ears/m^2.	W	306.6	291.4	468.3	402.8	505.8	490.2	D 0.61
		(17.5	17.1	21.6	20.1	22.5	22.1)	N 0.75
Number of plants/m^2.	W	235.0	191.8	267	151.5	180.4	162.8	D 0.46
		(15.3	13.9	16.3	12.3	13.4	12.8)	N 0.57
Crop height (cm.)	W	51.5	48.4	71.5	75.5	76.8	82.3	D 1.59
								N 1.95
Mean dry wt. of crop. g/m^2.	W	33.0	36.1	90.4	63.9	72.0	63.0	D 0.03
		(1.53	1.57	1.96	1.81	1.86	1.81)	N 0.04

Table ii. Mean number of weed species derived from square-root transformed data (in brackets) per 4m² plot, in an experiment in which two cereal types are sown at two densities and at three levels of nitrogen application. Standard errors apply to transformed data.
Crop type(C) B = Spring barley; W = Winter wheat.

a. CHILWORTH

		Seed density (kg/ha) D							
		125	75	125	75	125	75		
		Nitrogen level (kg/ha) N							
Species.	Crop (C)	0	0	75	75	150	150		s.e.m
Total no.	B	6.7	7.0	5.5	5.9	2.3	1.9	C	0.07
of rare		(2.58	2.65	2.34	2.43	1.52	1.38)	D	0.07
species/plot	W	7.9	7.3	4.6	6.0	3.8	4.0	N	0.09
		(2.83	2.70	2.15	2.45	1.96	1.99)		
Total no.	B	15.5	17.6	13.6	14.6	12.3	11.7	C	0.07
of common		(3.94	4.2	3.68	3.82	3.51	3.42)	D	0.07
species/m².	W	16.0	14.6	13.0	14.7	14.0	11.5	N	0.08
		(4.00	3.83	3.6	3.83	3.74	3.39)		
Total no.	B	65.6	52.4	30.3	31.5	16.0	8.5	C	0.29
of rare		(8.10	7.24	5.50	5.61	4.00	2.91)	D	0.29
plants/plot.	W	50.6	40.1	14.7	28.2	11.4	12.2	N	0.35
		(7.11	6.33	3.83	5.31	3.37	3.49)		
Total no.	B	128.4	163.1	131.6	127.7	79.0	103.0	C	0.33
of common		(11.3	12.8	11.5	11.3	8.9	10.2)	D	0.33
plants/plot.	W	205.3	114.7	118.4	125.0	116.0	179.9	N	0.41
		(14.3	10.7	10.9	11.2	10.8	10.9)		

b. MANYDOWN. Winter wheat only.

Total no.	65.1	56.0	38.1	38.9	26.8	34.3	D	0.17
of rare	(8.07	7.48	6.17	6.24	5.18	5.86)	N	0.20
plants/plot.								
Total no.	112.0	114.3	103.6	113.6	95.3	87.1	D	0.34
of common	(10.7	10.6	10.2	10.7	9.8	9.3)	N	0.42
plants/m².								
Total no.	12.0	11.0	11.0	10.3	8.9	11.7	D	0.09
of rare	(3.46	3.31	3.31	3.21	2.99	3.41)	N	0.10
species/plot.								
Total no.	20.3	18.9	16.9	17.1	16.2	14.8	D	0.16
of common	(4.50	4.19	4.11	4.13	4.02	3.85)	N	0.20
species/m².								

Table iii. Mean number of weed plants derived from square-root transformed data (in brackets) per $4m^2$ plot, in an experiment in which two cereal types are sown at two densities and at three levels of nitrogen application. Analysis of variance performed on square-root transformed data. Standard errors apply to transformed data.
Crop type(C) B = Spring barley; W = Winter wheat.

a. CHILWORTH.

		Seed density (kg/ha) D						
		125	75	125	75	125	75	
		Nitrogen level (kg/ha) N						
Species.	Crop (C)	0	0	75	75	150	150	s.e.m
Papaver rhoeas	B	9.00	7.67	6.25	4.62	3.06	1.00	C 0.23
		(3.00	2.77	2.50	2.15	1.75	1.00)	D 0.23
	W	2.13	1.93	2.40	3.61	4.08	2.89	N 0.28
		(1.46	1.39	1.55	1.90	2.02	1.70)	
Myosotis arvensis	B	3.09	1.64	3.80	1.3	2.19	0.22	C 0.20
		(1.76	1.28	1.95	1.14	1.48	0.47)	D 0.20
	W	0.83	1.00	0	1.93	0.11	0,67	N 0.24
		(0.91	1.00	0	1.39	0.33	0.82)	
Silene alba	B	0	0.34	2.99	3.84	3.53	2.16	C 0.13
		(0	0.58	1.73	1.96	1.88	1.47)	D 0.13
	W	0.11	0	0	0	0.11	0	N 0.16
		(0.33	0	0	0	0.33	0)	
Papaver hybridum	B	5.48	8.64	3.76	4.16	0	0	C 0.18
		(2.34	2.94	1.94	2.04	0	0)	D 0.18
	W	2.78	1.90	0.11	1.9	0.11	0.34	N 0.22
		(1.67	1.38	0.33	1.38	0.33	0.58)	
Silene noctiflora	B	19.54	9.99	12.53	12.96	9.99	5.06	C 0.22
		(4.42	3.16	3.54	3.60	3.16	2.25)	D 0.22
	W	4.32	3.88	1.99	4.67	1.3	2.96	N 0.27
		(2.08	1.97	1.41	2.16	1.14	1.72)	
Chrysanth--emum segetum	B	10.18	6.97	5.62	6.92	6.30	2.16	C 0.16
		(3.19	2.64	2.37	2.63	2.51	1.47)	D 0.16
	W	1.3	0.45	0.45	1.3	1.3	0.11	N 0.20
		(1.14	0.67	0.67	1.14	1.14	0.33)	
Misopates orontium	B	8.94	3.96	1.63	1.66	0	0.11	C 0.15
		(2.99	1.99	1.28	1.29	0	0.33)	D 0.15
		0.11	1.54	0	0	0	0	N 0.18
		(0.33	1.24	0	0	0	0)	
Papaver argemone	B	0.11	1.64	1.1	0.22	0.22	0	C 0.17
		(0.33	1.28	1.05	0.47	0.47	0)	D 0.17
	W	7.29	3.65	0.56	3.31	0.45	2.16	N 0.21
		(2.70	1.91	0.75	1.82	0.67	1.47)	

Filago spathulata	B	11.49	11.63	0.45	2.40	0	0	C 0.17
		(3.39	3.41	0.67	1.55	0	0)	D 0.17
	W	13.76	14.67	4.12	8.29	2.89	1.99	N 0.21
		(3.71	3.83	2.03	2.88	1.70	1.41)	
Alyssum alyssoides	B	7.3	8.53	0.77	0.64	0	0	C 0.17
		(2.70	2.92	0.88	0.80	0	0)	D 0.17
	W	11.29	9.8	5.48	8.18	3.42	2.22	N 0.21
		(3.36	3.13	2.34	2.86	1.85	1.49)	
Arnoseris minima	B	0.22	0.11	0	0.11	0	0	C 0.11
		(0.47	0.33	0	0.33	0	0)	D 0.11
	W	3.85	0.33	0	0	0	0	N 0.14
		(1.96	0.58	0	0	0	0)	
Myosurus minimus	B	0	0	0	0	0	0	C 0.14
		0	0	0	0	0	0	D 0.14
	W	2.96	2.2	0.11	0	0	0	N 0.17
		1.72	1.48	0.33	0	0	0	
Mean no. of common plants/m²·	B	128.6	163.0	131.6	127.7	79.0	103.6	C
		(11.33	12.77	11.47	11.30	8.89	10.18)	D
	W	205.3	114.7	118.4	124.0	115.0	117.9	N
		(14.33	10.71	10.88	11.18	10.77	10.86)	
Mean no. of rare plants/4m²	B	65.61	52.42	30.25	31.47	16.0	8.47	C
		(8.10	7.24	5.50	5.61	4.00	2.91)	D
	W	50.55	40.07	14.67	28.20	11.36	12.18	N
		(7.11	6.33	3.83	5.31	3.37	3.49)	

Table iii b. MANYDOWN; winter wheat only.

Species.								
Seed density (kg/ha) D	125	75	125	75	125	75		
Nitrogen level (kg/ha) N	0	0	75	75	150	150		s.e.m
Papaver	26.83	28.41	18.06	27.56	19.45	19.71	D	0.17
rhoeas	(5.18	5.33	4.25	5.25	4.41	4.44)	N	0.21
Myosotis	16.89	16.97	20.98	18.15	11.29	19.01	D	0.17
arvensis	(4.11	4.12	4.58	4.26	3.36	4.36)	N	0.21
Tripleuro-	13.84	16.24	13.03	7.34	8.76	7.9	D	0.29
-spermum inodorum	(3.72	4.03	3.61	2.71	2.96	2.81)	N	0.36
Scandix	7.18	6.97	2.85	6.25	3.61	2.59	D	0.25
pecten- -veneris	(2.68	2.64	1.69	2.50	1.90	1.61)	N	0.30
Ranunculus	12.72	11.48	8.66	6	3.96	8.83	D	0.13
arvensis	(3.57	3.39	2.94	2.45	1.99	2.97)	N	0.16
Papaver	2.4	0.64	1.00	1.22	0.67	0.91	D	0.34
hybridum	(1.55	0.8	1.00	1.49	0.45	0.83)	N	0.42
Buglossoides	7.56	8.29	4.62	5.2	10.43	7.24	D	0.19
arvensis	(2.75	2.88	2.15	2.28	3.23	2.69)	N	0.23
Valerian-	12.25	11.22	6.3	7.24	1.10	3.31	D	0.21
-ella rimosa	(3.5	3.35	2.51	2.69	1.05	1.82)	N	0.25
Filago	12.60	3.96	10.37	2.37	1.49	3.31	D	0.50
spathulata	(3.55	1.99	3.22	1.54	1.22	1.82)	N	0.61
Bupleurum	5.2	6.1	3.31	5.24	2.99	5.9	D	0.26
rotundi- -folium	(2.28	2.47	1.82	2.29	1.73	2.43)	N	0.32

Table iv. Geometric mean dry weight (g/4m^2) produced by weed plants per 4m^2 plot, in an experiment in which two cereal types are sown at two densities and at three levels of nitrogen application. Analysis of variance performed on $\log_{10}(n+1)$ transformed data. Standard errors apply to transformed data.
Crop type(C) B = Spring barley; W = Winter wheat.

a. CHILWORTH.

Species.	Crop (C)	Seed density (kg/ha) D: 125 Nitrogen level (kg/ha) N: 0	75 0	125 75	75 75	125 150	75 150	s.e.m	
Papaver rhoeas	B	9.8	4.3	18.1	9.6	3.9	1.5	C	0.13
		(1.04	0.72	1.28	1.03	0.69	0.40)	D	0.13
	W	5.5	1.3	4.3	7.0	14.7	8.9	N	0.16
		(0.81	0.37	0.7	0.9	1.2	0.98)		
Myosotis arvensis	B	5.0	1.9	2.5	1.1	4.1	0.3	C	0.10
		(0.78	0.47	0.55	0.32	0.71	0.11)	D	0.10
	W	0.6	1.1	0	4.0	0.9	2.0	N	0.12
		(0.2	0.31	0	0.7	0.28	0.3)		
Silene alba	B	0	0.5	9.1	9.8	15.5	7.9	C	0.08
		(0	0.18	1.00	1.04	1.22	0.95)	D	0.08
	W	0.65	0	0	0	0.9	0	N	0.10
		(0.22	0	0	0	0.28	0)		
Papaver hybridum	B	2.6	3.3	4.6	2.2	0	0	C	0.09
		(0.56	0.63	0.75	0.51	0	0)	D	0.09
	W	1.7	0.5	0.4	3.4	0.2	1.1	N	0.10
		(0.43	0.16	0.16	0.65	0.08	0.32)		
Silene noctiflora	B	12.4	5.2	7.8	14.9	16.0	9.2	C	0.12
		(1.13	0.79	0.94	1.2	1.23	1.0)	D	0.12
	W	2.4	1.8	2.1	5.4	3.6	8.8	N	0.14
		(0.54	0.45	0.5	0.8	0.66	0.99)		
Chrysanth. segetum	B	41.6	8.8	82.8	82.4	51.6	35.6	C	0.09
		(1.63	0.99	1.92	1.92	1.72	1.56)	D	0.09
	W	6.3	0.3	0.2	9.3	4.2	0.6	N	0.11
		(0.86	0.1	0.08	1.01	0.72	0.21)		
Misopates orontium	B	2.5	1.1	1.1	2.3	0.5	0.1	C	0.05
		(0.54	0.33	0.31	0.51	0.19	0.03)	D	0.05
	W	0.01	0.3	0	0	0	0	N	0.06
		(0.004	0.11	0	0	0	0)		
Papaver argemone	B	0.3	1.5	2.1	0.2	0	0	C	0.10
		(0.11	0.4	0.49	0.09	0	0)	D	0.10
	W	16.5	2.5	1.3	8.4	1.5	4.9	N	0.12
		(1.24	0.54	0.35	0.97	0.40	0.77)		

Filago spathulata	B	10.5	8.8	0.04	0.7	0	0	C	0.08
		(1.06	0.99	0.02	0.24		0)	D	0.08
	W	39.8	29.1	3.9	6.9	2.3	3.7	N	0.09
		(1.61	1.48	0.69	0.9	0.51	0.68)		
Alyssum alyssoides	B	3.6	2.9	0.9	0.3	0	0	C	0.07
		(0.66	0.59	0.28	0.11	0	0)	D	0.07
	W	7.1	2.2	2.9	5.4	2.1	1.8	N	0.09
		(0.91	0.5	0.59	0.81	0.49	0.45)		
Arnoseris minima	B	0.03	0.03	0	0.02	0	0	C	0.01
		(0.01	0.01	0	0.01	0	0)	D	0.01
	W	0.56	0.17	0	0	0	0	N	0.01
		(0.19	0.07	0	0	0	0)		
Myosurus minimus	B	0	0	0	0	0	0	C	0.01
		(0	0	0	0	0	0)	D	0.01
	W	0.17	0.15	0.02	0	0	0	N	0.01
		(0.07	0.06	0.01	0	0	0)		
Mean dry wt. of total associated species/m^2.	B	7.7	3.8	20.3	33.7	38.9	34.7		
		(0.94	0.68	1.33	1.54	1.60	1.55)		
	W	3.1	3.0	6.0	14.4	9.4	16.5		
		(0.61	0.60	0.84	1.19	1.02	1.24)		

Table iv b. Manydown; Winter wheat only.

Species.							s.e.m
Seed density (kg/ha) D	125	75	125	75	125	75	
Nitrogen level (kg/ha) N	0	0	75	75	150	150	
Papaver rhoeas	210.8	221.8	76.1	252.3	391.6	199.0	D 0.08
	(2.33	2.35	1.89	2.40	2.59	2.30)	N 0.10
Myosotis arvensis	14.6	10.4	24.8	40.1	8.7	19.3	D 0.09
	(1.19	1.06	1.41	1.61	0.99	1.31)	N 0.11
Tripleuro-spermum inodorum	24.9	36.2	94.9	22.7	26.6	31.4	D 0.12
	(1.41	1.57	1.98	1.38	1.42	1.51)	N 0.15
Scandix pecten-veneris	5.7	10.7	3.6	15.0	4.9	6.7	D 0.12
	(0.83	1.07	0.66	1.20	0.77	0.89)	N 0.14
Ranunculus arvensis	5.6	8.8	5.4	3.5	2.8	7.2	D 0.06
	(0.82	0.99	0.81	0.65	0.58	0.91)	N 0.08
Papaver hybridum	3.7	1.1	1.6	1.6	1.6	0.6	D 0.16
	(0.57	0.32	0.20	0.42	0.19	0.21)	N 0.19
Buglossoides arvense	4.0	20.1	11.2	19.9	47.3	51.0	D 0.11
	(0.7	1.32	1.09	1.32	1.68	1.72)	N 0.13
Valerianella rimosa	2.4	1.6	1.4	2.0	0.6	0.9	D 0.05
	(0.54	0.42	0.38	0.48	0.19	0.29)	N 0.06
Filago spathulata	4.6	1.5	2.3	0.7	0.5	0.3	D 0.13
	(0.75	0.39	0.52	0.23	0.19	0.11)	N 0.16
Bupleurum rotundi-folium	4.0	9.9	2.9	6.8	8.3	22.2	D 0.10
	(0.72	1.04	0.59	0.89	0.97	1.37)	N 0.12
Mean dry wt. of associated weeds/m².	10.4	18.4	48.2	39.3	85.7	45.3	D
	(1.06	1.29	1.69	1.61	1.94	1.67)	N

Table v. Geometric mean number of seed produced by weed plants per $4m^2$ plot, in an experiment in which two cereal types are sown at two densities and at three levels of nitrogen application. Analysis of variance performed on $\log_{10}(n+1)$ transformed data. Standard errors apply to transformed data.
Crop type(C) B = Spring barley; W = Winter wheat.

a. CHILWORTH.

Species.	Crop (C)	Seed density (kg/ha) D: 125 Nitrogen level (kg/ha) N: 0	75 0	125 75	75 75	125 150	75 150		s.e.m
Papaver rhoeas	B	60.7	33.7	76.6	43.7	24.6	6.2	C	0.18
		(1.79	1.54	1.89	1.65	1.39	0.86)	D	0.18
	W	18.1	7.3	14.5	32.1	66.6	24.7	N	0.22
		(1.28	0.92	1.19	1.52	1.83	1.41)		
Myosotis arvensis	B	287.4	315.2	511.9	157.5	0	3.5	C	0.29
		(2.46	2.50	2.71	2.20	0	0.65)	D	0.29
	W	28.5	67.6	0	124.9	5.0	8.6	N	0.35
		(1.47	1.83	0	2.10	0.78	0.98)		
Silene alba	B	0	0	3.5	4.2	12.5	1.7	C	0.09
		(0	0	0.66	0.71	1.13	0.43)	D	0.09
	W	0.7	0	0	0	0	0	N	0.10
		(0.23	0	0	0	0	0)		
Papaver hybridum	B	9.7	23.1	10.3	6.7	0	0	C	0.12
		(1.03	1.38	1.05	0.88	0	0)	D	0.12
	W	11.4	2.5	0.7	10.9	0.6	2.4	N	0.15
		(1.09	0.54	0.23	1.08	0.2	0.53)		
Silene noctiflora	B	46.0	20.9	52.1	37.9	57.2	16.4	C	0.14
		(1.67	1.34	1.72	1.59	1.77	1.24)	D	0.14
	W	9.0	6.1	4.1	12.5	8.7	16.0	N	0.17
		(1.0	0.85	0.70	1.13	0.94	1.23)		
Chrysanth. segetum	B	114.4	38.5	60.6	178.1	165.3	62.0	C	0.13
		(2.06	1.6	1.83	2.25	2.22	1.8)	D	0.13
	W	12.0	1.0	0.3	20.0	9.2	1.5	N	0.16
		(1.11	0.30	0.10	1.33	1.01	0.4)		
Misopates orontium	B	21.2	10.6	6.5	10.1	0	0	C	0.10
		(1.35	1.06	0.87	1.05	0	0)	D	0.10
	W	0.3	1.8	0	0	0	0	N	0.12
		(0.1	0.44	0	0	0	0)		
Papaver argemone	B	1.1	9.5	5.0	0.9	1.1	0	C	0.15
		(0.32	1.02	0.78	0.28	0.32	0)	D	0.15
	W	99.0	19.9	2.7	29.2	2.9	6.4	N	0.18
		(2.00	1.32	0.57	1.48	0.59	0.87)		

Filago spathulata	B	217.8	182.0	0	7.9	0	0	C	0.15
		(2.34	2.26	0	0.95	0	0)	D	0.15
	W	954.0	690.8	73.1	176.8	23.0	31.4	N	0.18
		(2.98	2.84	1.87	2.25	1.38	1.51)		
Alyssum alyssoides	B	811.8	511.9	10.5	27.2	0	0	C	0.20
		(2.91	2.71	1.06	1.45	0	0)	D	0.20
	W	1736.8	630.0	488.8	1348.0	345.7	101.3	N	0.24
		(3.24	2.80	2.69	3.13	2.54	2.01)		
Arnoseris minima	B	0.9	0.7	0	0.8	0	0	C	0.07
		(0.28	0.23	0	0.26	0	0)	D	0.07
	W	29.4	1.7	0	0	0	0	N	0.09
		(1.48	0.43	0	0	0	0)		
Myosurus minimus	B	0	0	0	0	0	0	C	0.06
		(0	0	0	0	0	0)	D	0.06
	W	5.2	3.6	0.7	0	0	0	N	0.08
		(0.79	0.66	0.23	0	0	0)		

Table v. b. MANYDOWN; Winter wheat only.

	Seed density (kg/ha) D						
	125	75	125	75	125	75	
	Nitrogen level (kg/ha) N						
Species.	0	0	75	75	150	150	s.e.m
Papaver	275.1	817.5	298.9	574.4	873.0	513.0	D 0.10
rhoeas	(2.44	2.91	2.48	2.76	2.94	2.71)	N 0.13
Myosotis	2375.8	2442.4	2830.4	3419.8	996.7	2684.3	D 0.10
arvensis	(3.38	3.39	3.45	3.53	3	3.43)	N 0.12
Tripleuro-	127.8	140.3	301.0	55.0	92.3	99.0	D 0.14
-spermum	(2.11	2.15	2.48	1.74	1.97	2.00)	N 0.18
inodorum							
Scandix	129.1	208.4	98.0	175.0	87.1	134.6	D 0.13
pecten-	(2.11	2.32	1.99	2.24	1.95	2.13)	N 0.16
-veneris							
Ranunculus	111.4	144.5	58.3	81.7	43	93.5	D 0.08
arvensis	(2.05	2.16	1.77	1.91	1.64	1.97)	N 0.10
Bugloss-	129.9	310.2	172.8	236.1	854.1	925.7	D 0.10
oides	(2.12	2.49	2.24	2.38	2.93	2.97)	N 0.12
arvensis							
Valerian-	198.5	194	101.3	119.2	16	116.5	D 0.17
-ella	(2.30	2.29	2.01	2.08	1.23	2.07)	N 0.21
rimosa							
Filago	76.6	6.7	23	10.2	5.8	5	D 0.27
spathulata	(1.89	0.89	1.38	1.05	0.83	0.78)	N 0.33
Bupleurum	128.8	445.7	50.1	194	123	977.2	D 0.20
rotundi-	(2.11	2.65	1.7	2.29	2.09	2.99)	N 0.24
-folium							

Table vi. Mean number of fruits produced per plant in an experiment in which two cereal types were sown at two densities and at three levels of nitrogen application.

a. CHILWORTH. B = Spring barley; W = Winter wheat.
* Kruskal-Wallis test; standard errors prsented for significant differences only. Results averaged over the two crop densities.

Species.	Crop (C)	Nitrogen level (kg/ha) N 0	75	150	s.e.m
Papaver* rhoeas	B	5.72	11.92	15.04	
	W	10.12	9.83	19.59	
Papaver* hybridum	B	3.46	3.44		
	W	2.64	5.8	5.84	
Silene* noctiflora	B	2.45	3.75	6.45	
	W	2.37	3.72	12.13	
Chrysanthemum* segetum	B	8.27	24.94	32.54	N 6.45
Papaver* argemone	W	8.7	10.52	13.58	
Filago* spathulata	W	57.47	30.49	27.27	
	B	17.22			
Alyssum* alyssoides	W	98.86	167.61	201.27	

Table vi. b. MANYDOWN; Winter wheat only.
* Kruskal-Wallis test, results averaged over the two crop sowing densities, S.E.s for significant results only, and apply to untransformed data .

	Seed density (kg/ha) D						
	125	75	125	75	125	75	
	Nitrogen level (kg/ha) N						
Species.	0	0	75	75	150	150	s.e.m
Papaver rhoeas	11.43	29.41	18.01	21.5	45.24	27.25	D 0.09
	(1.06	1.48	1.28	1.35	1.67	1.45)	N 0.11
Myosotis arvensis	167.7	147.3	134.8	194.4	88.7	142.2	D 0.08
	(2.23	2.17	2.13	2.29	1.95	2.16)	N 0.09
Tripleuro--spermum inodorum	9.42	9.12	23.55	8.08	18.32	13.26	D 0.06
	(1.02	1.01	1.39	0.96	1.29	1.15)	N 0.07
Ranunculus arvensis	8.91	12.71	6.74	13.52	9.84	10.78	D 0.05
	(1.00	1.14	0.89	1.16	1.04	1.07)	N 0.06
Buglossoides arvensis	17.71	39.83	40.02	79.91	83.14	129.62	D 0.11
	(1.27	1.61	1.61	1.91	1.93	2.12)	N 0.14
Bupleurum rotundi--folium	43.87	81.79	15.79	37.73	102.75	160.81	D 0.11
	(1.67	1.92	1.23	1.59	2.02	2.21)	N 0.13
Scandix* pecten--veneris	23.62		26.23		36.04		
Filago* spathulata	4.67		2.78		12.80		
Valerianella* rimosa	16.8		18.35		43.3		N 16.6

Table vii. Mean number of plants present per plot derived from square-root transformed data (in brackets), in two types of cereal sown at two densities, and in uncropped plots cultivated at the same times as those that were cropped. Analysis performed on square-root transformed data. Standard errors are for the transformed data.
Crop types (C) B = barley; W = Winter wheat.

a. CHILWORTH.

Crop type.(C)	B	W	B	W	B	W		
	Seed density (kg/ha).							
Species	0	0	75	75	150	150		
Papaver	7.29	5.02	7.67	1.93	9.0	2.13	C	0.28
rhoeas	(2.70	2.24	2.77	1.39	3.00	1.46)	D	0.35
Myosotis	0	1.32	1.64	1.00	3.1	0.83	C	0.29
arvensis	(0	1.15	1.28	1.00	1.76	0.91)	D	0.36
Papaver	12.25	8.12	8.65	1.9	5.48	2.79	C	0.27
hybridum	(3.50	2.85	2.94	1.38	2.34	1.67)	D	0.33
Silene	10.37	4.16	9.99	3.88	19.54	4.33	C	0.24
noctiflora	(3.22	2.04	3.16	1.97	4.42	2.08)	D	0.30
Chrysanthemum	7.45	0.45	10.18	1.3	0.97	0.45	C	0.28
segetum	(2.73	0.67	3.19	1.14	2.64	0.67)	D	0.34
Misopates	6.92	0.11	8.94	0.11	3.96	1.54	C	0.16
orontium	(2.63	0.33	2.99	0.33	1.99	1.24)	D	0.19
Papaver	1.17	10.96	1.64	3.65	0.11	7.29	C	0.21
argemone	(1.08	3.31	1.28	1.91	0.33	2.70)	D	0.26
Filago	11.33	11.99	11.63	14.66	11.51	13.76	C	0.12
spathulata	(3.36	3.46	3.41	3.82	3.39	3.71)	D	0.15
Alyssum	7.62	15.13	8.53	9.80	7.29	11.29	C	0.22
alyssoides	(2.76	3.89	2.92	3.13	2.7	3.36)	D	0.26
Arnoseris	0.11	3.2	0	0.34	0.22	3.84	C	0.23
minima	(0.33	1.79	0	0.58	0.47	1.96)	D	0.28
Myosurus	0	2.62	0	2.96	0	2.19	C	0.30
minimus	(0	1.62	0	1.72	0	1.48)	D	0.36

Table vii. b. Manydown. Winter wheat only.

Species	Seed density (kg/ha). 0	75	150	s.e.m.
Papaver hybridum	2.31 (1.52	0.64 0.8	2.40 1.55)	0.58
Papaver rhoeas	25.10 (5.01	28.41 5.33	26.83 5.18)	0.32
Myosotis arvensis	16.56 (4.07	16.97 4.12	16.89 4.11)	0.31
Scandix pecten-veneris	5.02 (2.24	6.97 2.64	7.18 2.68)	0.22
Ranunculus arvensis	10.86 (3.30	11.49 3.39	12.72 3.57)	0.11
Buglossoides arvensis	5.90 (2.43	8.29 2.88	7.56 2.75)	0.34
Valerianella rimosa	14.29 (3.78	11.22 3.35	12.25 3.50)	0.30
Filago spathulata	10.30 (3.21	3.96 1.99	12.60 3.55)	0.74
Bupleurum rotundifolium	8.88 (2.98	6.10 2.47	5.20 2.28)	0.57

Table viii. Geometric mean fruit production per $4m^2$ plot in two types of cereal sown at two densities, and in uncropped plots cultivated at the same times as those that were cropped. Analysis performed on Log10+1 transformed data, (in brackets). Standard errors are for the transformed data.
Crop type. B = Spring barley; W = Winter wheat.

a. CHILWORTH.

	Crop type. C						
	B	W	B	W	B	W	
	Crop sowing density (kg/ha) S						
	0	0	75	75	150	150	s.e.m.
Papaver rhoeas	108.7	137.0	33.7	8.8	60.7	18.1	C 0.21
	(2.04	2.14	1.54	0.92	1.79	1.28)	S 0.26
Myosotis arvensis	0	189.6	315.2	66.6	287.4	28.5	C 0.50
	(0	2.28	2.50	1.83	2.46	1.47)	S 0.61
Papaver hybridum	112.5	59.5	23.1	2.47	9.7	11.4	C 0.13
	(2.06	1.78	1.38	0.54	1.03	1.09)	S 0.16
Silene noctiflora	30.6	14.7	20.9	6.1	46.0	9.0	C 0.10
	(1.5	1.19	1.34	0.85	1.67	1.0)	S 0.13
Chrysanthemum segetum	113.8	1.1	38.8	1	113.8	11.9	C 0.15
	(2.06	0.33	1.60	0.30	2.06	1.11)	S 0.19
Misopates orontium	27.6	0.26	10.6	1.76	21.2	0.26	C 0.09
	(1.45	0.1	1.06	0.44	1.35	0.1)	S 0.11
Papaver argemone	4.1	268.2	9.5	19.9	1.1	99.0	C 0.15
	(0.71	2.43	1.02	1.32	0.32	2.0)	S 0.19
Filago spathulata	264	1482	180	683	218	952	C 0.09
	(2.42	3.17	2.26	2.84	2.34	2.98)	S 0.11
Alyssum alyssoides	995	4425	509	637	810	1717	C 0.08
	(2.99	3.65	2.71	2.80	2.91	3.24)	S 0.10
Arnoseris minima	4.3	54.0	0.7	1.7	1.9	29.2	C 0.15
	(0.72	1.74	0.23	0.43	0.28	1.48)	S 0.18
Myosurus minimus	0	4.65	0	3.61	0	5.21	C 0.14
	(0	0.76	0	0.66	0	0.79)	S 0.17

Table viii b. MANYDOWN; Winter wheat only.

	Crop sowing density (kg/ha) S			
	0	75	150	s.e.m.
Papaver rhoeas	1457.8 (3.16	817.5 2.91	275.1 2.44)	0.11
Myosotis arvensis	2916.4 (3.47	2442.4 3.39	2376.8 3.38)	0.14
Filago spathulata	76.6 (1.89	6.76 0.89	76.6 1.89)	0.41
Bupleurum rotundifolium	345.7 (2.54	445.7 2.65	127.8 2.11)	0.43
Valerianella rimosa	641.7 (2.81	192.6 2.29	198.1 2.3)	0.11
Buglossoides arvensis	219.3 (2.34	310.2 2.49	129.9 2.11)	0.11
Ranunculus arvensis	208.4 (2.32	143.5 2.16	110.43 2.05)	0.10
Scandix pecten-veneris	122.0 (2.09	207.9 2.32	127.8 2.11)	0.26

Table ix. Geometric mean seed production per individual plant in two types of cereal sown at two seed rates, and in uncropped plots cultivated at the same times as those that were cropped. Analysis performed on $\log_{10}+1$ transformed data (in brackets) Standard errors of differences are for the transformed data. * Mann-Whitney test.

a. CHILWORTH. Results for cropped plots averaged over both sowing densities, 75kg/ha and 150kg/ha.

	Crop type.(C)			
	W	W	B	B
	Crop sowing density (kg/ha)(S)			
Species	0	cropped	0	cropped
Papaver* rhoeas	30.4 (1.5	11.1 1.08	15.15 1.21	6.0 0.85)
Papaver* hybridum	7.66 (0.94	3 0.6	9.52 1.02	3.51 0.65)
Silene* noctiflora	3.94 (0.69	2.48 0.54	3.21 0.62	2.56 0.55)
Papaver* argemone	25.3 (1.42	10.76 1.07)		
Alyssum* alyssoides	303.57 (2.48	108.3 2.04	128.9 2.11	88.36 1.95)
Arnoseris* minima	19.22 (1.31	6.16 0.85)		
Myosurus* minimus	2.43 (0.53	2.05 0.48)		
Chrysanthemum* segetum			17.06 (1.26	8.48 0.98)
Misopates* orontium			4.06 (0.70	2.68 0.57)

Table ix. b. **MANYDOWN;** Winter wheat only.

Species	Crop sowing density (kg/ha).(S) 0	75	150	s.e.m.
Papaver rhoeas	58.8 (1.77	29.41 1.48	10.43 1.06)	0.11
Myosotis arvensis	176.4 (2.25	147.3 2.17	167.7 2.22)	0.13
Filago* spathulata	7.93	5.08		3.82
Tripleurospermum inodorum	11.82 (1.11	9.12 1.01	9.42 1.02)	0.13
Ranunculus arvensis	19.51 (1.31	12.71 1.14	8.91 1)	0.07
Buglossoides arvensis	37.9 (1.59	39.74 1.61	17.62 1.27)	0.19
Scandix* pecten-veneris	40.48	30.90	32.63	24.74
Bupleurum rotundifolium	39.73 (1.61	82.17 1.92	46.86 1.68)	0.29
Valerianella* rimosa	47.89	17.06		20.29

Appendix 4.

THE GAME CONSERVANCY'S FIELD MARGIN

GUIDELINES FOR THE MANAGEMENT OF FIELD MARGINS 1989/90

(Conservation Headlands and Field Boundaries)

HEDGE

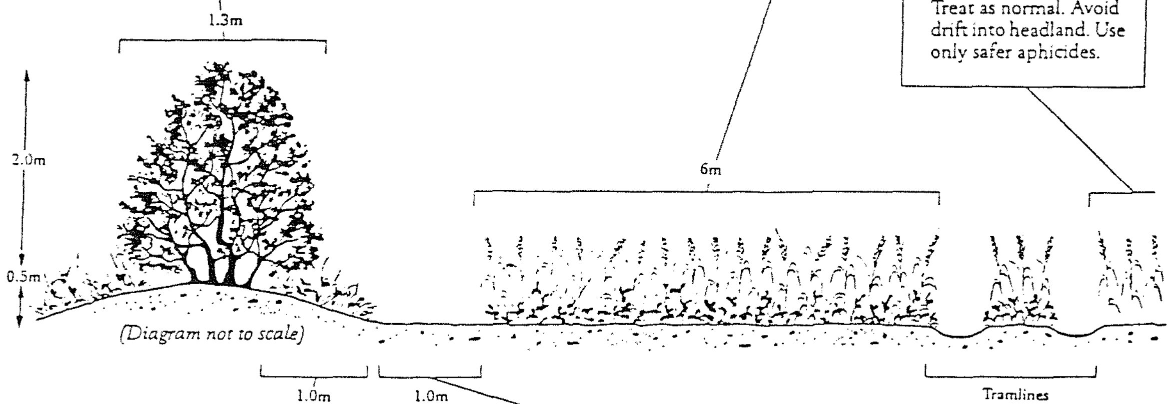
Trim hedges every other year and keep to a maximum height of 2m. Do not allow hedge to overgrow adjacent grassy strip which is the vital area for nesting.

CONSERVATION HEADLANDS

The area between the crop edge and the first tramline (usually 6m wide according to boom width). This is an area of crop treated with selective pesticides (see guidelines) to control grass weeds, cleavers and diseases whilst allowing most broad-leaved weeds and beneficial insects to survive. Ploughing of headlands is recommended especially on heavy soils or where grass weeds are a problem. Avoid turning furrow onto grassy strip as this area can create ideal conditions for annual weeds. Choose headlands next to good nesting cover. Avoid headlands infested with difficult weeds (especially barren brome and cleavers).

SPRAYED CROP

Treat as normal. Avoid drift into headland. Use only safer aphicides.



GRASSY BANK/NESTING STRIP

The area used for nest sites by gamebirds and for overwintering by beneficial insects. At least 1m wide and preferably sited on a bank. Should be composed of perennial grasses and other non-weedy herbaceous species. Avoid spray and fertiliser drift into this area. Allow build up of dead grass material essential for successful nesting, but top the vegetation every 2-3 years to avoid scrub encroachment.

BOUNDARY OR STERILE STRIP

Purpose is to prevent invasion of crop by cleavers and barren brome where they have become abundant. Should be at least 1m wide. Maintain by rotovation or herbicides (e.g. atrazine) in February/early March. Do not spray out grassy bank. Drill crop further out into the field to leave area of bare cultivated ground for the sterile strip. Avoid spray drift by shielding nozzle down to ground level. Not essential for conservation purposes, purely intended for weed management.

INTRODUCTION

This document contains The Game Conservancy's recommendations for the management of field margins, incorporating the field boundary (hedge, fence, wall etc and associated herbaceous vegetation), the boundary strip (cultivated area between field boundary and crop), where present, and the outer few metres of crop, known as the Conservation Headland. Previous guidelines have been mainly concerned with Conservation Headlands, but to obtain maximum benefits, attention should also be given to field boundaries. Consequently the management guidelines have been extended to include this area also. A laminated leaflet summarising these guidelines and suitable for use in the field is also available free from The Cereals and Gamebirds Research Project, The Game Conservancy Trust, Fordingbridge, Hampshire, SP6 1EF.

CGRP FIELD OFFICER

Peter Thompson, The Cereals and Gamebirds Research Project Field Officer, joined the Project in October 1988. He is employed to give free advice on field boundary and headland management in cereal fields, based on these guidelines. In his first year he has made 107 farm visits in 24 Counties, representing an estimated 110,300 acres. During the year there were an estimated 474 miles of Conservation Headlands on 68 farms. However, many farm visits were made too late in the season for Conservation Headlands to be established, so a considerable increase is expected for 1989/90. If you would like a visit from Peter, he can be contacted at The Game Conservancy Trust, Fordingbridge, Hampshire, SP6 1EF, telephone (0425) 52381, or in the evenings on (0962) 79348. Details are given in the enclosed insert.

MANAGEMENT OF CONSERVATION HEADLANDS

AIMS

The aims of conservation headlands are to encourage the growth of a number of broadleaved weed species and hence the insects which live on them. These insects in turn are the food of gamebird chicks and other birds. The weeds and their seeds also provide food for birds and the flowers are important nectar sources for butterflies and pollinating insects. Conservation headlands are also a refuge for rare and declining members for the arable flora.

To achieve these aims, all insecticidal chemicals should be avoided after March 15th. Grass weeds may be selectively controlled using certain specified herbicides, but use of herbicides which control broadleaved weeds should be avoided wherever possible. Headlands which are known to have severe infestations should not be chosen as conservation headlands.

SITING OF CONSERVATION HEADLANDS

The area of a 6m wide headland as a proportion of the field will vary with the size of that field, as shown in the table below. These figures are for square fields. If the field is not square, the proportion contained in the headland will be greater, so that in a very long narrow field the headland will occupy a large part of the field.

Field size in hectares (acres)		Proportion contained in 6m headland (assuming field is square)	
20	(50)	5.4	i.e. all headlands need
16	(40)	6.0	to be in the conservation regime
12	(30)	6.9	
10	(25)	7.6	
8	(20)	8.5	only about 3/4 of the
6	(15)	9.8	headlands need be selected
4	(10)	12.0	only 1/2 of the headlands
2	(5)	17.0	need be selected

The aim of the conservation headland technique is to carry out the guidelines on about 6% of the cereal area. Therefore if the average field size is smaller than 16ha (40 acres) it is not essential to apply the technique to all headlands. From the table, it can be seen that with square fields averaging 8ha (20 acres) only three-quarters of the headlands need be considered; with fields averaging 4ha (10 acres) the figure is only half of the total headlands. In practise, not all fields are square and extra allowance can be made for fields of a rectangular shape.

It can be seen that unless all fields are large there is some scope for choosing where conservation headlands can be sited. At present it is probably best to concentrate on avoiding areas infested with difficult weeds, especially cleavers and sterile brome. Where these are not problems, conservation headlands are best sited next to good nesting habitat (see below).

CULTIVATIONS

Ploughing of headlands is recommended wherever possible, especially on heavy soils and where black-grass and sterile brome are problems. Ploughing helps to keep grass weeds and cleavers under control, and encourage the more useful broadleaved weeds. However, care should be taken not to turn the furrow onto the grass strip at the edge of the field, as this creates ideal conditions for annual weeds such as sterile brome to establish.

INSECTICIDES

Insecticides may be used in autumn for control of BYDV, but **great care should be taken to avoid drift into hedgerows or other field boundaries,** as this could affect overwintering populations of beneficial insects. If it is at all windy the sprayer should be switched off for at least the outer 12m when travelling the outer tramline on the downwind side of the field.

No insecticides should be used after 15th March.

Please also be careful with insecticide use on the remainder of your cereal fields. These areas also have some importance for brood survival. Returns from our most recent aphicide survey are showing an alarmingly high use of dimethoate at growth stages that would imply insurance treatment of crops. We have a growing body of evidence that this practice is detrimental to the survival of wild gamebirds. Where aphid control is necessary in the summer, always try to use pirimicarb (Aphox, Pirimor), but NOT on the conservation Headland.

FUNGICIDES

Fungicides may be used, with the exception of pyrazophos (Missile), which has been shown to have significant insecticidal properties. Pyrazophos may only be used before 15th March.

WEED CONTROL

1. Wild Oats

The following herbicides may be used to control wild oats in autumn or spring; tri-allate (Avadex, Avadex BW), diclofop-methyl (Hoegrass), difenzoquat (Avenge 2). Flamprop-m-isopropyl (Commando) may be used in spring only.

Certain precautions are necessary with some wild-oat herbicides to avoid crop damage. Please read the label carefully before use.

2. Control of black-grass in autumn-sown crops

The recommended treatment for black-grass is diclofop-methyl (Hoegrass), preceded by tri-allate (Avadex BW, Avadex BW granular) where infestations are severe. To be effective, **diclofop-methyl must be applied at full rate before the black-grass tillers (4-leaf stage)** but after the seedlings have emerged, **so timing is crucial**. The sequence with tri-allate is recommended to achieve a high level of control. **Tri-allate must be applied pre-emergence** to control blackgrass, and follow-up with diclofop-methyl is essential to achieve full control.

3. Control of black-grass in spring-sown crops

Black-grass is generally a weed of autumn-sown crops, but in some years infestations may occur in spring-sown crops. In this situation diclofop-methyl (Hoegrass) should be used to control the weed before the plants begin to tiller (4 leaf stage). NB. diclofop-methyl must not be applied to spring barley which has more than 4 fully-expanded leaves and 2 tillers.

Where flamprop-m-isopropyl (Commando) is used to control wild-oats, it will also suppress black-grass and onion couch, but will not provide complete control.

4. Sterile Brome

Headlands with sterile brome infestations should not be chosen as conservation headlands if at all possible. Effective control of this weed can only be achieved at present by ploughing followed by a herbicide sequence eg. tri-allate pre-emergence followed by isoproturon post-emergence up to the 3 fully expanded leaf stage of the weed. Careful use of such a programme should eliminate sterile brome from the crop in 2-3 years, after which re-invasion should be prevented by ploughing headlands wherever possible and using a sterile strip between crop and field boundary (see below).

5. Perennial weeds

Glyphosate (Roundup, Muster etc) may be used pre-harvest to control couch, black bent, onion couch (barley only), creeping thistle, docks, field bindweed, perennial sowthistle, volunteer potato etc. It may also be used at a lower rate to clean up the crop before harvest if desired. (NB the valuable polygonum weeds are not susceptible to the lower rate). The manufacturers instructions should be carefully followed when using this technique.

Flamprop-m-isopropyl (Commando) may also be used for control of onion couch, and will give better results than glyphosate in winter wheat.

6. <u>Cleavers</u>

Although broadleaved weeds should not generally be controlled, cleavers are a special case in view of the damage they can cause. **Wherever possible, headlands with known cleavers infestations should not be chosen as conservation headlands, since there is at present no truly selective chemical control for** cleavers.

Where tri-allate is used for control of wild oats and grass weeds, it will also give partial control of cleavers. Application of fluroxypyr (Starane 2) at 0.75 l/ha in late autumn have given good control provided cleavers has emerged and weather conditions are still relatively warm. However, best results have been obtained by using fluroxypyr at 1.0 l/ha in late March, i.e. as soon as the weather warms up in spring, but before 1st April. This treatment will give good control of cleavers with some damage to other weed species, but will not affect spring germinating weeds such as the valuable *Polygonum* species. Spraying after 1st April will severely reduce the game and wildlife value of Conservation Headlands. If possible, it is recommended that treatment with fluroxypyr is restricted to those headlands or parts of headlands where cleavers are known to occur.

In emergency situations fluroxypyr is safe to apply up to flag-leaf emergence (Zadoks GS 39), and will give good control of cleavers, but at the expense of controlling other broadleaved weeds at the same time.

7. <u>Other broadleaved weeds: autumn drilled crops</u>

In general, **use of herbicides which affect broadleaved weeds is to be avoided, and consequently headlands which are known to suffer from high weed infestations should not be chosen as conservation headlands.** Where such headlands cannot be avoided, or an unexpectedly large number of weeds appears such that substantial crop loss seems likely, a contact herbicide could be used in the autumn to remove the first flush of seedlings, but this may affect the value of the conservation headlands. If such problems are encountered please ring Peter Thompson at The Game Conservancy Trust, Fordingbridge for specific advice.

<u>PLEASE NOTE</u>

These guidelines apply only to the area between the outer tramline and the field edge. All recommendations for herbicide use refer to the manufactures recommended rates unless otherwise stated.

C. & G. Willmot (AMC) Ltd., have designed a sprayer that can spray a six metre headland at the same time as the main sprayer is in use, even though it is totally independent of it. This makes a special trip to spray headlands unnecessary. For further information contact Maurice Patchett on 0235/817701.

GRASS STRIP

This is the area used for nest sites by gamebirds and overwintering by beneficial insects. It should be at least 1 metre wide and preferably sited on a bank. Grassy banks are used even where no hedge is present.

The vegetation should be composed of perennial grasses and herbs, preferably including tussock-forming species such as cocksfoot. Patches of stinging nettles are favoured by breeding red-legged partridges.

Nesting success of grey partridges is greatly improved by the presence of dead grass from the previous year. Regular annual cutting of the grass strip should therefore be avoided, but rotational trimming every 2-3 years is necessary to prevent scrub encroachment.

Under no circumstances should non-selective herbicides be used in this area. Not only is the habitat destroyed, but ideal conditions are created for the establishment of annual weeds such as sterile brome and cleavers, which are usually present as a minority component of the herbaceous flora in even the best managed hedgerows. Likewise avoid spray and fertiliser drift into field boundaries. Cleavers in particular are very responsive to fertiliser and thrive under high nutrient conditions.

BOUNDARY STRIP OR STERILE STRIP

Where sterile brome, cleavers or other annual weeds have become abundant in the field boundary flora, a strip of bare ground may be created either by rotovation or application of a broad-spectrum, residual herbicide to prevent encroachment into the crop. This strip should be created **in the cultivated ground**, leaving at least 1m of undisturbed herbaceous vegetation in the field boundary.

It is suggested that the crop should be drilled so that an area of bare ground is left between the crop edge and the edge of the cultivated land for creation of the sterile strip. This should be at least 1 metre wide.

Atrazine applied in autumn or early spring, before weed have started growing, will give good control of most species, though some perennials such as creeping thistles are not fully controlled. Where these are a problem, rotovation may be preferable. Disadvantages of rotovation are that it is expensive, needs to be repeated, and the minimum width of the strip is limited by the width of the rotavator. Advantages are avoidance of herbicide drift and control of all weed species.

Other herbicides with label recommendations for use in sterile strips are propyzamide and glyphosate. Glyphosate needs to be used in spring when plants are actively growing, and produces an unsightly yellow strip of dying vegetation. It is also more difficult to avoid harmful drift into the crop or field boundary.

Avoidance of drift is essential and great care should be taken to shield the nozzle(s) to ground level. Use low pressure to avoid production of fine droplets. A purpose-built piece of equipment, which can be mounted at the front of the tractor , is available from the Manydown Company at a cost of around £150. For further information ring 0256/464292.

SUMMARY OF RECOMMENDATIONS FOR PESTICIDE USE

	Autumn-sown cereals	Spring-sown cereals
INSECTICIDES	Only until 15th March	NO
FUNGICIDES	YES (not pyrazophos after 15th March)	YES (not pyrazophos)
HERBICIDES (Grass weeds only)	Avadex BW, Avadex BW granular, Avenge 2, Commando, Hoegrass, Muster, Roundup	Avadex BW, Avadex BW granular, Avenge 2, Commando Hoegrass, Muster, Roundup
HERBICIDES (Broadleaved weeds)	NO (some exceptions e.g. cleavers) If broadleaved weeds are a problem, contact Field Officer	NO
GROWTH REGULATORS	YES	YES

Read the label before you buy: Use pesticides safely.

MANAGEMENT OF FIELD BOUNDARIES

AIMS

Most of the animals which benefit from Conservation Headlands also make use of the more permanent habitat of the field boundary. Most partridges and up to 30% of wild pheasants nest in grassy strips in field boundaries. Larvae of butterflies, moths and other insects feed on plants growing there, and many predatory beetles overwinter in field boundaries before dispersing into the field in the spring, where they become important aphid control agents. Hedgerows provide nesting sites for songbirds and, in winter, berries can be an important food source.

HEDGE

Berries are formed on the previous year's wood, and so are encouraged by trimming every third year, or every other year if cutting can be postponed until the months of January/February. Cutting should not be carried out during spring and summer when birds are nesting and insects feeding.

Partridges avoid tall hedges, therefore nesting hedges should be kept at or below 2 metres high. The hedge should not be allowed to grow over the adjacent grassy strip which is where nesting takes place. For this reason, trimming sides vertically is more appropriate to game management than trimming to an 'A; shape and shading out the grassy verge.

Sterile strips are recommended solely as a technique for weed management, where problem weeds occur at the field edge. There is no evidence that they produce any direct benefit for gamebirds or other wildlife. They are not a substitute for Conservation Headlands.

PRODUCT NAMES AND MARKETING COMPANIES OF PESTICIDES (mentioned in text)

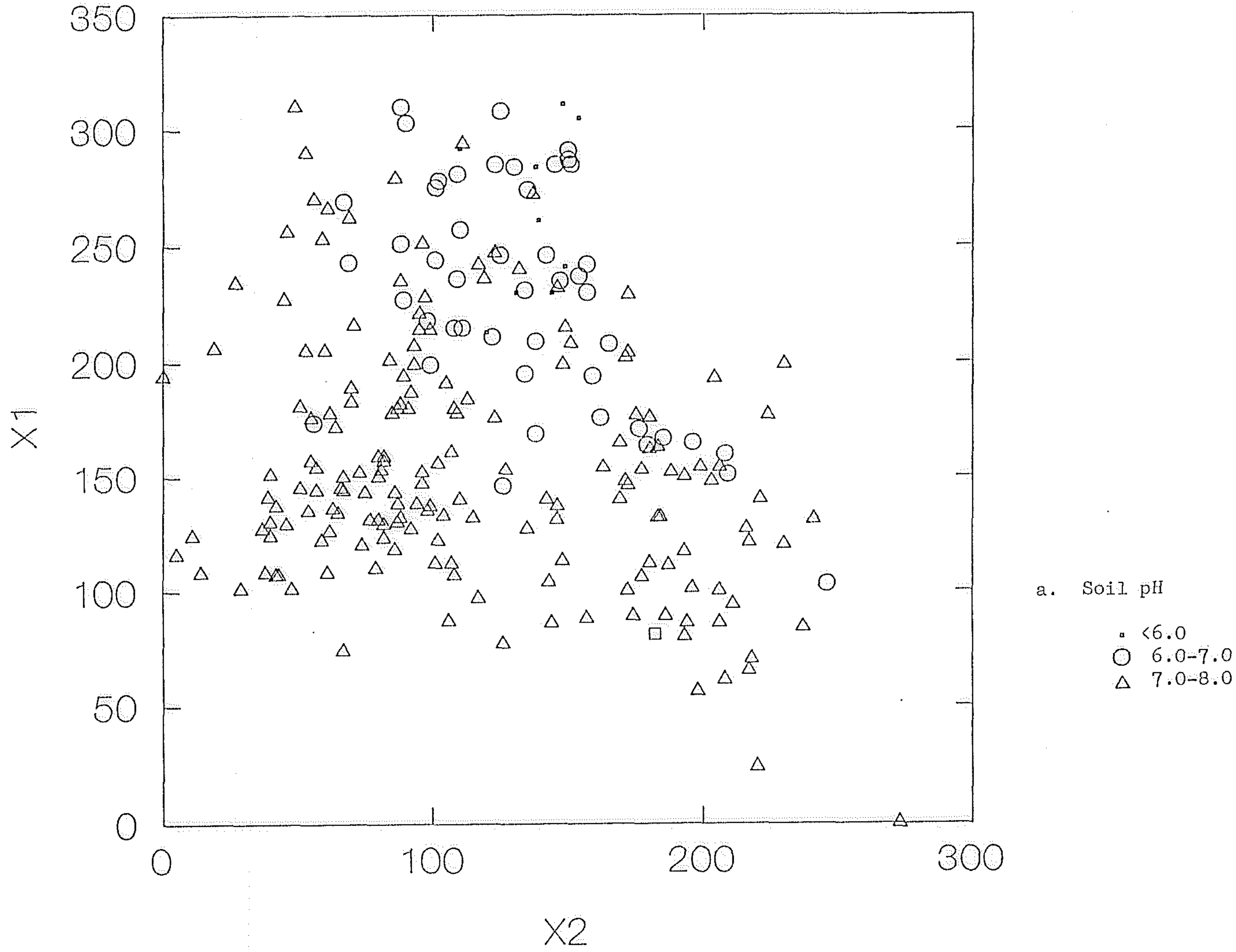
Chemical Name	Product	Marketing Company
Atrazine**	Gesaprim 500 FW	Ciba-Geigy
	+ various others	+ others
Diclofop-methyl	Hoegrass	Hoechst
Difenzoquat	Avenge 2	Cyanamid
Dimethoate*	various products	various
Flamprop-m-isopropyl	Commando	Shell
Fluroxypyr	Starane 2	Dow
Glyphosate	Roundup	Monsanto, Schering
	Muster	ICI
	+ various others	
Isoproturon (IPU)*	various products	various
Mecoprop (CMPP)*	various products	various
Pirimicarb*	Aphox	ICI
	Pirimicarb 50	Schering
	Pirimor	ICI
Propyzamide**	Kerb 50w	PBI, Rohm & Haas
	Kerb flowable (Kerb Flo)	PBI, Rohm & Haas
	+ various other	various
Pyrazophos*	Missile	Hoechst
Tri-allate	Avadex BW	Monsanto
	Avadex BW granules	Monsanto

* not recommended for use on Conservation Headlands

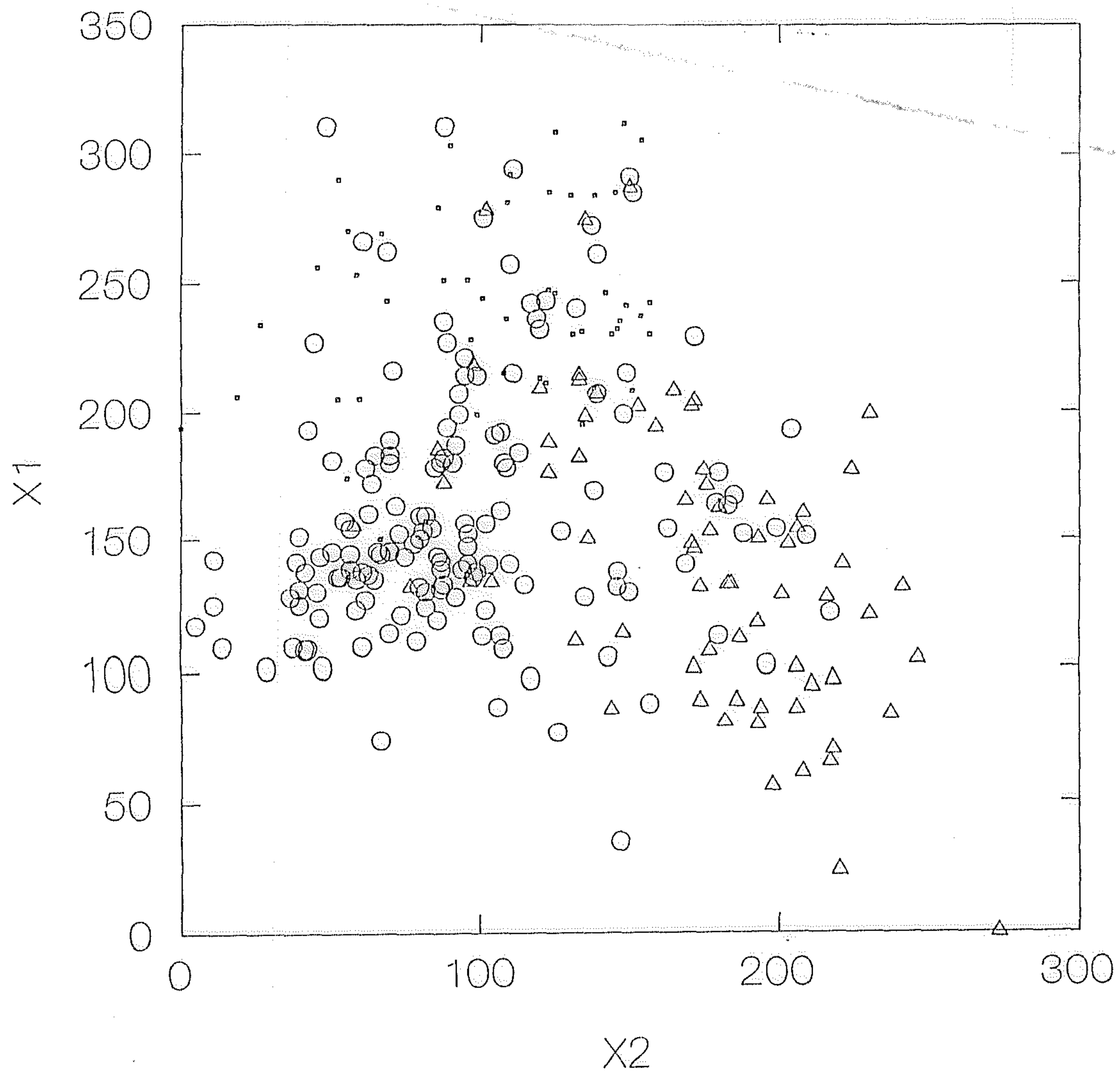
** for use on sterile strips only

NB: The number of products now available containing some chemicals makes it impractical to produce a complete listing. No criticism is intended of any product not mentioned. Users are advised to read the label carefully to determine whether a product is suitable.

Figure 3. Overlays

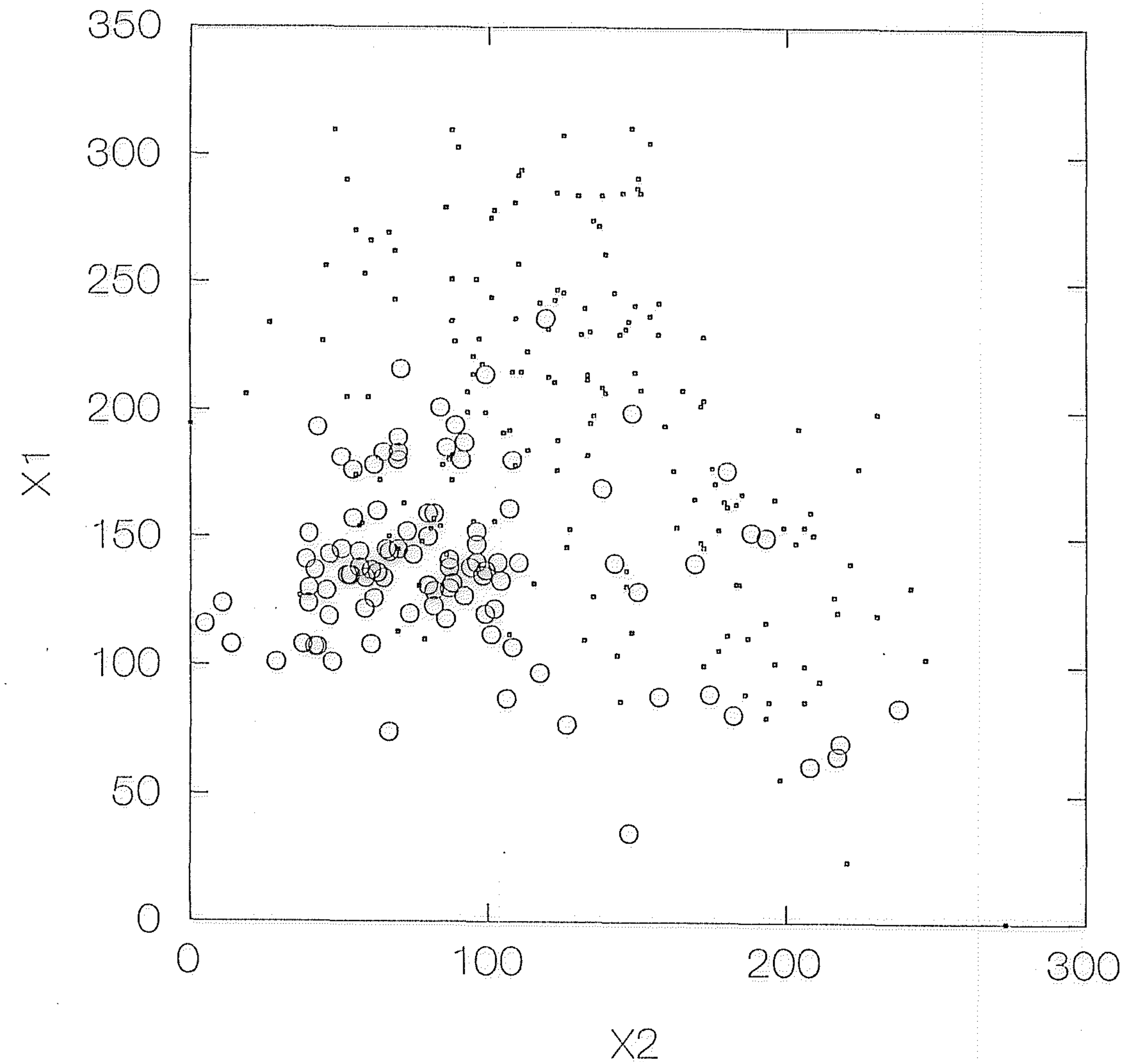


a. Soil pH



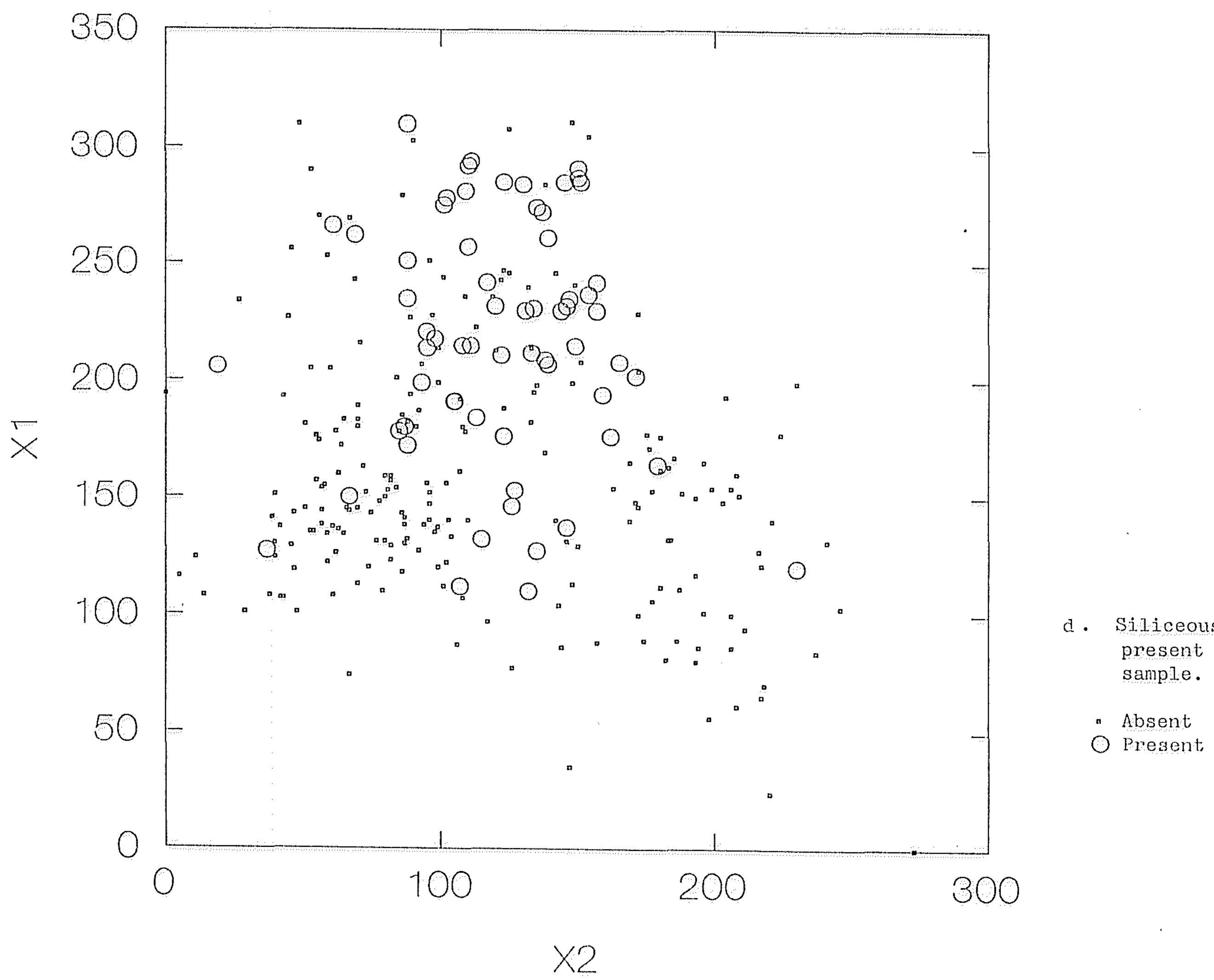
b. Soil texture

"Light" soils with a high sand fraction
"Medium" soils
"Heavy" soils with a high clay fraction

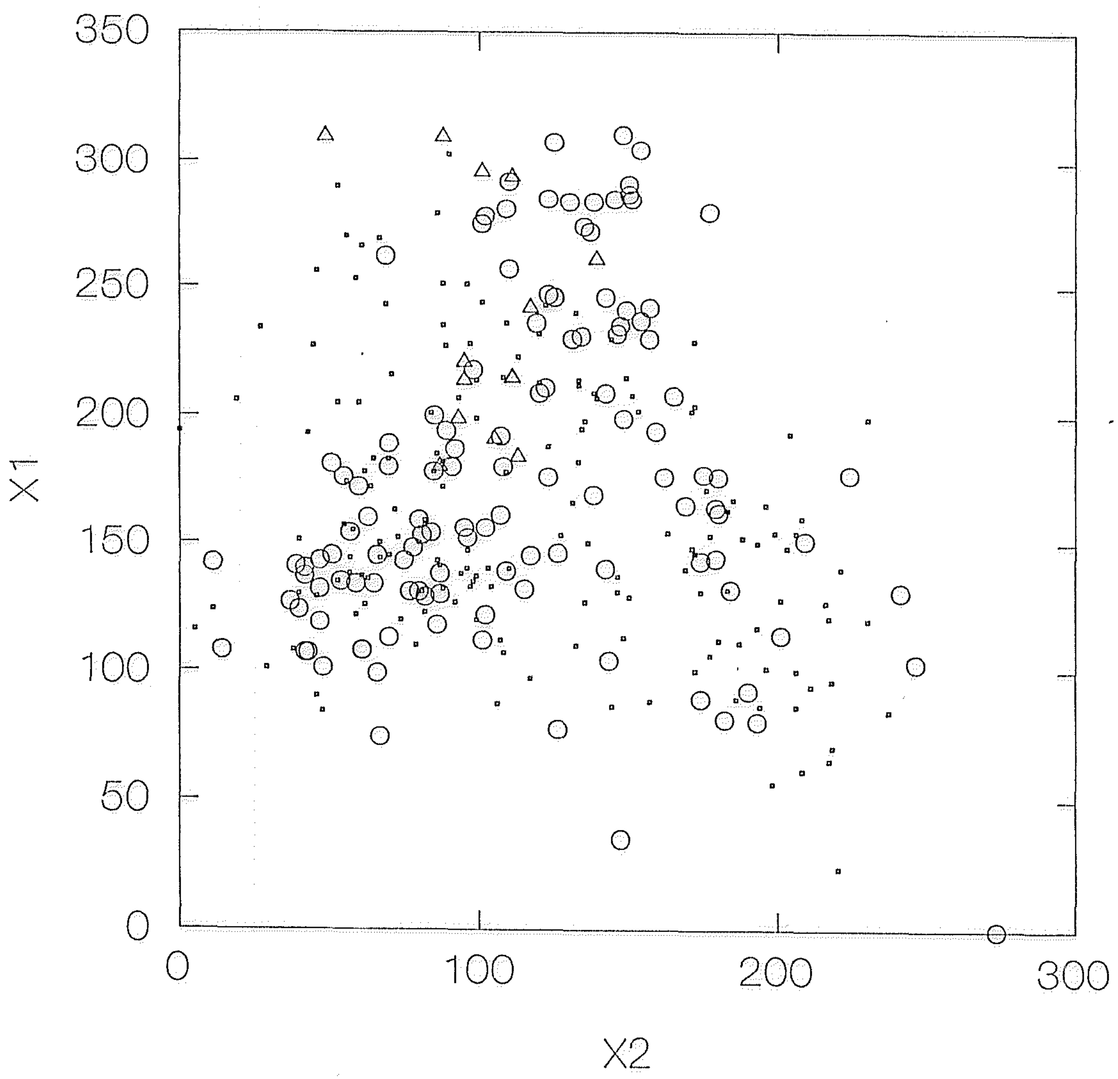


c. Chalk or limestone present in the soil sample.

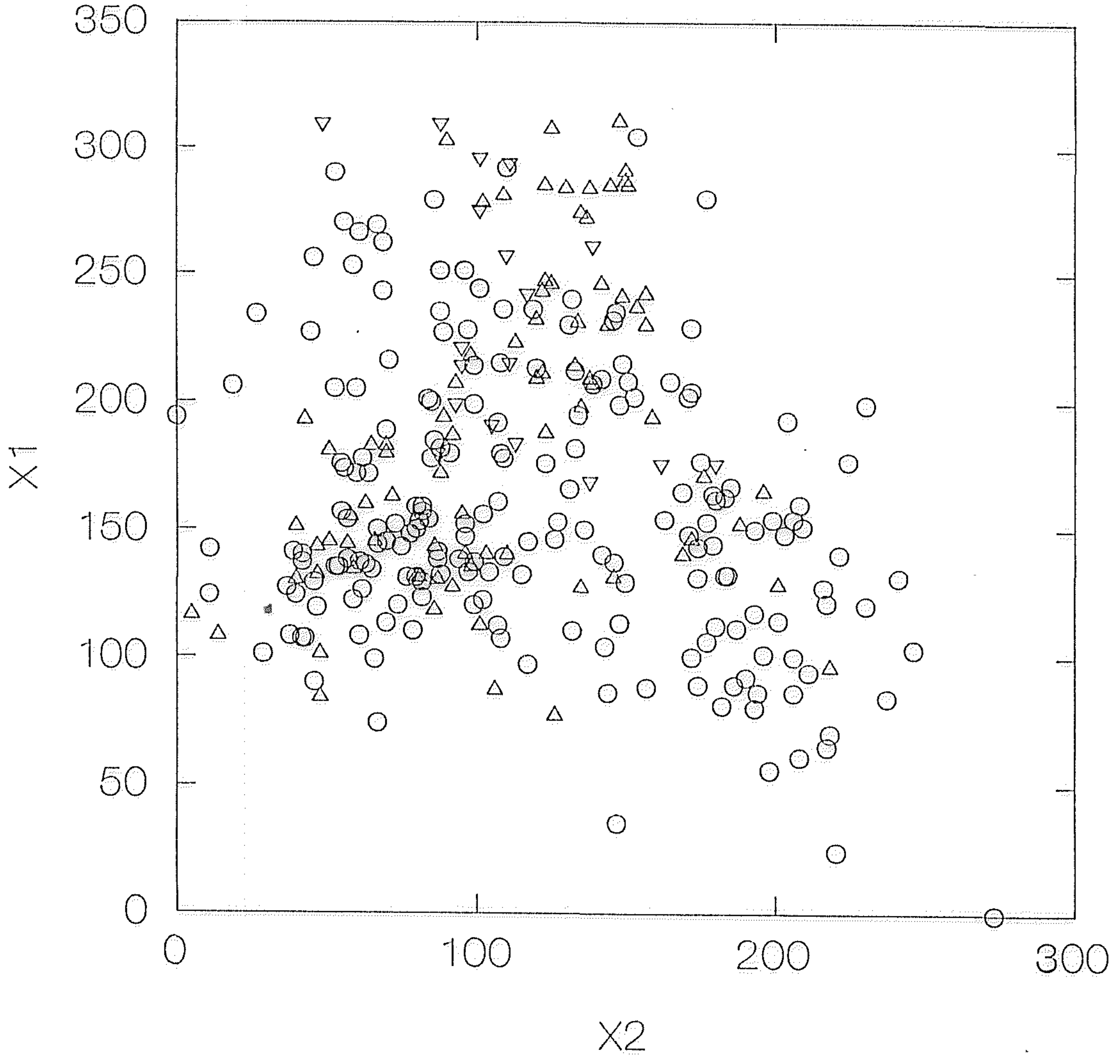
- Absent
- Present



d. Siliceous stones present in the soil sample.

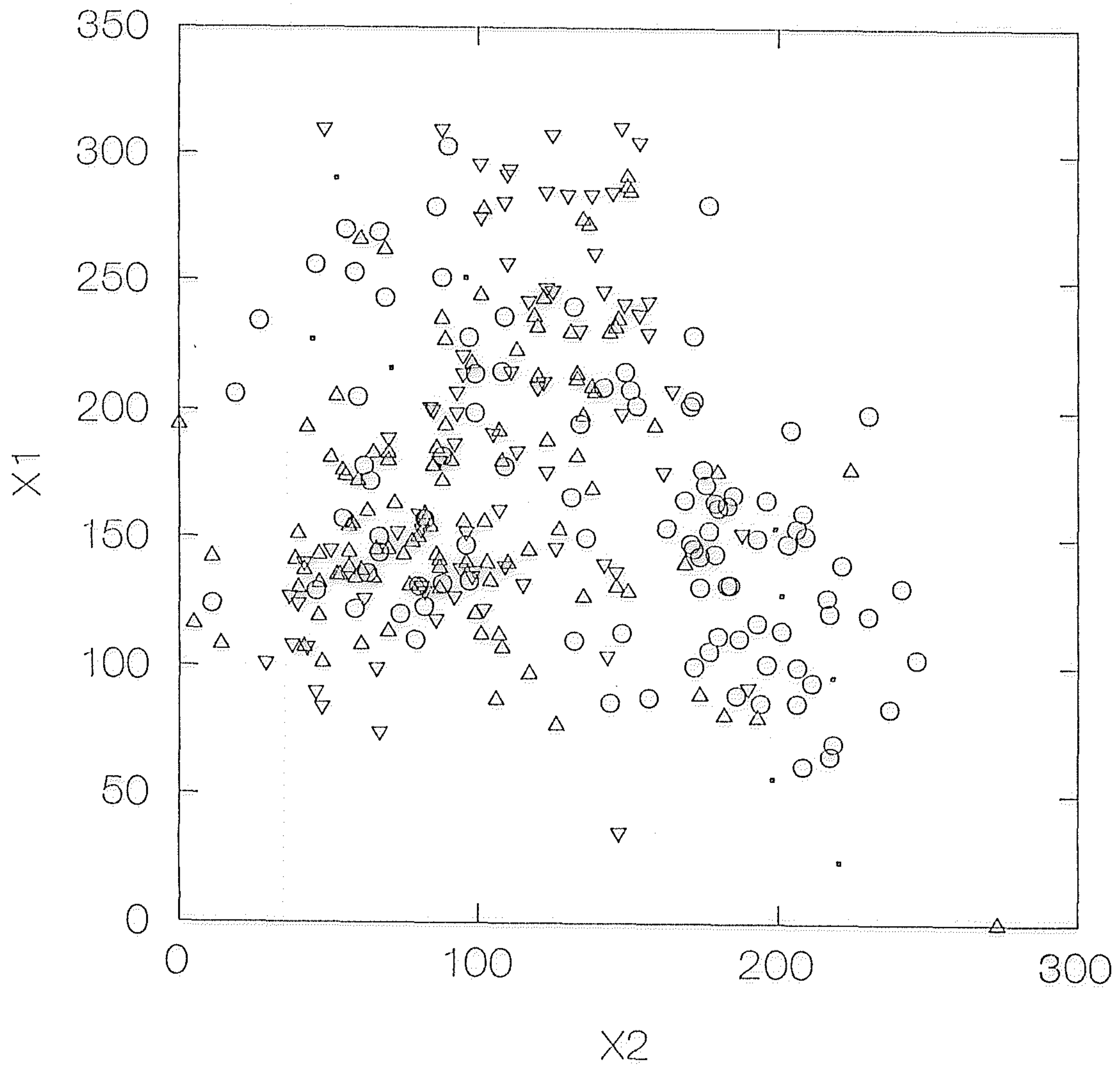


e. Mean air temperature (°C) at 0900 hours GMT in screen 1.3m above ground level. January - March.



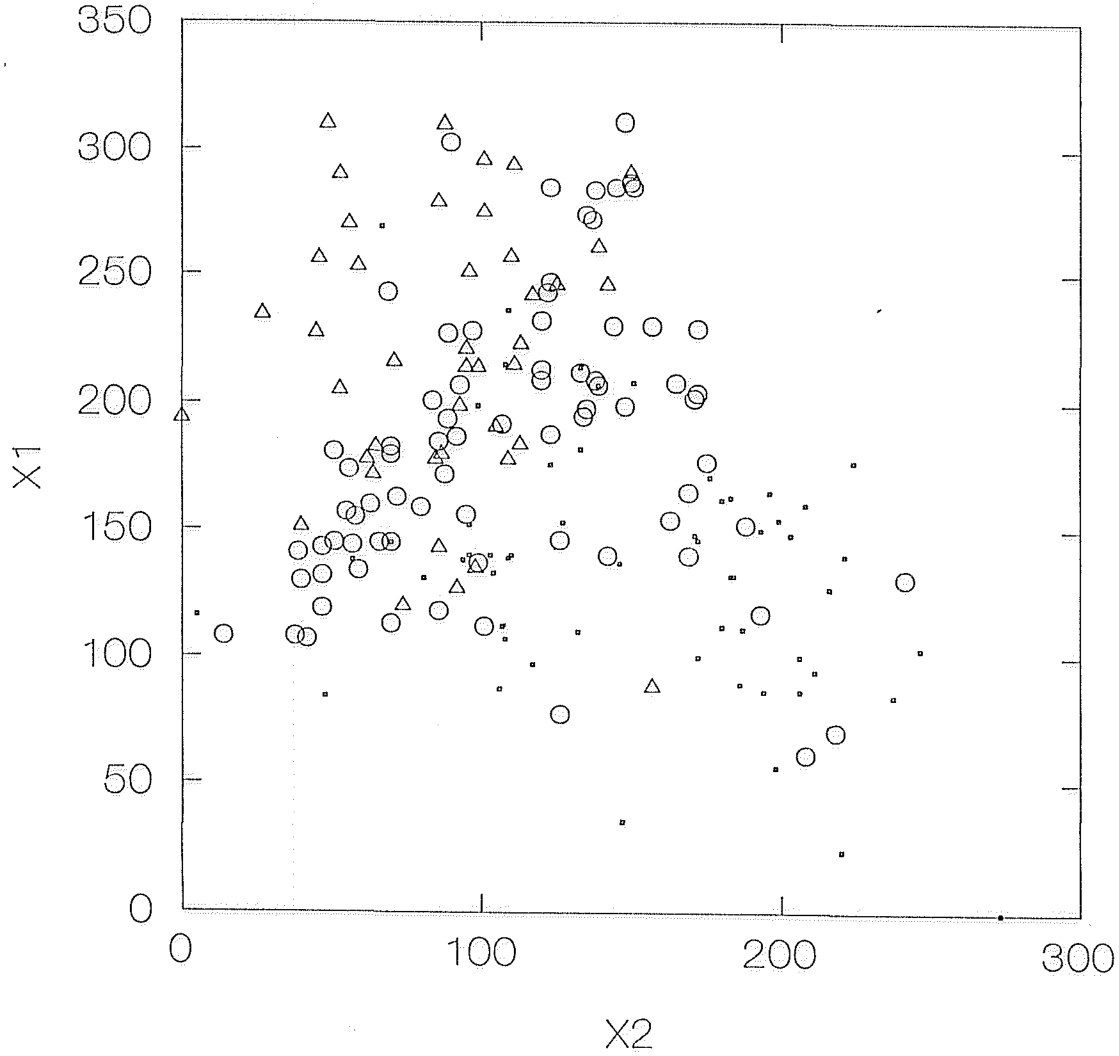
f. Mean rainfall (cm/day).
April - June.

- <0.15
- ○ 0.15-0.20
- △ 0.20-0.25
- ▽ 0.25-0.30



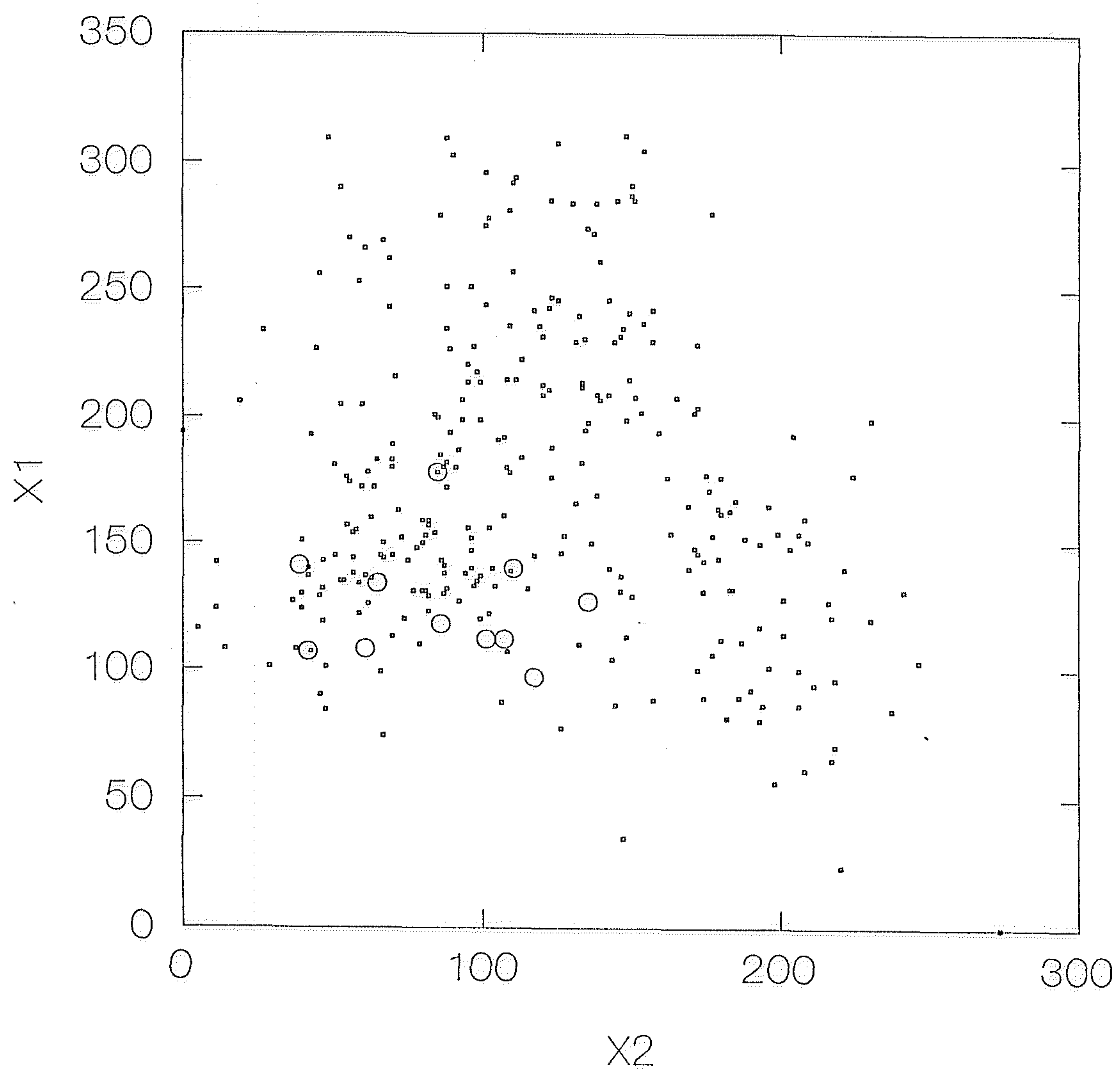
g. Mean duration of bright sunshine (hours/day). April - June.

▪ <5.6
○ 5.6-5.9
△ 5.9-6.2
▽ >6.2

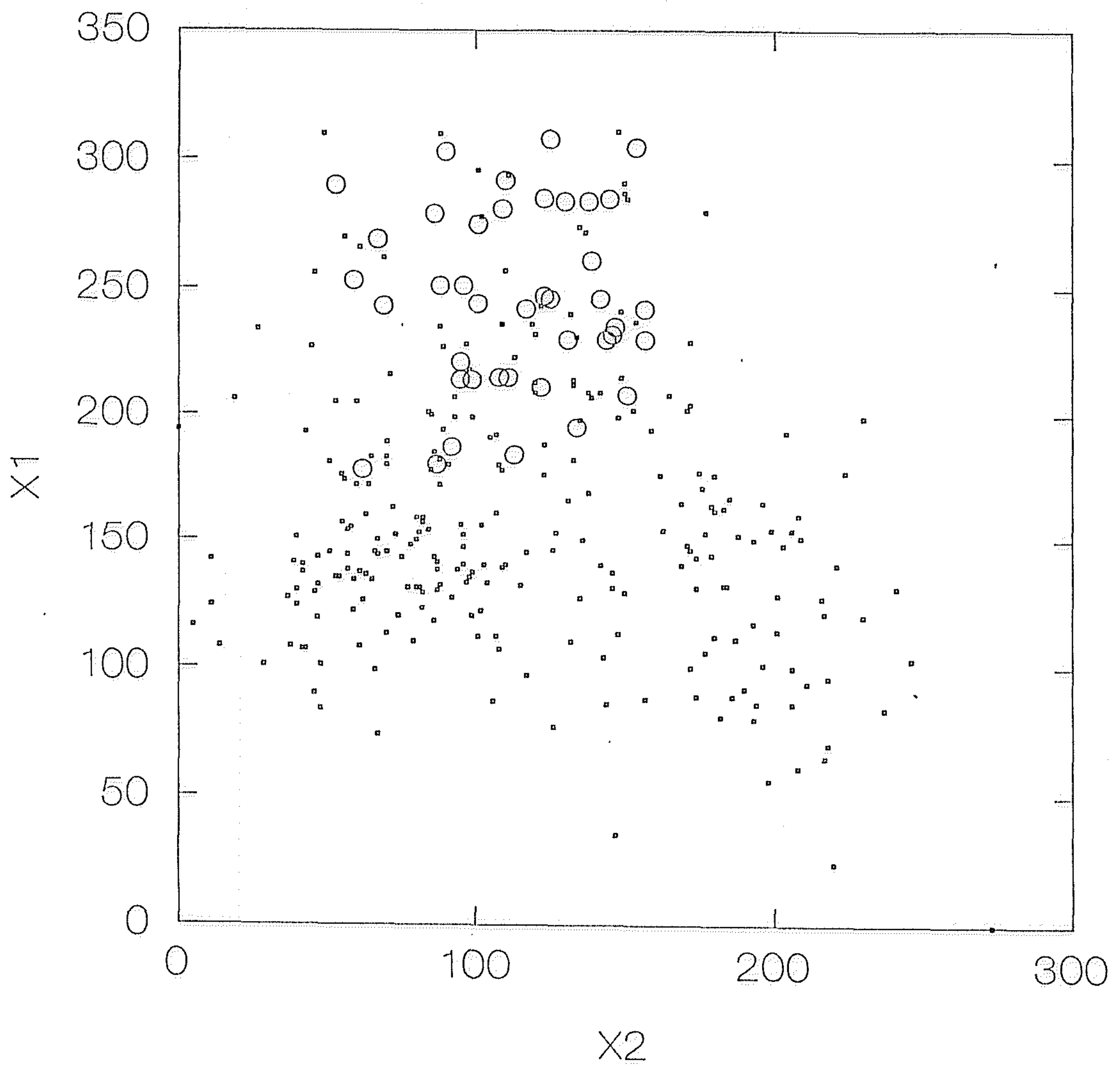


h. Crop index. Based on crops grown since 1980.

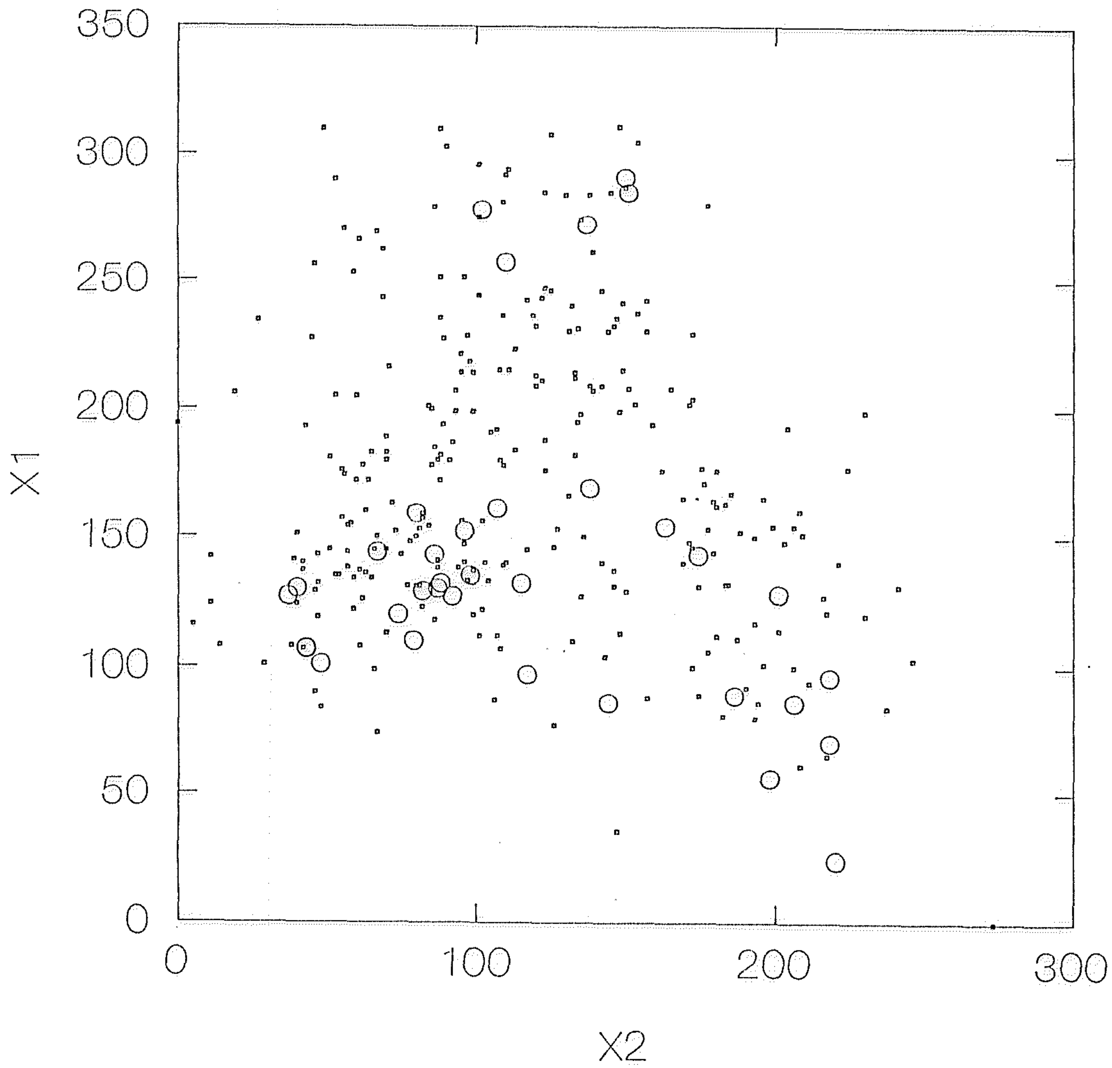
- ▫ <10 Predominantly winter crops.
- ○ 10-20 Mixed winter and spring crops.
- △ >20 Predominantly spring crops.



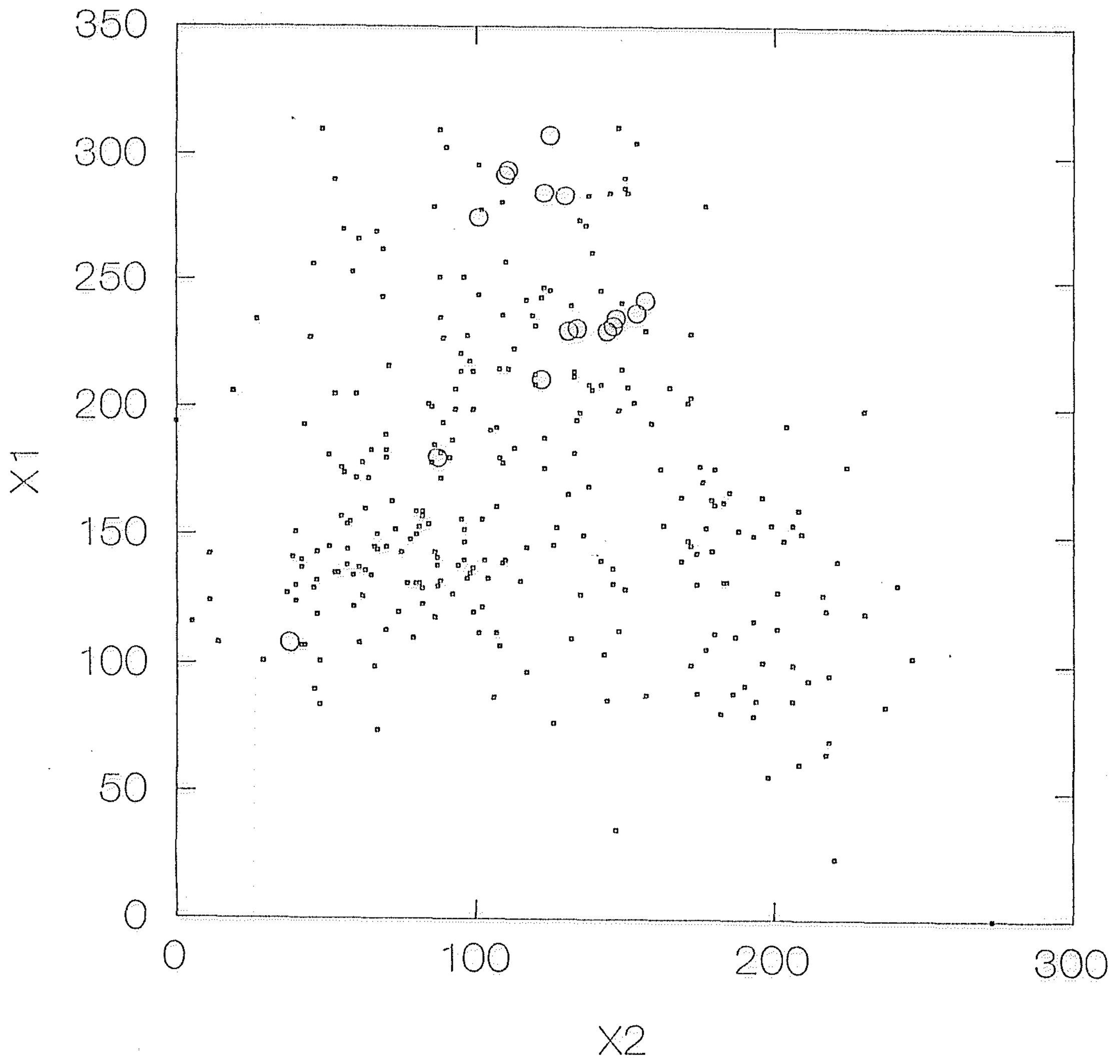
i. <u>Adonis annua</u>



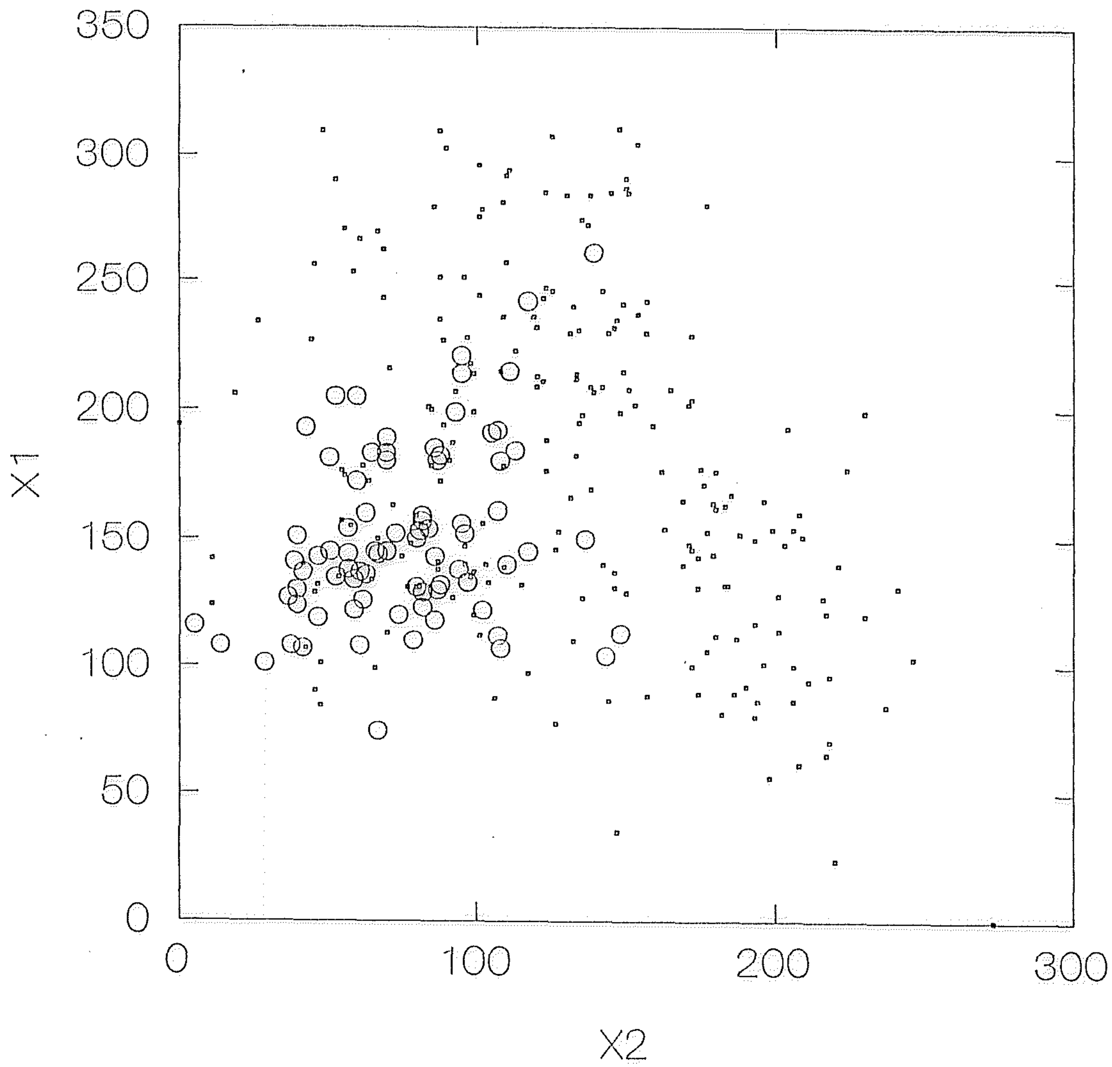
j. Chrysanthemum segetum



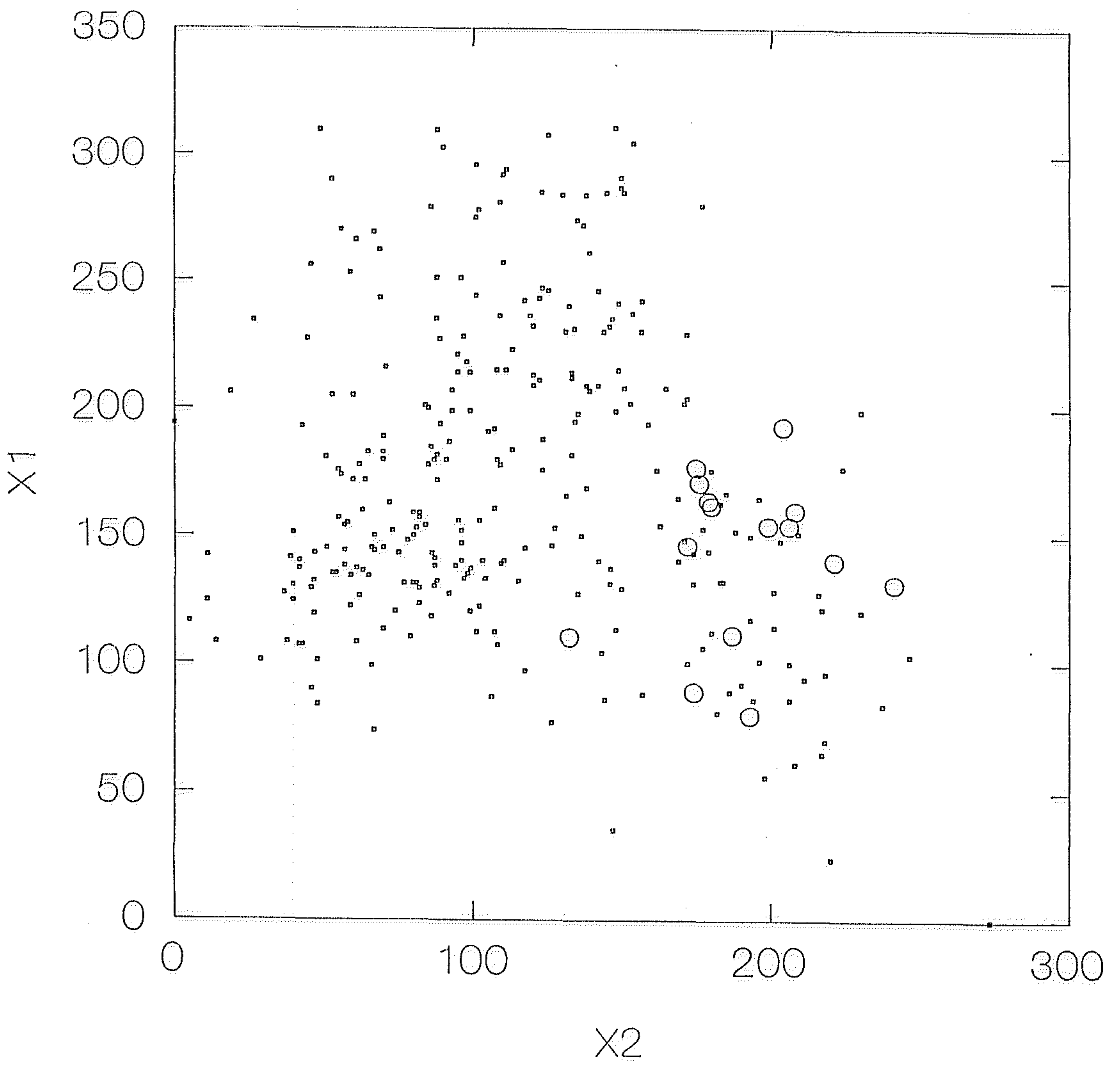
k. *Lithospermum arvense*



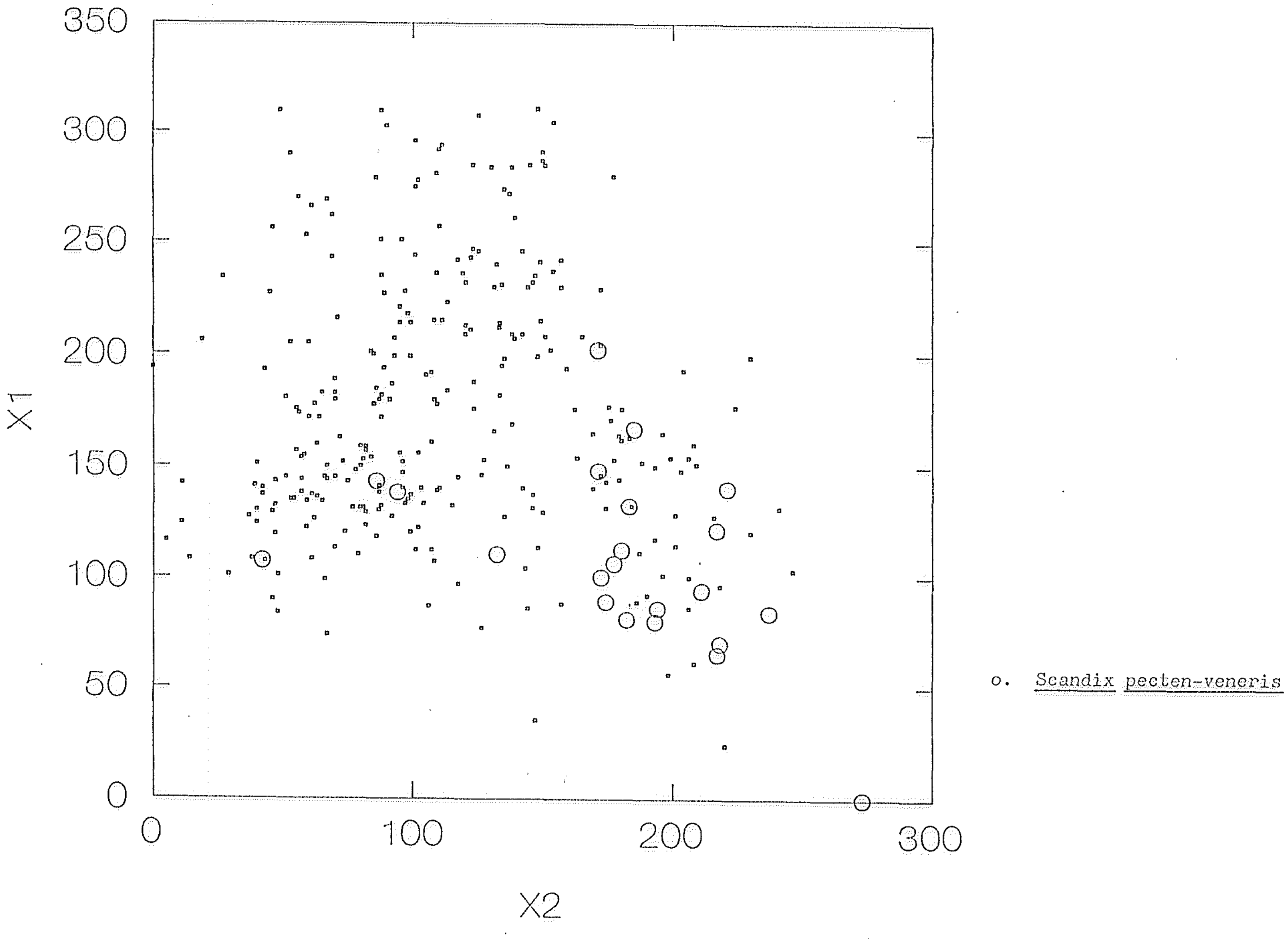
1. Misopates orontium



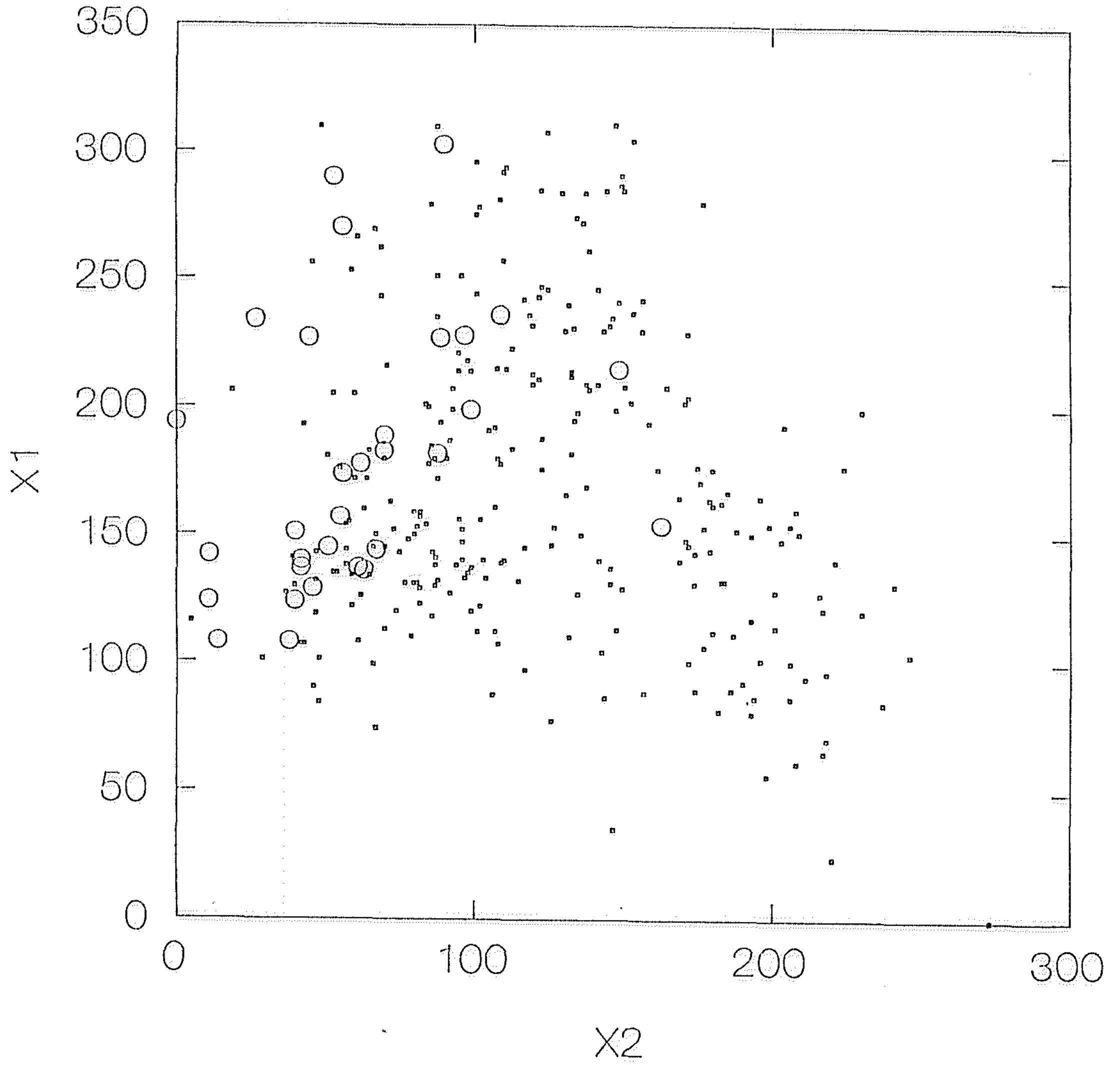
m. Papaver hybridum



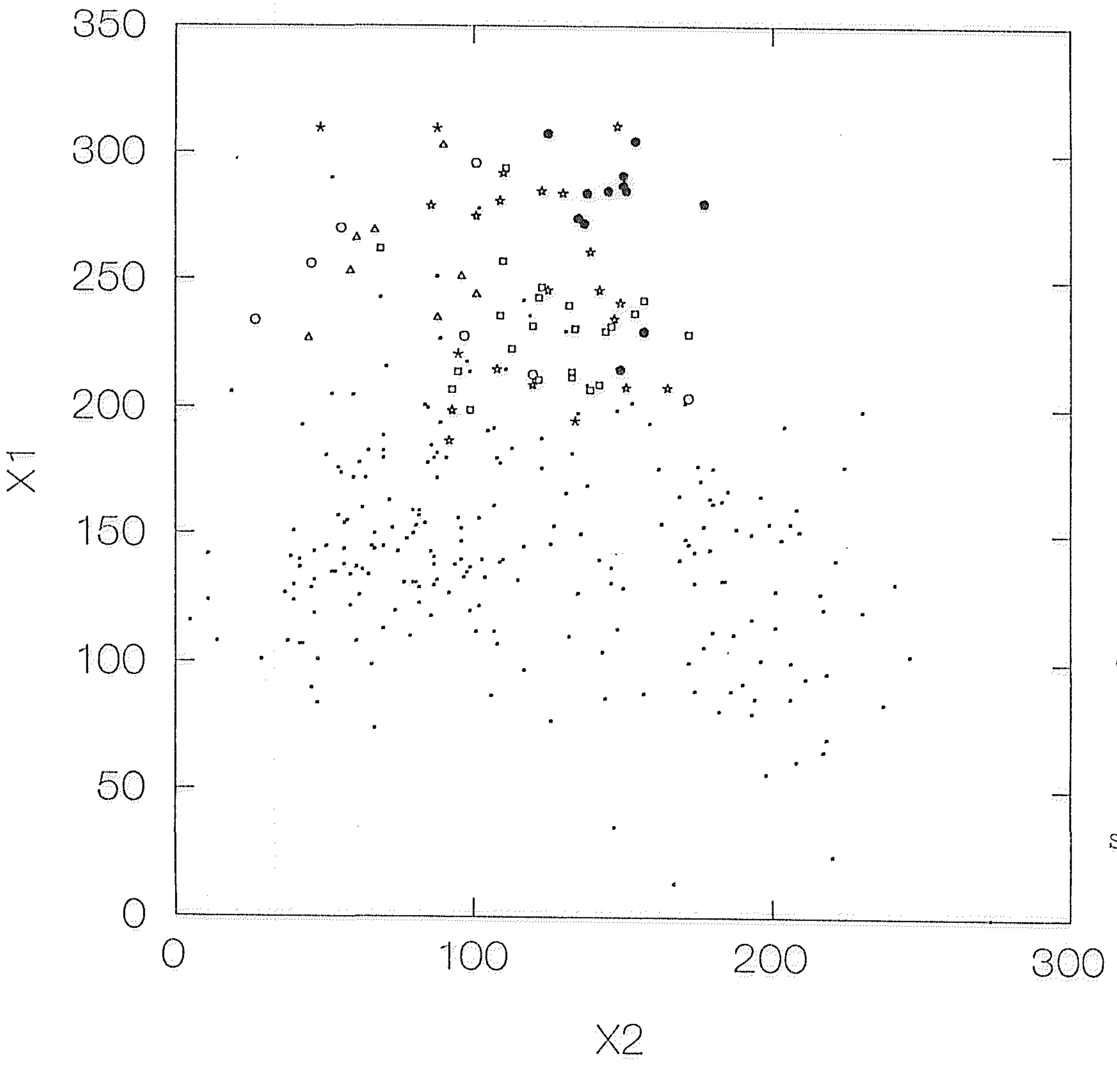
n. Ranunculus arvensis



350
300
250
200
150
100
50
0
X1
0
100
200
300
X2
o. Scandix pecten-veneris

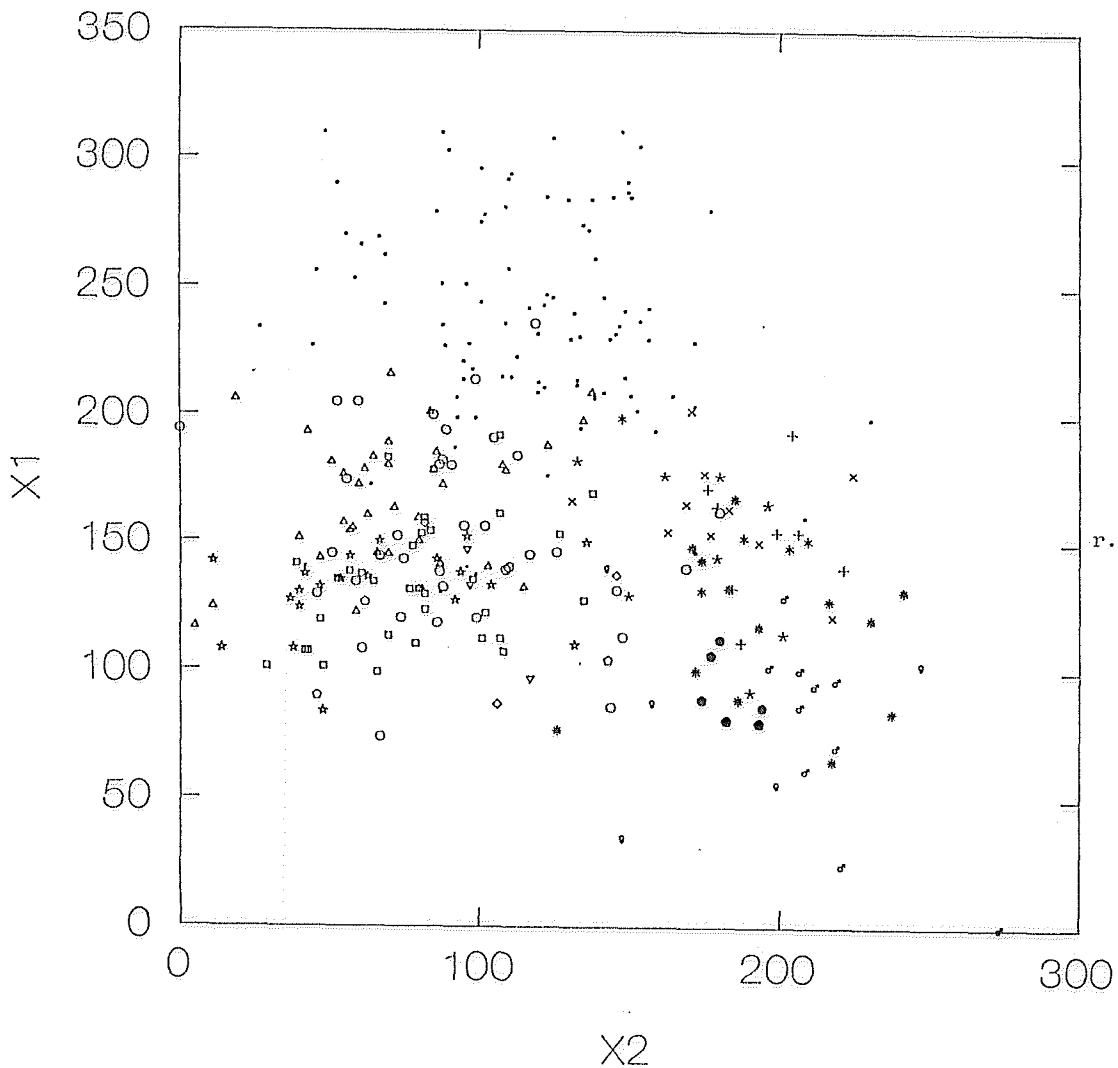


p. *Silene noctiflora*



q. Classification of sites by TWINSPAN (see figure 5. Final groups 1-9 not plotted). Group 0. (· - sites classified into Group 1)

Symbol	Final Group Number
o	10
Δ	11
□	12
*	13
•	14



r. Classification of sites by TWINSPAN (see Figure **5**) Group 1 (· - sites classified into Group 0).

Symbol	Final Group Number
○	16
△	17
□	18
☆	19
▽	20 + 21
◇	22
⬠	23
+	24
×	25
✻	26
●	27
★	28
*	29
♂	30
♀	31