SESSION 8B

THE ENVIRONMENTAL EFFECTS OF HERBICIDES AND THE MANAGEMENT OF VEGETATION

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SOME ECOLOGICAL ASPECTS OF THE MANAGEMENT OF VEGETATION

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SUMMARY

Wildlife is a crop and much of it requires some form of management. The effect on grassland wildlife of grazing, cutting, burning, fertilisers and herbicides is discussed. High inputs of chemicals and intensive management result in a diminution in amount and possible extinction of most wildlife species. In order to maintain our wildlife for future use it is necessary to conserve dwindling stocks by management systems based on the perpetuation of traditional methods by which the grasslands originated. This means removing growth normally annually and re-cycling nutrients by means of sheep and cattle or by hay cutting in specialised circumstances with back end grazing and occasional applications of farm yard manure.

INTRODUCTION

Although many habitats require some form of management in order to maintain their existence, none is as dependant on correct management as grasslands. For the purposes of this paper grasslands are divided into 3 categories.

a. Those which have been sown down with an agricultural seed mix, based mainly on ryegrass.

b. Those permanent (unsown) grasslands which have received high inputs of fertilisers and possibly applications of herbicides.

c. Those permanent grasslands which have received only little and perhaps sporadic inputs of fertilisers and herbicides together with those which have received nothing other than animal returns.

The first two categories are not the subject of this paper being solely concerned with maximising agricultural production. Clearly there is a grey area between the second category and those in the third which have received some chemical input. The effects of this are discussed later. This paper is concerned with the production and conservation of a large range of species, plant and animal, which naturally occur in British grasslands. A detailed account of the great variability within British unimproved grasslands is irrelevant here but can be found in some detail in Duffey et al (1974). Suffice it to say that over a quarter of the British flora occurs in grasslands and over half of the British butterflies. Such species rich grasslands are the result of traditional management over the centuries leading to a habitat rich in plant and animal life.

This wealth of a natural resource requires as much thought given to ensure its survival and optimum production as any other product of a land use, for example wheat, beef, timber or roads. Grassland communities in the temporate world are the result of arrested succession by human intervention through stock grazing, cutting or burning. Without management all grassland communities are relatively unstable and their composition changes through the ingress of shrubs and trees to some form of secondary woodland with the loss of many species.

Grasslands consist of a mixture of grasses, herbs, mosses and associated fauna. The exact composition depends on soil type, climate, aspect, water table and management. Raunkiaer (1934) classified plants according to the position of the overwintering growth points. The four major groups are chamaephytes with aerial overwintering buds up to 25 cm above soil surface; hemicryptophytes with buds at the surface; geophytes with buds underground and therophytes which overwinter as seeds. In grasslands more than two thirds are hemicryptophytes, not surprising as this group contains grasses, sedges prostrate and rosette herbs. This attribute clearly helps to protect the growing point from grazing and cutting. Geophytes form the next largest group and includes the orchids, with chamaephytes and therophytes making up small proportions only. Therophytes (annuals) require a degree of openness not normally associated with grasslands. The few, including, Rhinanthus minor, Linum catharticum and Euphrasia spp rely on some form of small disturbance by worm cast, mole heap or trampling to create the conditions for germination and establishment. Plants which are frequently defoliated must be capable of quick regeneration and of having growing points and storage organs out of reach of the defoliator. Longevity is an important characteristic of grassland plants with over ninety per cent being perennials. Many of the herbs regularly reproduce vegetatively and establishment from seed is rare. Such species are therefore confined to existing sites with a very poor chance of colonising new areas.

It is sometimes argued that because there are thousands of species comprising our grasslands, management of them requires a great deal of research to find the requirements of each and every species, plant and animal. I do not hold that view because:

a. money so used would be better spent in giving protection to sites

b. sufficient is known of how grasslands came to be and how they were managed in the past

c. life is too short!

I am in favour of research into the autecology of those species known to be in decline due to the adverse activities of man in order to arrest and in some circumstances, reverse this trend.

The management aspects I wish to consider are, grazing, cutting, burning, fertilisers and herbicides with an outline of their effects on plants and animals.

GRAZING

Although several workers, including Linnaeus, have offered various plants to stock and noted palatability it was Jones (1933) who noted in the field the effect of sheep grazing on a grass/clover sward. The relationship between grazing animals and the plant and animal communities is complex. Three major factors are involved, namely defoliation, trampling and manuring.

Defoliation prevents the build up of dead material which in itself is a requirement for certain spiders, ground beetles and other invertebrates but which ultimately reduces the number of plant species and is likely to lead to colonisation by shrub and tree species. This conflict between different groups of species highlights the need for management plans, as necessary here as in agriculture. Selection of some plants and avoidance of others can have a marked effect on the botanical composition and structure of grasslands. Of the many factors which determine selection, availability and palatability are the most important. These factors are related and dependant on stocking rates. At low stocking rates livestock can choose and exercise preferences for certain species together with the choice of old or young portions of the same plant. At high stocking rates less herbage is available and livestock are forced to be less selective. By this means the control of coarse grasses can be achieved or, by a low stocking rate, plant litter can be encouraged for utilisation by some invertebrates.

Time of grazing can determine which species are preferentially chosen. In Argyllshire, Martin (1964) found that Festuca rubra was the most frequent component of the sheep's diet at all seasons but did decrease in May and June when Molinia, Nardus and Eriophorum began growth. Similarly Williams et al (1974) noted that Juncus was taken by Galloway cattle only during the first fortnight of growth at Woodwalton Fen, Cambridgeshire.

Winter grazing, when many herbs are dormant underground is likely to lower the competitive grasses, thus favouring low growing species which can then compete on equal terms at the start of the growing season. Many insects overwinter below ground or sufficiently low down in the vegetation to avoid being harmed. Spring grazing will be beneficial to the establishment of annuals and these will increase when open conditions created by grazing plus treading occur. Summer grazing will remove flower heads and thus reduce seeding but most grassland plants rely on vegetative reproduction. Seeding is often possible from secondary flowering and seed production suffient to ensure the continuity of the species. A possible loss of sufficient nectar source for some invertebrates including Lepidoptera, may be a more serious loss. This will be increased if the loss cannot be made up from nearby flowering shrubs.

Trampling may cause soil compaction which in turn favours certain species not normal components of grassland such as Polygonum aviculare and Plantago major. Excessive trampling causing poaching of the sward can lead to the ingress of generally undesirable species like Cirsium arvense and Senecio jacobaea. Total poaching as occurs around gateways, water and feeding troughs often leads to colonisation by Chamomilla suaveolens and very occasionally the rare Myosurus minimus. Trackways of bare soil, particularly in grasslands on a light loam soil are regarded by many as an eyesore and potential sources of erosion. To the wild life manager these may be seen as being of direct benefit by offering nesting sites for certain solitary bees and wasps. Indirectly such paths can provide a zonation of vegetation with the exact composition depending on the substrate. On chalk slopes Thomas (1959) found that livestock grazed above the path and defecated below the path giving rise to distinctive lines across the slope of Bromus erectus and Avenula spp. Other zonations on tracks in upland pastures show progression from Lolium perenne, Trifolium repens through Agrostis capillaris to Anthoxanthum odoratum and Holcus lanatus (Bates 1935).

Manurial effects of grazing by cycling the nutrients within a grassland system are of great importance. In an ideal system nutrients would be returned to the spot where they were produced and for sheep and cattle this is roughly so. Horses tend to utilise one part, often a corner of an area, thus creating an excess of nutrients leading to eutrophication and ingress of species like Urtica dioica and Rumex obtusifolius. It is likely that the element mainly responsible is phosphorus rather than nitrogen. The former being excreted almost entirely in the dung, at least in sheep, (Herriott and Wells 1963) whilst most nitrogen is excreted as urine. This particular instance of massive faecal returns effecting a botanical change is exceptional. The normal situation with cattle and sheep is for manurial returns over the season to be much more uniform. In these circumstances the nutrient cycle of a system is maintained. It should be noted that the increase in weight put on by stock over the grazing season is mainly accounted for by the four elements naturally 'on tap' to plants namely carbon, oxygen, hydrogen and nitrogen.

Apart from cycling nutrients, dung has another function in providing a small, but important, habitat for certain fungi and coprophagous insects which in turn provide feeding sites for a number of birds notably the yellow wagtail (Motacilla flava flavissima) which is closely associated with cattle grazed pastures.

CUTTING

Unlike grazing, cutting is non-selective and dramatic in its effect on vegetation structure - here today, gone tomorrow. Many entomologists believe this abrupt change to be detrimental to the invertebrate interest. Unfortunately there has been little work on the role of hay meadows for invertebrate conservation. Whatever the pros and cons of the value of traditional hay meadows for invertebrates, no doubts exist about the floristic richness which exceeds that of any other type in Britain.

Natural selection, following a long continued management operates in favour of those species which are adapted to hay cutting with grazing either before shutting up for hay in the North or after in the South. Species like Bromus racemosus, Geranium sylvaticum, Sanguisorba officinalis and the rare Fritillaria meleagris can flourish under a hay regime. More frequent cutting is likely to reduce species numbers although many low growing species are able to survive, as in many semi-roughs on golf courses.

Reasons for removing cut material are debatable. It is argued that if left on site mineral enrichment will occur. I disagree, as with manurial effects, nutrients are being re-cycled not augmented. However the physical effect of mulching can lead to heating up by fermentation plus exclusion of light causing burning of the sward. For these reasons cuttings should be removed when the quantity being returned is likely to smother the sward.

BURNING

Heather communities have for long been extensively managed by burning to provide low young shoots suitable for sheep but particularly grouse. The role of fire in influencing the nature of grassland vegetation remains controversial. In semi arid regions it is a well established practice (Campbell 1960) and it has for long been a major factor in shaping the structure and composition of Southern African grasslands (Hall 1984). Its use in Britain is debatable. Green (1983) argues persuasively for its use but some are yet to be persuaded that fire is anything other than a reclamation, rather than a maintenance technique for most grasslands. It is used regularly on some of the Cotswold commons where burning (swaling) is carried out early in the year to control Brachypodium pinnatum.

An important effect of fire is the creation of small areas of bare ground providing good establishment conditions for both annuals and perennials from seed. In heathlands a quick burn, where the soil temperatures are raised but not excessively, stimulates germination of heather seeds. The effect of burning on invertebrates, particularly in their larval form is difficult to assess. Burning only occurs when sufficient combustible material (plant litter) is available. The removal of this by burning may not necessarily kill larvae direct but loss of cover may expose them to predators and climatic rigours.

FERTILISERS

These are used to increase production. Of the botanical components of a semi-natural grassland only a few are capable of making use of the higher nutrient levels afforded by applying nitrogen, phosphate and potash. Lolium perenne, Dactylis glomerata and to a lesser extent Alopecurus pratensis, Bromus hordeaceus, Festuca rubra and Holcus lanatus are the main species of grasses which can survive some additional nutrients. Similarly only a few herbs can tolerate fertiliser applications. The result is a more productive sward with reduced interest for wildlife.

It is important when evaluating a site for nature conservation not to get carried away with the 'numbers game'. It is often assumed, even by some conservationists, that the more species a site contains the 'better' it is for nature conservation. In some cases this is not so. In site evaluation only those species naturally associated with the community are important. Those which are not normally associated with that community, but which come in as a result of mismanagement should not be counted in any positive assessment of a site. Indeed there is a good arguement for their being given a negative assessment, indicating that all is not well with the site. The degree of naturalness of the community is a further point to be evaluated. Naturalness, defined as being unmodified by human influence, is a rare condition in Britain and confined to some cliffs and mountain tops. However the converse of this ie. communities sown or planted by man, have a low conservation value for these can readily be produced when required. A sown ryegrass sward even when invaded by Stellaria media and Holcus lanatus is of low wildlife value. Indeed within the context of where this paper is published the sward could be described as 'weedy'.

At this point may I register my objection to the misuse of the word weed. One definition of a weed is a plant out of place. The 450 or so grassland plants can hardly be said to be out of place in grassland. Another definition is an unwanted plant. This leads to the attitude that every effort must be made to remove all unwanted species regardless of any value they may have to agriculture. Many herbs are quite inoffensive and some are positively beneficial. They are likely to disappear in the end with continued fertiliser use but one should not hasten their departure by using herbicides because they have been called weeds.

The most widely used fertiliser on grassland is nitrogen which in grasses encourages tillering and leaf production. The species favoured most is Lolium perenne, which is absent from many semi-natural grasslands, but does occur in small quantities in swards on deep fertile soils. When such swards receive nitrogenous fertilisers a change in botanical composition takes place, leading at first to an increase in Festuca rubra, later such species as Alopecurus pratensis and/or Bromus hordeaceus and finally to the dominance of L. perenne. The speed and culmination of this process depending on the amount of fertiliser applied per annum. Like most biological changes this is a general result with individual cases showing variation due to pH, soil water, management and a host of other factors speeding or retarding the process.

As an agricultural student at Newcastle I was brought up on a 'diet' of Basic slag and wild white clover. The fact that phosphates encourage legumes may be thought to favour the application of phosphatic fertilisers to swards with wildlife interest. Unfortunately phosphates are yet a further example of harm coming from the introduction of extra nutrients into a system. Although increasing the proportion of legumes, phosphates suppress certain Carex spp and some orchids, and the higher nutrient levels arising from increased legume activity may reduce species diversity still further.

It appears that potash acts only as a limiting factor but this is not certain. Some will no doubt seize on this as a reason for more experimental work to find the answer. Bearing in mind the many variables involved and the scarcity of the habitat it is understandable that the conservationist, if not the scientist, says enough is enough. Small comfort to the former to be able to shout 'Eureka' as the last remaining semi-natural grassland succumbs to a fertiliser trial.

HERBICIDES

These are designed to kill plants and this is unlikely to endear them to wildlife conservationists. I have long held the view that herbicides have no place in a maintenance role on nature reserves. If a case for their use can be made out there is invariably a stronger case to be made for a re-appraisal of the overall management plan. It would be stretching credulity too far to conceive of a situation which required herbicides for its continuation rather than methods developed and practised over the last thousand or more years.

However, as the paper by Marrs (ibid) points out, conservationists can make use of certain herbicides to achieve their ends. These are where years of neglect have left the habitat in a condition where reclamation is required to save it. An example would be part colonisation of grasslands by shrubs. Reference should be made to Marrs's paper for which chemicals and methods to use bearing in mind the indirect as well as direct effects of the treatment. Bracken is a constant threat to a number of wildlife habitats and achieving its control over large areas is difficult and sometimes impossible for conservationists as well as farmers. Asulam kills bracken but it kills other ferns as well, many of w ich have a high conservation value. This is not always understood, neither are the indirect effects brought about by the removal of the bracken cover. This is an appropriate point at which to remind ourselves that bracken is part of the British flora, and although its extinction is not likely to be brought about it must not be forgotten that several species are dependant on bracken and many more, including the uncommon Nightjar (Caprimulgus europaeus europaeus) use bracken areas in particular for nesting and shelter.

Unfortunately producers of herbicides use two words, specific and safe, in different ways to those used by wildlife conservationists. Herbicides are sometimes quoted as being specific for a species meaning that the chemical is marketed for the control of that species. Many botanists relate the word specific to species and assume wrongly, that the herbicide will affect only that species. 'Kills 99% of all known herbs' might be against the Trades Description Act but phrases which suggest the wider effects of herbicides would be helpful. I understand the word 'safe' in herbicide language refers to its likely effects on man or some other named animal. To many conservationists, the word 'safe' implies that a herbicide can be used on a nature reserve without any effects other than on the target species.

In a recent paper, Bunyan et al (1980) gave a review of herbicide usage and its implications for safety and the environment. On environmental hazards they stated, "A number of environmental problems have been traced to the use of insecticides. These have occurred either because of their acute toxicity or through their propensity to be transported in various physical or biological systems and cause chronic effects in certain species or ecosystems often far removed temporarily and spatially from the site of action. Because of their generally low acute toxicity herbicides have received little comparable attention, but they undoubtedly have the potential to cause changes in the environment and there is some evidence that they do so" and later concluded, "although the safety record of herbicides has been reasonable, there is no cause for complacency. Increasing use and changing application methods suggest that continuing thought must be given to minimising non-target exposure." The introduction of weed wiper and glove applicators is to be welcomed for by these means a herbicide can be applied to the target species only. For the conservationist these methods plus a chemical that killed only one species would be approaching perfection. It is recognised that specific, in the botanical sense, herbicides may be uneconomic but does this really apply to Senecio jacobaea and Cirsium arvense? Both become invasive following mismanagement of grasslands, often as the result of changing agricultural policies or prices. An otherwise harmless change from sheep to cattle may encourage S. jacobaea. This is followed by pressure to eradicate it by use of herbicides which also remove other innocuous and often beneficial species. A specific herbicide controlling only these two species would be welcome and widely used.

Management for wildlife clearly takes account of, and acts on, plants making up the habitat but management must also take into account the faunistic components of the system, mainly invertebrates and birds. There are few vertebrates dependant on a particular vegetation type and most can adapt to a similar structural system if required.

INVERTEBRATE AND BIRD REQUIREMENTS FOR MANAGEMENT

Invertebrates are dependant to a large extent on sward structure as was illustrated by Duffey (1962) who noted that spiders used grassland plants to construct webs, to construct egg-cocoons, for hunting, and for platforms from which to become airborne. Those invertebrates which are in their larval stage specific feeders are at greatest risk from a drastic change in botanical composition. This is increased when the requirements of the adult for shelter and nectar are considered. The larvae of the Adonis blue butterfly (Lysandra bellargus) feeds on Hippocrepis comosa, but the presence of this plant on a windy site with little nectar supply for the adult is of no use to the Adonis blue. Similarly the Duke of Burgundy fritillary (Hamearis lucina) lays its eggs on the underside of the leaves of Primula veris. This is possible when the leaves grow upright as occurs when the plant is growing in tall grassland or under scattered shrubs, but difficult in tightly grazed pastures where a rosette of leaves pressed to the ground is produced. Many invertebrates are associated with particular parts of plants, leaves, shoots, buds, flowers, seeds so a steady supply of these is required. This may well mean some form of rotational management, the length of the rotation depending on the species and the growing conditions.

Birds have no specificity for one food plant although certain genera of plants are eaten by various groups of bird species: eg Teal (Anas crecca crecca) and Pintail (Anas acuta acuta) seek out the seeds of Carex, Polygonum and Rumex (Thomas 1982). Waders feeding on soil invertebrates are affected more by soil conditions enabling bill penetration than the vegetation cover, although the vegetation associated with the required high water table is more likely to be Alopecurus geniculatus and Glyceria fluitans than Lolium perenne. Many birds frequenting wet areas for food prefer to do so in short rather than tall rank vegetation. An unmanaged area of Glyceria maxima is unlikely to support many birds and its structural control is therefore of some importance in nature reserves primarily for birds. Ground nesting birds are influenced by habitat structure, or lack of it. Some, like the Ringed Plover (Charadrius hiaticula hiaticula) and Stone Curlew (Burhinus oedicnemus oedicnemus) preferring little cover, others like Shoveler (Spatula clypeata) and Garganey (Anas querquedula) preferring a tussocky sward. Although horse grazing has limitations on botanical grounds it does lead to a tussocky sward and should be considered where ground nesting birds are a primary objective. Stocking numbers require to be low to reduce trampling of nests and also to cut down on disturbance of the sitting bird which may lead to predation of the nest or young, by crows in particular.

CONCLUSION

The main ecological management requirements for herbs and grasses are to have aerial portions removed annually; and to be supplied with nutrients equal to those removed and to seed and establish. For invertebrates and birds, attention is necessary to provide food plants or feeding areas plus shelter for all stages in the life cycle.

Each species of plant and animal is part of the crop we call wildlife. Unlike agriculture and forestry crops which tend to be mono-cultures, wildlife crops are multi-species. The aim of wildlife management is not to achieve maximum production, either of yield or of numbers but simply to achieve the continuation of those species which should naturally occur in a given habitat. In the past the proportion of wildlife habitat (= semi-natural) to cultivated land (= arable and ryegrass leys) in any given time period was high. The revolution in agricultural technology since 1940 has brought about a situation not previously encountered. Three factors are mainly responsible: the high increase in chemicals added to the various cropping systems; the enormous advances in agricultural technology overcoming natural physical drawbacks; and the abandonment of rotational cropping systems designed to maintain soil fertility by stock. All these have resulted in wildlife now being confined to relatively small areas, often as isolated 'islands'.

The long term effects of high inputs of chemicals into current cropping systems is no doubt being monitored. The environmental objective should aim at not introducing the present vogue for a high input/output system into those areas currently managed on a low input/output and therefore likely to be of value for wildlife. To switch from low input/output to high input/output is easy and rapidly achieved. The reverse is fraught with problems and for many farmers may be impossible - the tread mill is easier to get on than get off.

There is an urgent need to halt the loss of wildlife habitats and to manage the areas that remain to the best of our ability so that this crop can yield its full potential and usefulness to present and future generations.

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HERBICIDES AND THE DECLINE OF THE PARTRIDGE: AN INTERNATIONAL PERSPECTIVE

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ABSTRACT

Partridge (Perdix perdix) diet, population ecology and the abundance of its foods were monitored on a 62km^2 ha area of farmland to the west of Brighton, Sussex from 1969 to 1984. Chick mortality rates were measured each year and found to be determined by the availability of their preferred insect food in cereal crops.

By removing host plants for insects, herbicides reduced the amount of insect food for chicks, increased chick mortality rates and in turn reduced the size of the partridge population.

In the world range there were each autumn about 120 million partridges prior to the use of herbicides, this number has now declined by an estimated 75%. In Britain the most important cause of the reduced partridge numbers has been the use of herbicides and this could be the case in other countries.

INTRODUCTION

Since the earliest observations on the partridge (Perdix perdix) it has been clear that the species obtains most of its food in cereal crops. Thirty-five detailed studies on the diet of the species have now been published and although only six give much data on chicks, the position is clear. The adults prefer to eat weed seeds, especially those of Polygonum spp., and the chicks prefer insects, especially plant bugs, sawfly larvae, leaf beetles and weevils.

The initial concern that pesticides could be harmful to partridges dates back to 1844 (Hawker 1922), but adverse effects only became important with the advent of the di-nitro-ortho-cresol herbicides. Used from 1935, but especially in the early 1950's, these killed both adult partridges (e.g. Soyez 1978) and insects (Johnson et al 1955).

When safer herbicides, such as MCPA and 2,4-D, were introduced concern switched to the indirect ecological effects of pesticides: weed seeds might disappear, insecticides might reduce the supply of insect food, and so on (e.g. Lynn-Allen & Robertson 1956, Wentworth-Day 1957). However at the time it was not realised that herbicides could, by removing the food plants of many insects, also have an effect equivalent to that of the insecticides. Such an indirect effect was apparently first described in Hungary in 1960 (see Ubrizy 1968), but it was Southwood & Cross (1969) who drew attention to it and who first linked it to partridge chick survival.

Subsequent work at the Game Conservancy has quantified these effects of herbicides, and shown, by experiments, that the indirect effects of herbicides on the insect foods of the chicks is currently a major limiting factor for many partridge populations in Britain (Potts 1980, Rands 1985).

The partridge occurs in 31 countries and has declined in numbers wherever populations have been monitored. This short paper considers the extent to which herbicides might be the cause of the current low numbers of partridges throughout their range, in Europe, North America and Asia.

METHODS

Since 1956 the Game Conservancy has carried out a study on the population ecology of the partridge on a 62 km^2 area of farmland a few miles to the west of Brighton. Detailed studies began on this site in the spring of 1968 with the establishment of the Partridge Survival Project. The main aim was to determine the cause of the high chick mortality rates which had become apparent during the 1960's, and to see what could be done to reduce them. The study area and basic methods used are described in detail in Potts & Vickerman (1974), with further methods including population simulation modelling being described in Potts (1980). The densities of weeds and insects have been measured in 100-150 cereal fields per year in the third week of June, in the same way each year, for the past 16 years. The insects were sampled with a Dietrick vacuum insect net. Estimates of chick mortality up to the age of six weeks were made for each of five groupings of farms in the study area throughout this period. Detailed records have been kept of all pesticides used.

Since 1932 the Game Conservancy has organised counts of spring stocks of partridges and further counts in August on about 50 estates throughout Britain, from which estimates of chick mortality rate have been made (Potts 1978). There is a gap in this data during the period of World War II, but the partridge is one of the very few species whose population dynamics were established prior to the use of modern pesticides.

A thorough search of the literature was made in order to obtain information on the ecology and status of the partridge in other countries, with follow-up visits to most of the study areas used there.

RESULTS AND DISCUSSION

Value of insects

The evidence that chick mortality rates vary in response to the abundance of their insect food in cereal crops, can be summarised as follows:

1. Extensive correlations between the chick mortality rate on the Sussex study area and the measured density of preferred insect food on this area. The correlations were consistent spatially (between farms) and temporally (between the years 1969-1984 inclusive) (between-year data are plotted in Fig. 1 ($P<0.02$)). Chick mortality rates were not related to non-preferred insects.

2. The correlations established in 1 have been verified by experiments which altered the amount of insect food available to the chicks (reductions by using insecticides and increases by not using herbicides (Moreby & Potts 1985, Rands 1985)).

3. Feeding trials, the digestibility of plant food eaten by chicks (Green 1984) and consideration of the need for certain amino acids (methionine and cystine) (Potts in prep) confirm that insects are normally essential to ensure the growth of the young chick.

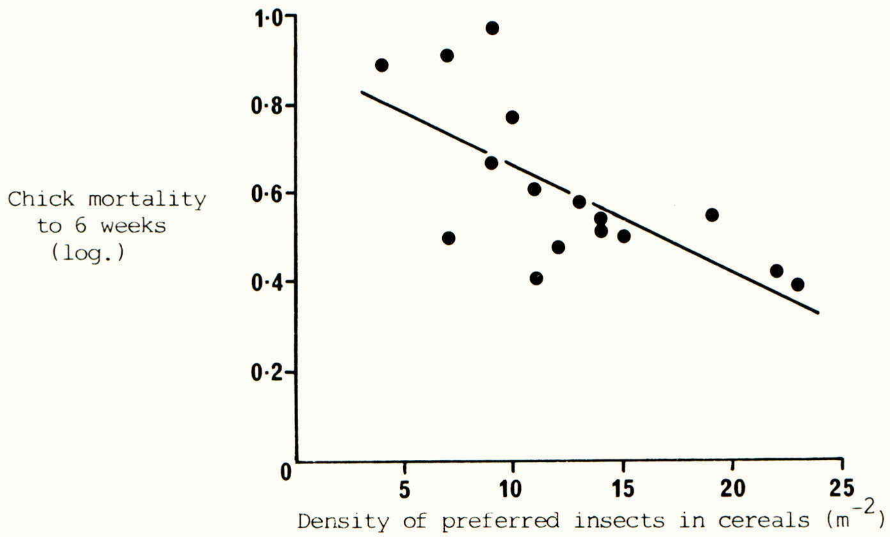

Fig. 1. Chick mortality is lower when the density of preferred insects is higher. Sussex: years 1969 to 1984.

Long-term increase in chick mortality rates

The evidence that chick mortality rates have increased since 1952 is summarised in Fig. 2. The upward trend in Britain, monitored by the Game Conservancy, is statistically significant with the main change occurring between 1952 and 1962, as herbicide use increased (Potts 1984 and Fig. 3).

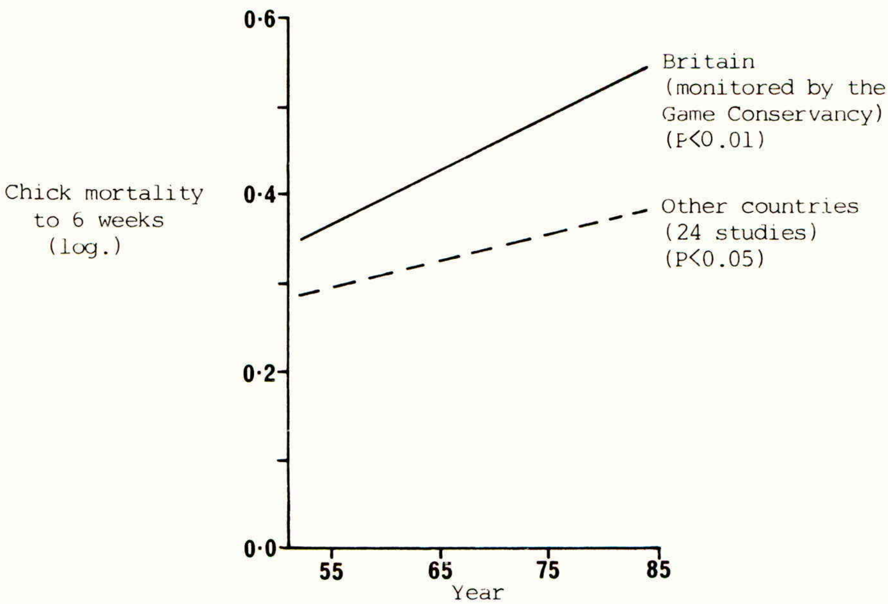

Fig. 2. Trends in chick mortality since 1952.

The literature search yielded 24 studies from which chick mortality rates could be estimated. All studies were of relatively short duration, many being of the PhD. type i.e. for three seasons, which is inadequate for the calculation of trends. However the overall trend through all the studies combined was statistically significant ($P<0.05$).

Chick mortality rates tend to be lower in the mid-continental areas of North America and Europe which are warmer in the chick-rearing period than Britain. In Sussex we found that for a given level of abundance of insect food for the chicks, chick mortality fell as post-hatch temperatures rose. However, temperature fluctuations explained only 12% of the annual variation in chick mortality rates in this study, and higher densities of insects such as grasshoppers, scarce in cereals in Britain, may also have contributed to the differences between Britain and the areas studied overseas.

Increase in the use of herbicides

Where national data on pesticide use is available at all, it has been collected and calculated in different ways. As a result it has only been possible to give a rather crude estimate of the proportion of cereals sprayed at least once for Britain (Woodford 1964), Denmark, Germany (F.R.D. and D.D.R.), Finland, U.S.A., and (with incomplete data) Russia and Hungary.

Nevertheless it is clear (Fig. 3) that the introduction of herbicides to cereals took place earlier in Britain than elsewhere, and that the overall position overseas is now similar to the point reached in Britain in 1962.

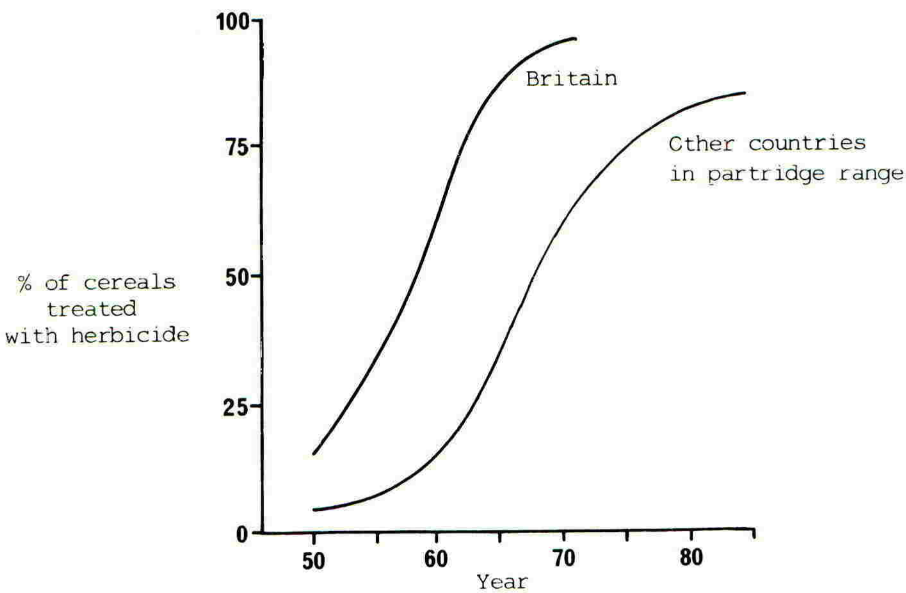

Fig. 3. Trends in herbicide use on cereals.

Summer use of foliar insecticides on cereals is rising quickly but still involves a rather small percentage of the total cereal acreage - recently exceeding 20% only in England (in aphid years), France and parts of southern Russia. More data would be welcome on this and other use of pesticides on cereals from countries not mentioned here.

Decline of breeding stocks of the partridge

The mean decline of spring stocks as monitored by the Game Conservancy is given in Fig. 4, with the overall decline since 1952 amounting to 72%. Trends in the spring stock from the studies in the literature (Europe and North America Fig. 4) amounted to 60%, but the trend was not statistically significant (P>0.05). However, trends monitored in Eastern Europe and the one long-term study from North America show similar declines to those monitored in Britain (Fig. 4). Other, independent, data on numbers shot confirm these trends, and suggest an overall decline in the world partridge population approaching 75% over the period 1952-1984. Prior to the use of herbicides, in early autumn, numbers were about 120 million (Potts *in prep*).

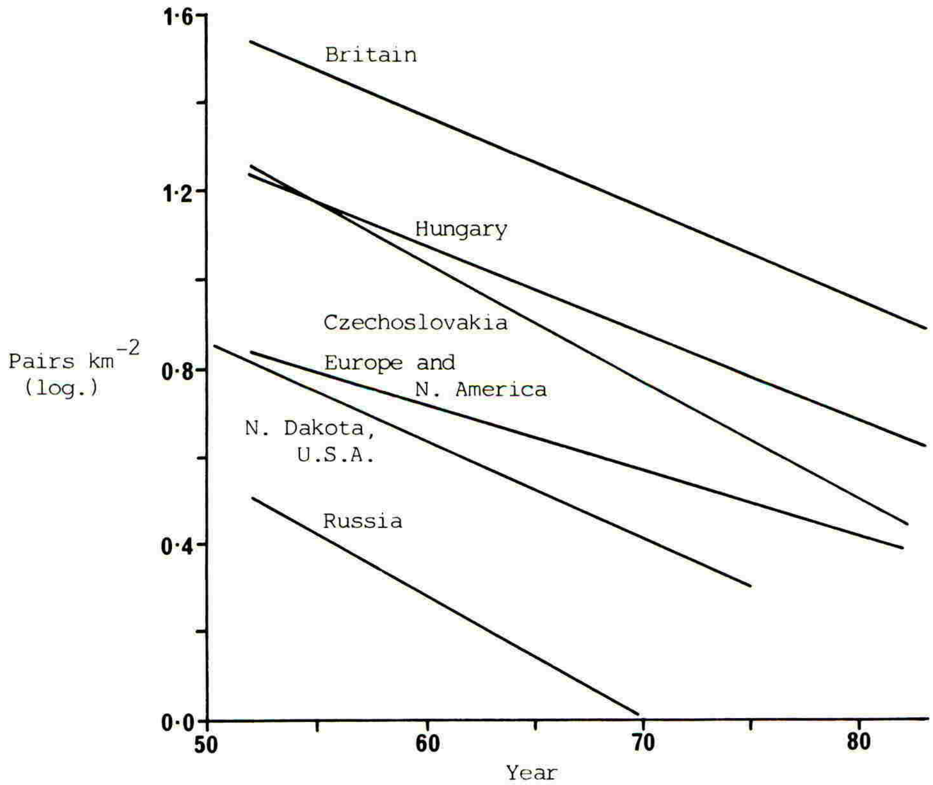

Fig. 4. Trends in partridge pair densities since 1952.

Simulation model

The chick mortality rate is of course only one part of the total population dynamics, and there is compensation for variation in chick mortality rates at several points in the annual cycle. For example shooting is often curtailed altogether after a poor season for the chicks (Potts 1980).

A simulation model has therefore been developed to incorporate all the important features in the population dynamics (Potts 1980). This model has successfully predicted annual variation in population parameters (except chick mortality rates which were entered annually) since 1976. The model shows that the increase in chick mortality rate recorded by the Game Conservancy's National Game Census could directly explain 75% of the decline in spring stocks.

Hypothesis

Accepting the above explanation for the decline in Britain, together with the evidence presented from other countries, a hypothesis for the whole world range can be proposed: that the major cause of the decline of partridge densities is an increase in chick mortality rates, resulting from the adverse effects of pesticides (mainly herbicides) on the insect food of the chicks in cereal crops.

The evidence so far, and particularly from experiments and techniques such as those described in the next paper (Sotherton, Rands & Moreby 1985), indicates that the hypothesis is correct for many arable areas in Eastern Britain. Certainly the connection between pesticide use and chick survival rate is confirmed. The simulation modelling suggests that if the policy of not spraying cereal headlands was repeated nation-wide, the partridge population would recover to equilibrium levels determined by nest predation, and by the extent and quality of nesting cover (see Potts 1980). However numbers would not necessarily be restored to the 1952 level, if herbicides were no longer used. In Sussex the initial cause of the partridge decline seems certainly to have been herbicide use, but this reduced the effectiveness of predator control by gamekeepers. The gamekeepers therefore turned their attention to rearing pheasants and nest predation then became the main limiting factor.

In Eastern Europe, more than anywhere else, increased nest predation and shortage of nesting cover are likely to have contributed to the partridge decline. There, the changes from almost feudal estates with extensive predator control by gamekeepers and small fields or strips to the unkeepered very large fields of the modern state and collective farms, has been dramatic. Yet, astonishingly, the partridge population decline rate in Czechoslovakia and Hungary over the period 1952-1984 (Fig. 4) is the same as that in Britain with its well-hedged and keepered estates of the kind monitored by the Game Conservancy. The downward trend in numbers, to the same extent but much later than in Britain, is in line with expectations from the hypothesis, but it could be that the widespread reduction of nesting cover in the collectivized agricultures of Eastern Europe has offset the effects of a lower level of use of pesticides there. More data on pesticide usage, especially from Russia, might settle the point. Lower rates of partridge decline in parts of North America especially the Prairie provinces of Canada reflect the lower use of herbicides there.

CONCLUSION

The picture of the decline of the partridge is probably clearer than that for any other species of threatened wildlife on farmland.

Nevertheless, many pieces of the jigsaw are still missing. The reasons why this is so need to be recognized, given the current interest in and concern about the adverse effects of modern agriculture on farmland wildlife.

The lack of continuous monitoring programmes for wildlife on farmland is at the root of the difficulties. Many, or even most, supposed long-term changes have not been properly quantified and defined. The main worry arising from our Sussex monitoring is the steady decline for the past 16 years in most species of insects in cereal crops; cereal thrips may be the only notable exception.

Our monitoring is so far as we know unique, but the same kind of trends may have occurred throughout the huge cereal growing areas in Britain and internationally.

The partridge population depends on modern cereal crops, and may continue to decline unless something is done to prevent this - the subject of the next paper.

ACKNOWLEDGEMENTS

This work is part of the Partridge Survival Project of the Game Conservancy. A large number of people have helped with this project over the years and I am very grateful to them.

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Note

A Monograph on the grey partridge has been prepared which contains a full bibliography.

COMPARISON OF HERBICIDE TREATED AND UNTREATED HEADLANDS FOR THE SURVIVAL OF GAME AND WILDLIFE

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ABSTRACT

The benefits of unsprayed headlands in cereal fields to game and wildlife were investigated in the U.K. in 1983 and 1984. Six metre strips around the edges of cereal fields were left unsprayed with all pesticides (herbicides, fungicides and insecticides) from 1 January until harvest. Comparisons were made of the weed flora and associated insect fauna of unsprayed headlands and of equivalent sprayed headlands.

Total weed densities and total weed cover scores were significantly higher in unsprayed headlands and, in both years, the insects preferred by gamebird chicks were found in significantly higher numbers in unsprayed headlands compared to sprayed headlands. These increases were reflected in the increases in grey partridge brood sizes in 1983 and 1984 and pheasant brood sizes in 1984. Increases in the numbers of butterflies between treated and untreated areas are reported, and other areas of research concerned with unsprayed headlands are discussed.

INTRODUCTION

Few herbicides currently approved for use in cereal fields are directly toxic to farmland wildlife. However, weed removal by herbicides has been shown to have indirect effects upon a number of species, particularly gamebirds (Potts 1984, 1985) and some songbirds (O'Connor & Shrubb 1985). These effects act both via the removal of the weeds themselves and via the removal, or changes in the composition, of the insect fauna of cereal fields (Potts & Vickerman 1974, Vickerman 1974, Sotherton 1982). The use of pesticide-free cereal headlands has been shown to be of benefit to the production of wild grey partridges (*Perdix perdix*) and pheasants (*Phasianus colchicus*) (Rands 1985, in press) and could offer a possible compromise between the demands of high imput, intensive arable farming and the needs of farmland wildlife conservation. This report describes the weed flora and the associated insect fauna of unsprayed compared with sprayed headlands, and discusses some of the implications for other forms of farmland wildlife.

MATERIALS AND METHODS

Study area

The principal study area was part of an 11km^2 mixed farm in north-east Hampshire (G.R. SU5852). The farm was divided into six trial plots, two plots in each of the three gamekeepers' beats. In 1983 and 1984, in one plot per beat, a 6m strip around the edge of every field was left unsprayed with pesticides from 1 January until harvest. In the other plot of each beat, the entire area of each field was sprayed. The scale of the pesticide exclusion experiments are given in Table 1.

TABLE 1

The number of fields, plot sizes and areas of crop unsprayed in the 1983 and 1984 pesticide exclusion experiments.

Year	Unsprayed plots			Sprayed plots	
	No. of fields	Plot sizes (ha)	Unsprayed area (ha)	No. of fields	Plot sizes (ha)
1983					
Beat 1	7	94.9	4.9	9	129.9
Beat 2	3	31.6	1.9	3	32.2
Beat 3	8	125.3	7.1	7	107.0
Total	18	251.8	13.9	19	269.1
1984					
Beat 1	10	148.1	7.7	8	130.3
Beat 2	6	59.5	3.6	3	36.4
Beat 3	9	108.5	6.2	6	53.8
Total	25	316.1	17.5	17	220.5

Pesticide applications

In the autumn of 1982 and 1983, most winter-sown cereal fields were sprayed with herbicides, fungicides and insecticides and fields destined to be sown with spring barley the following year were treated with a broad-spectrum herbicide. In all fields, no part of the field remained unsprayed at this time of year. The treatments of the plots in 1983 were reversed in 1984, i.e. those fields having unsprayed headlands in 1983 were fully sprayed in 1984 and vice versa. The pesticides omitted from the headlands are listed elsewhere (Rands 1985, in press).

Weeds

In 1983 and 1984, estimates were made of the density of grass and broad-leaved weeds in cereal field headlands both unsprayed with herbicides or fully sprayed in the usual manner. In 1983, one assessment of weed density was made in mid-June in a total of thirty-four cereal fields covering a range of winter and spring sown crops. In each headland, 3m from the crop edge, the weed plants from each of 10 x $1m^2$ quadrats were recorded.

In 1984, two assessments of weed cover/density were made in a total of sixteen spring barley fields. The very dry weather conditions in the spring reduced the germination rate of many species of spring weeds with the result that the autumn applications of herbicides to winter-sown crops gave sufficient weed control to necessitate no further herbicide spraying in these fields the following spring. In 1984, weed assessments were therefore made in spring barley fields only. In May, broad-leaved weeds were scored according to cover on a 0 to 3 point scale in each of 10 x $0.25m^2$ quadrats in each headland 3m from the crop edge. In addition, grass weed panicle densities were counted (m^{-2}) in May and July, at the same distance from the crop edge.

Insects

The insects available to wild gamebird chicks in sprayed and unsprayed headlands were sampled from the north-east Hampshire study farm in 1983 and 1984. In 1983, one headland in each of the thirty-seven cereal fields was sampled for insects, whereas in 1984, thirty-four cereal field headlands were sampled. In addition in 1984, thirty-eight headlands from a farm in Suffolk and sixteen headlands from a farm in south-west Hampshire were sampled for insects. In all cases, insects were sampled with a 1.0 x 0.4m sweep net. Fifty sweeps were made per field edge in 1983, and twenty sweeps per field edge in 1984. Samples were sorted and counted as described by Green (1984).

Gamebirds and butterflies

The size and composition of coveys of wild gamebirds were recorded by making systematic counts on plots with or without unsprayed headlands, after the crops had been harvested. This was carried out on the north-east Hampshire study farm in 1983 and 1984 as well as on eight other farms in the Eastern Counties in 1984.

Butterflies were counted on two plots (c. 220ha) of the principal study farm. The relative abundance of butterflies was measured using the transect recording methods described by Pollard *et al* (1975) and Pollard (1977). The transect route was counted at least once a week from mid-May to harvest and the route was chosen to include seven sprayed and seven unsprayed cereal field headlands. To compensate for differences in butterfly numbers arising from variation in field boundary type and aspect, sprayed and unsprayed headlands with similar adjacent habitats were paired.

RESULTS

In 1983, 4 species of grass weeds and 9 species of broad-leaved weeds were recorded in sprayed cereal field headlands compared with 5 grass weed and 14 broad-leaved weed species in unsprayed headlands. Table 2 lists the weeds recorded and gives their mean densities on sprayed and unsprayed headlands. Considered species by species, 2 broad-leaved weeds and 4 grass weeds occurred at significantly higher densities and overall both groups of weeds were much more abundant on unsprayed headlands.

In 1984, 3 species of grasses and 9 species of broad-leaved weeds were recorded in sprayed spring barley headlands compared with 3 grasses and 21 broad-leaved weeds in unsprayed headlands. Significantly greater total scores of broad-leaved weeds were found in the May survey of unsprayed spring barley headlands than in sprayed headlands. (Table 3). Where weeds scores were recorded in sprayed headlands, they were often as high as those found in unsprayed headlands. No significant differences were found in either grass weed densities or grass weed panicle densities (m^{-2}) between sprayed or unsprayed headlands (Table 4).

TABLE 2

Mean densities (m^{-2}) of all weeds in sprayed and unsprayed headlands, June 1983.

Weed Species	Sprayed headlands (n = 16)	Unsprayed headlands (n = 18)	t_{32}*	P.
Broad-leaved				
Fumaria officinalis	0.0	1.9	0.95	NS
Galium aparine	0.1	0.0	- 1.03	NS
Polygonum aviculare	1.1	14.4	1.81	NS
Bilderdykia convolvulus	0.0	0.1	0.95	NS
Stellaria media	3.2	13.3	1.57	NS
Myosotis arvensis	0.0	0.5	1.75	NS
Veronica persica	1.4	19.9	3.39	<0.01
Matricaria perforata	0.5	12.8	2.51	<0.02
Sonchus oleraceus	0.4	0.2	0.13	NS
Viola arvensis	0.06	0.1	0.28	NS
Aphanes arvensis	0.1	15.1	1.26	NS
Crepis capillaris	0.0	0.1	0.95	NS
Cirsium spp.	0.4	0.0	- 1.34	NS
Capsella bursa-pastoris	0.0	0.1	0.95	NS
Arenaria serpyllifolia	0.0	0.1	0.95	NS
Volunteer oilseed rape	0.0	0.2	0.95	NS
Total broad-leaved weeds	7.2	82.7	3.14	<0.01
Grass				
Poa annua	56.2	320.6	2.72	<0.01
Poa trivialis	3.2	20.7	2.83	<0.01
Alopecurus myosuroides	2.9	63.9	2.50	<0.02
Elymus repens	0.0	1.4	2.04	<0.05
Lolium perenne	0.1	0.9	0.97	NS
Total grass weeds	62.8	407.5	3.25	<0.01

*t tests calculated on ($\log_{10}$ n + 1) number of prey items

TABLE 3

Total species scores and average total of broad leaved weed scores per field found in sprayed and unsprayed spring barley field headlands, May 1984.

Weed species	Sprayed headlands (n = 9)	Unsprayed headlands (n = 7)
Papaver rhoeas	--	5
Fumaria officinalis	—	1
Sinapis arvensis	--	4
Galium aparine	--	1
Polygonum aviculare	12	12
Bilderdykia convolvulus	--	3
Chenopodium album	--	3
Stellaria media	10	12
Rumex obtusifolius	1	--
Myosotis arvensis	1	2
Veronica persica	6	13
Matricaria perforata	2	11
Lamium purpureum	—	1
Sonchus oleraceus	—	2
Viola arvensis	7	10
Atriplex patula	--	1
Convolvulus arvensis	1	4
Senecio vulgaris	--	1
Silene alba	--	1
Geranium robertianum	1	3
Volunteer oilseed rape	--	2
Total	41	92
Average total score per field	18.6	51.7

TABLE 4

Mean grass weed density and grass weed panicle density (m^{-2}) found in sprayed and unsprayed spring barley headlands, May 1984.

Weed species	Sprayed headlands (n = 9)	Unsprayed headlands (n = 7)
Poa annua	---	4.4
Poa trivialis	1.7	---
Poa pratensis	---	3.3
Bromus sterilis	0.3	---
Alopecurus myosuroides	9.1	10.6
Grass weed panicles *	9.2	11.0

(* maximum from May and July surveys)

On the principal study farm in 1983, the abundance of several preferred chick food insect groups in sprayed and unsprayed headlands is given in Table 5. In all groups, except the larvae of Lepidoptera and Tenthredinidae there were significantly higher prey densities where headlands were left unsprayed.

TABLE 5

The abundance of wild gamebird chick food insects in sprayed and unsprayed headlands on the north-east Hampshire study farm, June 1983.

Prey species	Mean (± one S.E.) number of prey items per fifty sweeps			
	Sprayed headlands (n = 19)	Unsprayed headlands (n = 18)	t_{35}*	P.
Heteroptera	53.89 ± 21.36	163.17 ± 44.77	2.74	<0.02
Tenthredinidae & Lepidoptera larvae	3.53 ± 0.98	4.95 ± 1.03	0.82	NS
Chrysomelidae, Curculionidae & small Carabidae	4.15 ± 0.47	12.33 ± 2.84	2.42	<0.05
Total prey	62.21 ± 21.45	180.00 ± 45.20	3.72	<0.001

*t tests calculated on ($\log_{10}$ n + 1) number of prey items

In 1984, a total of 88 headlands were sampled from three study farms (46 on sprayed, 42 on unsprayed). Unsprayed headlands contained significantly more chick food insects than sprayed headlands (Table 6) except in the case of Chrysomelidae, Curculionidae and small Carabidae.

TABLE 6

The abundance of wild gamebird chick food insects in sprayed and unsprayed headlands on three study farms, June 1984.

Prey species	Mean (± one S.E.) number of prey items per twenty sweeps			
	Sprayed headlands (n = 46)	Unsprayed headlands (n = 42)	t_{84}*	P.
Heteroptera	26.47 ± 5.82	49.19 ± 8.81	2.10	<0.05
Tenthredinidae & Lepidoptera larvae	3.67 ± 1.20	4.42 ± 0.83	2.40	<0.02
Chrysomelidae, Curculionidae & small Carabidae	5.39 ± 0.93	6.52 ± 1.25	0.61	NS
Total prey	34.41 ± 6.15	60.38 ± 9.62	2.32	<0.05

*t tests calculated on ($\log_{10}$ n + 1) number of prey items

In 1983 and 1984 on the principal study farm, mean grey partridge brood size was significantly higher on areas of cereal crops which had had their headlands unsprayed with pesticides from 1 January. Significant differences also occurred for the pooled data of the grey partridge brood counts from eight other East Anglian farms (Table 7). In addition, in 1984, significantly higher pheasant brood sizes were recorded on the principal study area where headlands were left unsprayed (Table 7).

TABLE 7

The benefits of unsprayed headlands to wild game birds and butterflies 1983 and 1984.

	Sprayed headlands	Unsprayed headlands	P.
Average grey partridge brood size			
north-east Hants. 1983	2.2	6.4	<0.01
north-east Hants. 1984	7.4	10.0	<0.05
East Anglia 1984*	4.7	7.8	<0.01
Average pheasant brood size			
north-east Hants. 1984	3.2	6.9	<0.05
Total number of butterflies recorded during 15 weeks	297	868	<0.001
Average number of butterflies recorded per week	19.7	57.9	<0.001

* Eight study farms

Total numbers of butterflies recorded on unsprayed headlands were significantly higher than those seen on sprayed headlands (Table 7). Species that appeared to benefit most were Common Blue (*Polyommatus icarus*), Large and Small Skipper (*Ochlodes venata* & *Thymelicus sylvestris*), Orange Tip (*Anthocaris cardamines*), Meadow Brown (*Maniola jurtina*) and Small Heath (*Cocnomympha pamphilus*).

DISCUSSION

Our results suggest that unsprayed areas within cereal fields are potentially useful for wildlife conservation on farmland. The headland appears to be the best position for such an unsprayed area, both in terms of the benefits to wildlife and the potential inconvenience to farming operations. Crop edges are the preferred feeding areas for partridge chicks (McCrow 1980, Green 1984) and potentially good feeding and breeding sites for other species of farmland wildlife. Herbicide-free headlands may also reduce the risk of spray drift into hedge bottoms and other uncultivated areas which already act as havens for wildlife. Some species of hedgerow nesting songbirds may benefit from increased insect abundance associated with weedy headlands. Also many species of butterflies may feed as adults, lay their eggs or rear their larvae on the weeds in headlands or hedgerow bottoms and potentially benefit from this technique. All these benefits of unsprayed headlands to wild game and wildlife are currently under investigation by staff working for the Game Conservancy's Cereals and Gamebirds Research Project. The possible reductions in farm profit arising from this technique are also being investigated. It is widely known that field edges adjacent to hedgerows and shelterbelts produce lower cereal yields compared to other parts of the field. Preliminary results suggest that headland yields are very similar (at least in the short-term) regardless of whether headlands receive pesticides or not in the spring and summer (Rands *et al* 1985).

ACKNOWLEDGMENTS

We are grateful to all the farm owners who have allowed us access to their farms for our experiments.

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FIELD AND FIELD EDGE FLORAS UNDER DIFFERENT HERBICIDE REGIMES AT THE BOXWORTH E.H.F. - INITIAL STUDIES

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ABSTRACT

The Boxworth Project is a multidisciplinary study of the economic and ecological effects of different levels of pesticide use in commercial cereal growing. The floras of three fields receiving three different levels of herbicide input at the Boxworth Experimental Husbandry Farm are described. Data on field and field margins from a baseline year and two treatment years for three fields are presented. The preliminary results show reductions in grass weed populations on the high input field where numbers of dicotyledonous species recorded in the fields were also lowest. There was evidence of a trend for increased species diversity in the field margin where fewest herbicides were applied.

INTRODUCTION

The multidisciplinary MAFF project on pest and disease control systems, based at the Boxworth Experimental Husbandry Farm, Cambridgeshire and known as the Boxworth Project, seeks to assess the economic and ecological consequences of different levels of pesticide use in commercially grown cereals. AFRC Weed Research Organization (now LARS Weed Research Division) became responsible in 1982 for advising on the use of herbicides and in 1983 for assessing the changes in the flora of both the fields and the field boundaries. The 120ha study area made up of 11 fields (Fig. 1.) is divided into three blocks receiving the following regimes:

1. Full insurance - receiving pesticides on a prophylactic basis. A high regular but realistic input is achieved.
2. Supervised - receiving pesticides only when pests achieve levels likely to affect yield. Decision thresholds are being used.
3. Integrated - receiving pesticides on the same basis as the Supervised area but husbandry and cultural operations are combined to further minimise pesticide use.

The treatment regimes were imposed for the 1984 harvest year and will continue to the 1988 harvest. Baseline data were collected in the 1983 harvest year. The data presented in this paper are a summary of some assessments taken over the initial and first two treatment years. Only an interim picture is therefore presented. Major conclusions should not be drawn at this stage, especially as no reference is made to the studies on invertebrates, birds and small mammals.

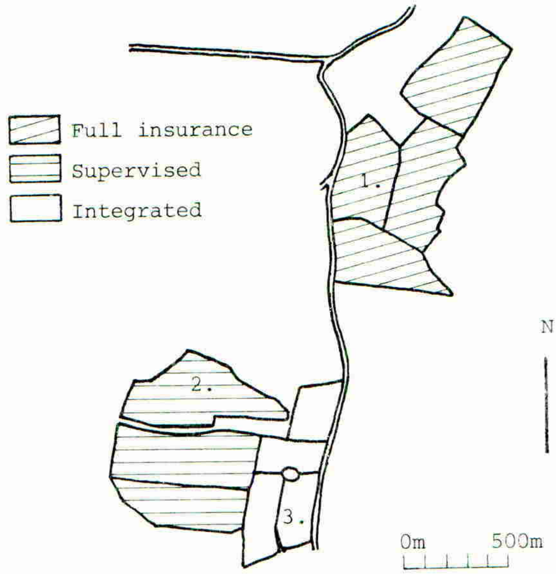

Fig. 1. The Boxworth Project study areas. 1=Grange Piece field; 2=Knapwell; 3=Extra close East.

METHODS

Plant population assessments were based on extensive surveys and intensive Study Areas for field and field margin floras. Data is presented from Grange Piece (1), Knapwell (2) and Extra Close East (3) fields (Fig.1), which are in the Full Insurance, Supervised and Integrated areas respectively.

Field floras

These were assessed by quadrat counting in November, March and July on a grid based on wheelings through the crop. The grid gave 6 points ha^{-1}; at each point four quadrats were counted. In July grass panicles were counted; broad-leaved plants were scored for cover on a scale: 1 = <1%, 2 = >1% <10%, and 3 = >10%. The diversity of the flora was estimated using the Information Index of Pielou (1966). The viable buried seed flora is to be estimated from selected 0.5ha areas within each field. First soil samples, 48 2.5cm diameter cores per area, were taken in 1984. Samples are germinated for two years in shallow clay pans in an unheated greenhouse (Roberts, 1981).

Field edge floras

These were assessed on a presence/absence basis at points every 50m around the defined perimeters of each field. A 2m wide transect running through the field boundary (mean length=3m) was examined at each point and the species present recorded. The mean number of species per sample point was estimated and an index of diversity calculated (Margalef, 1951). In addition, a subjective assessment of species cover and abundance in each perimeter length with different aspect has been made from 1984. The three fields described were of different sizes; the physical dimensions and numbers of sampling points are given below:

Field	Area(ha)	Field survey points	Edge survey points
Grange Piece	12.04	75	24
Knapwell	16.92	100	45
Extra Close East	5.69	38	17

Flora of Intensive Study Areas

On matched 50m hedge lengths, one in each treatment, intensive studies of insects, small mammals and plants are being conducted. The flora was assessed in autumn, spring and summer along 11 5m long transects per Study Area from the hedge base into the crop. In autumn and spring plants were counted in $0.25m^2$ quadrats divided into $0.01m^2$ squares. In summer the presence of vegetation was recorded in $0.01m^2$ squares along the 5m transect and 0.5m into the hedge. Buried seed populations were estimated from soil cores taken within the boundary and at 5m, 25m and 100m into the crop.

RESULTS

Herbicide applications

The use of herbicides in the three fields is given below in Table 1. Decreasing numbers of herbicide applications were made in the order Full Insurance, Supervised and Integrated.

TABLE 1

Herbicide treatments applied in three areas.

Treatment	Full Insurance Grange Piece 1984	1985	Supervised Knapwell 1984	1985	Integrated Extra Close E. 1984	1985
Pre-harvest	/	/	/		/	
Seed bed	/	/	/			
Autumn grass	/	/	/	/	/	/
herbicides	/	/	/	/	/	
Broad- leaved herbicide Autumn	/				/	/
Broad- leaved herbicide Spring	/	/	/	/		/
Wild oat control	/	/	/	/		
Number of applications	7	6	6	4	4	3

Field floras

Results of assessments of the field floras from 1983 to 1985 is given in Tables 2 and 3. Grass populations are described as panicle densities (m^{-2}) in early July (Table 2). Good weed control is evident on Grange Piece; only Bromus commutatus was recorded in the 1985 survey. There has been an increase in Bromus spp. on Knapwell field and the two species have maintained populations on Extra Close. On the latter field Elymus repens has reappeared after a year without a pre-harvest glyphosate application.

TABLE 2

Panicle densities (m^{-2}) of grasses in early July over three seasons.

Treatment	Full Insurance			Supervised			Integrated		
Year	83	84	85	83	84	85	83	84	85
Bromus sterilis	0.8	0	0	4.5	4.8	5.2	0.4	0.05	0.3
Bromus commutatus	2.7	0.4	0.4	5.4	4.4	9.4	0.5	0.6	0.4
Alopecurus myosuroides	1.4	0.01	0	0.8	0.3	0.04	19.4	16.7	5.6
Avena fatua	0.01	0	0	0.2	0.01	0.02	0.02	0	0
Elymus repens	0.9	0.08	0	0.5	0.2	0.3	0.2	0	0.4
Poa trivialis							0.3	0	0
Lolium perenne	1.2	0	0				0.1	0.03	0

The broad-leaved flora of the fields surviving to early July are shown in Table 3 as mean scores for all sample points. Each field had a somewhat different flora, probably reflecting differences in farming history. Numbers of species found showed differences from year to year and did not reflect size of sample. There was some indication that numbers of species found over the season as a whole was increasing on the Integrated treatment field (Extra Close East).

TABLE 3

Broad-leaved flora in early July expressed as mean scores, and as numbers of species recorded in July and during the season.

Treatment	Full Insurance			Supervised			Integrated		
Year	83	84	85	83	84	85	83	84	85
Galium aparine	0.01	0.3	0.01	0.4	0.1	0.01	0.1	0.2	0
Stellaria media	0	0.01	0				0	0.3	0
Veronica hederifolia	0	0.01	0.01				0	0.03	0.1
Veronica persica	0	0.04	0				0	0	0.06
Sinapis arvensis				0	0.1	0.01	0	0.1	0
Aethusa cynapium							0.05	0.1	0.05
Bilderdykia convolvulus	0	0.04	0	0.01	0.3	0.1	0.2	0.8	0
Polygonum aviculare				0	0.01		0	0.05	0
Capsella bursa-pastoris							0	0	0.01
Atriplex patula				0	0.01	0	0	0.03	
Chenopodium album	0	0.01	0	0	0.1	0.01	0	0	0.01
Kickxia sp.				0	0.02	0			
Heracleum sphondylium				0	0.01	0			
Convolvulus arvensis	0.01	0.4	0.01						
Cirsium arvense	0.01	0	0						
Carduus acanthoides							0	0.03	0
Tamus communis				0	0	0.01			
No. species in July	3	7	3	2	8	5	3	9	5
No. species in season	4	7	6	4	15	11	8	11	13

Field margin floras

A summary of species numbers (excluding trees, shrubs and woody climbers) recorded in field margins with an index of diversity is given in Table 4.

TABLE 4

Extensive field margin survey results.

Treatment	Full Insurance			Supervised			Integrated		
Year	83	84	85	83	84	85	83	84	85
Number of survey points		24			45			17	
Number of species	46	54	49	60	55	56	29	43	41
Total occurrences	221	329	291	436	598	580	160	267	237
Species number per point	9.2	13.7	12.1	9.7	13.3	12.9	9.4	15.7	13.9
Margalef diversity index	8.3	9.1	8.5	9.7	8.4	8.6	5.5	7.5	7.3

The majority of the additional species recorded in 1984 compared to 1983 were annuals associated with the disturbed ground between the crop and the hedge. This increase gave a rise in the number of species recorded per point for all three fields in 1984, with a grater increase in the Integrated treatment field compared to the other two. Margalef's Diversity Index was lowest initially in the Integrated treatment field (reflecting species number, sample size, and the occurrence of different boundary structures - hedge, wood edge, ditch - witnin the field). Although there was a marked increase between 1983 and 1984, it was still lower than the other treatments in 1985.

Intensive Study Areas

Surface flora

The field boundaries within the 50m Intensive Study Areas were hawthorn hedges in Grange Piece and Extra Close East. The Knapwell boundary was a ditch adjoining coppiced woodland. Each boundary can be divided physically into hedge or ditch, the area between the hedge or ditch and the crop (called edge), and the crop. Data on the vegetative frequencies of species within the three areas in Extra Close East in July 1983 are given in Table 5.

TABLE 5

Vegetative frequencies of species which achieved 5% in the Integrated Study Area. June 1983.

Boundary area Species	HEDGE(0.5m)	EDGE(1.05m) Frequency	CROP(2.95m)
Rubus fruticosus	13.3	18.3	0
Crataegus monogyna	100.0	45.2	0
Anthriscus sylvestris	11.1	26.1	0.6
Heracleum sphondylium	0	11.3	1.8
Convolvulus arvensis	0	22.6	1.2
Galeopsis tetrahit	0	6.1	0
Galium aparine	62.2	60.9	2.5
Cirsium arvense	0	17.4	3.4
Lapsana communis	0	6.1	0.6
Tamus communis	42.2	6.1	0
Poa trivialis	0	20.9	0.6
Bromus sterilis	0	74.8	4.9
Elymus repens	2.2	36.5	8.9
Avena fatua	0	16.5	0.3
Alopecurus myosuroides	0	23.5	0.9

Some species, especially the grasses, were largely limited to the edge area, while others were limited to the hedge.

The numbers of species found in the three Intensive Study Areas are given in Table 6. Lowest numbers were consistently found in Grange Piece, with the greatest in Knapwell where the widest edge area included a ditch.

TABLE 6

Total numbers of species in field margin transects of the Intensive Study Areas.

Treatment	Full Insurance			Supervised			Integrated		
Year	83	84	85	83	84	85	83	84	85
Transect area									
Hedge	9	9	12	29	23	24	9	12	20
Edge	13	16	15	31	38	30	26	27	19
Crop	1	4	4	5	10	12	20	17	15
Total No. species	15	16	18	38	38	34	30	27	25

Seed floras

Plants germinating from soil core samples have been identified and counted. So far only one sampling time has been examined; the data form a baseline for future comparisons. A summary of the numbers of species in the seed bank recorded at different distances from the hedgebottom is given in Table 7.

TABLE 7

Numbers of species in the seed bank in three fields at different distances from the hedgebottom. Soil core samples taken in March 1984; data as at 1 October 1984.

Distance (m)	0	5	25	100
Full Insurance	17	5	3	4
Supervised	20	15	7	7
Integrated	28	4	4	7

The seed flora of the relatively undisturbed field margin consistently contained greater numbers of species than the field area. Examination of the composition of the seed floras indicated that patterns of dispersion, relative to the hedge, found previously in the above-ground flora were repeated (Marshall, 1985).

DISCUSSION

The study at Boxworth is still at an early stage. However, it is apparent from some of the early data presented here that changes are occurring in the flora of the fields and field margins. The treatment regimes imposed on the three fields described are different, with the lowest number of herbicide applications being made to the Integrated treatment field and the most to the Full Insurance field.

Analyses of the form used for replicated plot trials are not appropriate for the Boxworth data at this stage. Multivariate analyses will be used in the future and cluster analyses have been used (Marshall & Wilson, unpublished) to associate similar lengths of field margin according to their species composition. The best use of the data is to search for consistent trends. The numbers of species in the fields (Tables 2 and 3) may show a trend of reductions on the Full Insurance treatment (Grange Piece), best illustrated for the grasses, with at least maintenance of species number on the other treatments. Broad-leaved species diversity, assessed using the Information Index (Table 8), show differences from year to year but again with higher values on Supervised and Integrated treatment fields in 1985.

TABLE 8

Information Indices for broad-leaved species in July, calculated using summed scores.

Treatment	1983	1984	1985
Full Insurance	1.10	1.26	1.01
Supervised	0.22	1.81	1.31
Integrated	1.01	1.58	1.28

The number of species found in the field margins of the three fields (Table 4) were different in 1983 and show some differences from year to year. Subsequently species number, mean number of species per sample and Margalef's Diversity Index have increased on Extra Close East. Continued assessment will show if this trend is maintained, and if the trend is repeated on other fields under investigation. If consistent the implication is that reduced use of herbicides has allowed greater diversity, both in the field flora and in the margin. The implications for future weed problems and control and the effects on aspects of crop yield will be explored as the Project progesses. At the time of writing only a single harvest has been taken after the imposition of treatments and the yield data is insufficient for trends to be observed. The broad-leaved weed flora does not appear to pose a threat to the crop (Table 3); a number of species present earlier in the year were absent in July. However, the grass weed flora may pose problems, particularly with the observed increases in *Bromus* species on Supervised treatment fields.

An increased plant diversity in the field margin would seem a postive step for wildlife. From an agronomic viewpoint, preliminary studies on weed ingress from field margins indicate that few economic species are involved (Marshall, 1985).

ACKNOWLEDGEMENTS

I should like to thank MAFF for their support and members of the Weed Research Organisation for their help with this work, in particular B J Wilson and students Gavin Bird and Helen Oakes. My thanks are also due to the Boxworth EHF staff and the Boxworth Steering Committee.

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THE USE OF HERBICIDES FOR NATURE CONSERVATION

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ABSTRACT

The use of herbicides for managing vegetation for nature conservation is reviewed with particular emphasis on the design of strategies for the effective control of 'weed' species, but where underlying non-target vegetation is left undamaged. The role of experimental studies to help choose suitable selective herbicides, and appropriate application techniques, is discussed in relation to bracken and scrub control on lowland heath, and other plagio-climax ecosystems.

INTRODUCTION

Many people who are interested in nature conservation are surprised to learn that weed invasion is a problem on many nature reserves, and are alarmed when it is suggested that chemicals may have a role to play in this weed control. Because of these misgivings it is essential to:

(1) explain why weed problems occur in natural and semi-natural vegetation, on sites set aside for nature conservation, and

(2) demonstrate that the herbicide based weed control techniques, which are to be used for nature conservation, have been designed specifically with conservation objectives in mind.

Weeds on nature reserves

The most common type of weed problem in conservation management is on sites where the management objective is to conserve a plagio-climax ecosystem, where succession to a woodland ecosystem is occurring (Gimingham 1972, Duffey *et al*. 1974): for example, on lowland heaths invaded by birch (*Betula* spp.), Scots pine (*Pinus sylvestris*) and bracken (*Pteridium aquilinum*); sand dunes invaded by birch, Scots pine and sea buckthorn (*Hippophäe rhamnoides*); and chalk grassland invaded by hawthorn (*Crataegus monogyna*). Unless these invasive species (weeds) are controlled, the plagio-climax communities will disappear.

In the past, these communities were maintained by man's activities through a combination of grazing (natural and agricultural), burning and cutting - practices which prevented succession to a climax community. However in the last 40 years, and for a variety of reasons, these forms of management have often been abandoned in areas of nature conservation interest, with a rapid invasion by weeds as a result. The conservation of such plagio-climax communities poses two problems:

(1) the need to keep good representative areas of the plagio-climax vegetation weed-free, i.e. succession must be prevented;

(2) the need to control existing weed problems, and then restore the original community, i.e. succession must be reversed.

The role of herbicides in nature reserve management

Ideally, from a nature conservation viewpoint, these weed problems would best be tackled by non-chemical means (pulling, bulldozing, grazing, cutting or burning). However, at many sites, invasive, woody weeds have already developed to such an extent that these techniques may be inappropriate. Scrub may be so large that hand-pulling and grazing will have little impact. Moreover, where deciduous scrub is cut or burned, regrowth from stem bases can be rapid and prolific (Marrs & Lowday 1983, Marrs 1984a, 1985a). Herbicides are, therefore, a useful supplementary tool to help control weeds in these situations, and moreover, do not disturb the soil like some mechanical treatments, thus preventing colonization by invasive weeds.

However, the use of herbicides for nature conservation is completely different from the more conventional agro-forestry uses. When managing crops, there is usually only one non-target species, the crop, and all other plants can be considered as weeds. In contrast, on nature reserves, there is usually only one target species, the weed, and, ideally, all other species, the non-targets, must be left undamaged. Therefore, before using herbicides on nature reserves, it is essential to know the answers to the following questions:

(1) What is the most appropriate herbicide to eliminate the target weed without damaging the non-target species?

(2) Can the potential risks of using herbicides be reduced by changing the methods of application?

By attempting to answer both of these questions in experimental studies, we can begin to design herbicide based strategies that are tailored for particular weed problems found on specific sites. It should be noted, however, that the work described here does not constitute recommendations for herbicide use, and users should confirm that any product is covered by label recommendations before use.

CHOOSING SUITABLE SELECTIVE HERBICIDES

Here the aim is to choose herbicides that, when applied by foliar spray, kill only the target species leaving all non-targets unaffected. For some conservation weed problems this absolute requirement for selectivity may be relaxed, for example, where the weed target species has invaded to such an extent that the non-target vegetation has been eliminated, e.g. dense stands of bracken. However, even in these cases, selective herbicides may often be preferred to reduce risks of damage to neighbouring areas by accidental spray-drift. There are two main ways we have attempted to provide information on selective herbicides for use on nature reserves: by collating a handbook of species' response to a range of herbicides (a relatively crude approach), and from experimental screening trials in the field (a more sensitive approach).

Handbook of species' response (Cooke 1985)

Information on the response of individual species (resistance/sensitivity) to 5 herbicides commonly used for bracken and/or scrub control (ammonium sulphamate, asulam, fosamine ammonium, glyphosate and triclopyr) was collated from published literature and manufacturer's information (Marrs & Griffith 1985, Cooke 1985). The aim was to provide tabulated information which reserve managers could use to determine which herbicide would, or would not, be suitable for use in specific plant communities where particular species mixtures were present.

There are, however, many problems with the use of this type of information, the main one being the lack of consistency of the data found in various sources. For example, in many instances, it was not apparent whether:

(1) the data were collected from the field or the laboratory,

(2) subjective or objective methods of assessment were used,

(3) a statistical assessment of error had been calculated,

and in a few instances conflicting data were found even in the same source! Nevertheless, this handbook (Cooke 1985) can be used as a crude method for selecting herbicides for particular weed control problems on nature reserves.

Experimental screening trials

A better and more sensitive approach is to screen a range of potentially suitable herbicides for damaging effects in a range of vegetation types. A major problem in this type of screening work is that very little is known about the amounts of herbicide likely to reach the non-target ground vegetation when used in practical nature conservation tasks. However, the worst possible effects can be deduced by spraying the understorey vegetation with herbicides applied at the rates recommended for controlling the weed species. In this type of experiment, damage to non-target vegetation is likely to be over- estimated, because, in practice, some, if not substantial, amounts of herbicide should be intercepted by the target species.

Screening trials have been done on two types of lowland heath, a *Calluna* heath and a grass heath (Marrs 1984b, 1985b). At each site, 9 herbicides - ammonium sulphamate, asulam, fosamine ammonium, glyphosate, hexazinone, picloram, 2,4,5-T, tebuthiuron and triclopyr - were applied at manufacturers' maximum recommended rates, and their subsequent effects on the non-target vegetation were monitored over a period of two years. Quantitative assessments of damage were made; at the *Calluna* site, 25 *Calluna* shoots were sampled, while, at the grass heath site, 20 cm x 20 cm sub-quadrats of ground vegetation were clipped. In both instances, the samples were separated into live and dead tissue, and damage expressed as the proportion of the dead material in the sample. At the grass heath site, the percentage of rooted frequency of all species was also noted.

Asulam, fosamine ammonium and 2,4,5-T did not significantly damage the non-target vegetation on the *Calluna* and grass heaths. Triclopyr did not damage the grass heath vegetation, but damaged the *Calluna* to an unacceptable degree in the first year, although there was evidence of recovery in the second year. The other herbicides, ammonium sulphamate, hexazinone, glyphosate, picloram and tebuthiuron caused unacceptable damage, and should not therefore be used for conservation purposes with conventional sprayers.

At present information is only available for these two lowland heath communities, but similar trials are in progress to screen herbicides for damage in sand dune vegetation (P. Kinnear personal communication). It is strongly recommended that this type of trial should be an essential precursor to large scale weed control treatments in nature reserves for three reasons:

(1) To provide additional information about the response of non-target species to different herbicides at individual sites.

(2) To allow reserve managers to gain experience in herbicide handling and application.

(3) To boost confidence in the role of herbicides for vegetation management on nature reserves.

Herbicide efficacy

It is, of course, not enough to show that herbicides do not affect non-target species, they must also give a good kill of the target weed. For most conservation purposes, the 4 herbicides which did not damage the lowland heath communities in the screening trials will be suitable: with asulam effective, at least initially, against bracken (Veerasekaran et al. 1978, Lowday 1984, Marrs & Lowday 1984), and fosamine ammonium, 2,4,5-T and triclopyr effective against woody scrub (Marrs 1984a, c, 1985a, Marrs & Lowday 1984). As the herbicide 2,4,5-T has been barred by many conservation bodies, fosamine ammonium and triclopyr may be used in preference.

CHOOSING APPROPRIATE APPLICATION METHODS

Selective herbicides are required when herbicides are to be applied by foliar spray. However, it is also possible in some situations to use a directed application method, i.e. where the herbicide is applied direct to the target individual. If this method is used, there should be no risk of contaminating the non-target (untreated) plants. When directed application is done, non-selective herbicides may be chosen.

The most commonly used direct application method for controlling woody scrub is to paint the stumps with herbicide after cutting. This painting is usually done manually, but it is possible to cut and apply the herbicide in one operation, e.g. using hypo-hatchets, and specially modified secateurs, chain saws and brush clearers (Christensen 1984, Evans 1980, Jones & Morgan 1978, Kossuth et al. 1978, Peevy 1972). A range of herbicides has been tested for ability to control birch in 4 season applications on lowland heaths (Marrs & Lowday 1984, Marrs 1985c), and a summary of the results is given in Table 1.

Recently, rope-wick applicators have been developed for the directed application of herbicide, and have been found useful for some conservation tasks. There are two types - those held in the hand for small-scale tasks, and tractor-mounted versions which are especially useful where there is a height difference between target and non-target species. The height of the bar carrying the rope-wick is set above the non-target species, but below the height of the target species. In this way, only target plants are smeared with the herbicide solution. These applications have been shown to be effective for controlling:

(1) woody weeds (sycamore, *Acer pseudoplatanus*) using glyphosate (Christensen 1984), and

(2) bracken using the selective herbicide asulam (Lowday 1985).

Further research on the use of directed methods of applying herbicides for weed control on nature reserves is likely to be worthwhile.

TABLE 1

A summary of successful herbicide treatments applied to cut birch stumps; herbicides shown below successfully killed or suppressed regrowth (Marrs & Lowday 1984, Marrs 1985c)

Selective herbicides

Season of application	Fosamine ammonium	2,4,5-T	Triclopyr
Autumn	50% in water	5% in oil	5% in oil 10% in water
Winter	10% in water	5% in oil	5% in oil 10% in water
Spring	10% in water	5% in oil	5% in oil 10% in water
Summer	10% in water	5% in oil	5% in oil 10% in water

Non-selective herbicides

Season of application	Ammonium sulphamate crystal	Ammonium sulphamate 40% w:vol	Glyphosate	Hexazinone 5%
Autumn	x	x	5% in oil 10% in water	x
Winter	√	√	5% in oil 10% in water	√
Spring	√	√	5% in oil 10% in water	√
Summer	√	√	5% in oil 10% in water	x

√ = successful : x = unsuccessful

CONCLUSIONS

Potentially, herbicides have an important, and increasing, role in the control of weeds in nature reserves. However, before herbicides are used for conservation purposes, their effects on a range of target and non-target species must be explored, and an appropriate method of application chosen. If a herbicide does not damage non-target vegetation in screening trials, it can be used with confidence in the field. However, the range of acceptable herbicides is increased by using a directed method of application. Together, the correct choice of herbicide and method of application will minimize greatly the risks to the non-target vegetation which is to be conserved.

Despite these improvements in our understanding of herbicide use for nature conservation, it is clear that herbicides will never be the sole panacea for vegetation management, especially if succession has proceeded and there is already a dense weed problem. It may be possible to eliminate the weeds using a herbicide, but positive steps will be needed to restore and maintain the desired plant communities. In this maintenance phase of vegetation management, the use of herbicides is a complement to the existing techniques of vegetation management, e.g. grazing, cutting and burning (Marrs & Lowday 1984), and may need to be done *ad infinitum*.

ACKNOWLEDGEMENTS

This work has been funded in part by the Nature Conservancy Council.

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THE ECOLOGICAL EFFECTS OF MALEIC HYDRAZIDE AND 2,4-D ON ROADSIDE VEGETATION

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ABSTRACT

Results from experiments at 2 roadside verge sites in Cambridgeshire over 17 years have shown that over the first 4 years there was little or no effect of maleic hydrazide (MH) on species richness of the vegetation. Thereafter there was a decline in the number and abundance of grasses and dicotyledonous plants in the treated plots at both sites. There were generally significantly greater effects from 2,4-D and the effects were greater following combined treatments of MH and 2,4-D. Five species significantly increased in frequency, of which *Plantago lanceolata* was the only one to do so at both sites. Twenty-seven species declined, with greatest effect on tall grasses (eg *Dactylis glomerata*) and tall herbs (eg *Heracleum sphondylium*). The results are discussed in relation to ecological factors influencing the composition of grass swards.

INTRODUCTION

Since the early 1950s, the growth retardant maleic hydrazide (MH), usually in mixtures with a selective herbicide such as 2,4-D, has been used as a method of controlling the growth of vegetation on roadside verges. This practice has caused concern for the conservation of wildlife habitats associated with this vegetation (Perring 1969, Way 1977).

The direct herbicidal effect of 2,4-D on dicotyledonous plants (dicots) is well known, and it is not surprising that severe ecological effects on the species richness of grass swards have been recorded following its use (eg Willis 1972). The main effects of MH are on plant growth and development and this has more subtle ecological effects on the competitive relationships between species, that can only be detected over a period of years, and about which there have been some differences of opinion. Thus, early results from a long-term field experiment at Bibury in Gloucestershire (Yemm & Willis 1962) showed a selective suppression of grasses compared to dicots, enhancing species richness. These findings, together with some other evidence, have been quoted by other authors describing effects of MH as encouraging species richness (Way 1970, Haggar 1980, Green 1983). However, MH does retard the growth of dicots (Schoene & Hoffman 1959), and longer-term effects of the use of MH at Bibury (Willis pers. comm.), other results from our work (Parr & Way 1984), together with results from Marshall & Craine (1984), all indicate that the use of this chemical is likely to lead to decreases in species richness of grass swards.

In this paper we present the 17-year results of applications of MH on the composition of herbaceous vegetation on road verges in 2 experiments, and discuss some of the ecological factors that seem to be involved. As MH is commonly used in mixtures with 2,4-D, and also later cutting of the vegetation, treatments involving these factors are included for comparison.

MATERIALS AND METHODS

The data used in this paper were taken from the results of a long-term experiment, done between 1965 and 1982, on the effects of management on the structure and species composition of roadside vegetation (Way 1969). The main objectives of the research were to examine the wider effects of management on the conservation of roadside flora and to provide advice on management techniques. Two sites in Cambridgeshire were used; the first at Keyston on Oxford clay and the second at Ickleton on a chalk soil with a naturally more species-rich vegetation.

The full experimental treatments included 19 combinations of mechanical cutting and application of MH and 2,4-D. Each treatment (except the control, for which there were 8 replicates) was replicated 4 times at each site in roadside plots measuring 1.8 m by 18.3 m. A subset of 8 of these treatments has been used in this paper, consisting of all combinations of 3 factors, MH (none or sprayed in April), 2,4-D (none or sprayed in April) and cutting (none or cut in June). Maleic hydrazide ('Regulox') and 2,4-D ('Vergemaster') were applied at 6.7 kg/ha a.i. in 900 litres/ha of water each year from 1965 to 1982.

Sampling and analysis

In July/August of most years between 1965 and 1982, species composition was determined by means of presence/absence recording from 40, 15 cm square, quadrats randomly placed in each plot. From this the total number of species per plot and the mean number of species per quadrat were calculated. (The latter measure is proportional to total frequency and can also be regarded as a measure of abundance). The data were analysed by a 3-way factorial analysis of variance to assess the main effects of maleic hydrazide, 2,4-D and cutting and their interactions. All significant differences are given at the P .05 level.

RESULTS

Effect of maleic hydrazide on species richness

The effect of MH on the number of species (= species richness) per plot was different at the 2 sites (Fig.1 and Table 1).

On the chalky soil at Ickleton, MH had no significant effect for the first 4 years but thereafter caused a decline in species richness. Between 1971 and 1982, the loss of, mainly, dicots resulted in an average of 4.8 (±1.19) species less in the plots treated with MH compared with the no-chemical treatments (Table 1). Changes in the number of species per quadrat were proportionately similar to those of total species per plot. This suggests that grasses were declining in frequency at this time, but not to the point of elimination. The decline in species per quadrat reflected changes in the frequency of individual species, 21 (5 grasses and 16 dicots) of which declined significantly compared to only 2 species which increased (Table 2).

On the Oxford clay soils at Keyston, MH resulted in an increase in the number of species per plot during the first 4 years, mainly due to an increase in the number of dicots. Thereafter, as at Ickleton, species richness declined to levels lower than the controls except that most of the species lost were grasses. There was no reduction in the number of dicots,

TABLE 1

Effect of chemicals on species richness of grasses and dicots after 5 years. Treatments significantly different from control (P<.05) shown by *.

Treatment	Species per plot Grasses	Dicots	Total	Species per quadrat Grasses	Dicots	Total
Ickleton						
No chemicals	8.2	14.1	22.3	4.18	2.21	6.39
MH	7.8	9.7*	17.5*	3.27*	1.77*	5.04
2,4-D	8.1	4.2*	12.3*	4.25	.54*	4.79
MH + 2,4-D	6.6*	4.1*	10.7*	3.35*	.66*	4.01*
5% LSD	.62	1.80	2.07	.203	.426	.501
Keyston						
No chemicals	9.4	9.8	19.2	3.99	2.00	5.99
MH	7.1*	9.9	17.0	2.57*	1.93	4.50*
2,4-D	9.3	3.4*	12.7*	3.63*	.68*	4.31*
MH + 2,4-D	8.1*	5.8*	13.9*	2.96*	.90*	3.86*
5% LSD	.98	2.01	2.50	.329	.472	.642

although twice as many species declined in frequency as increased (4) (Table 2).

Over the 2 sites a total of 27 species was significantly reduced in frequency compared to only 5 species which increased.

Effect of 2,4-D on species richness

At both sites 2,4-D resulted in reductions in species richness (Table 1) with an average loss of 10 (±1.19) species at Ickleton and 6.5 (±1.11) at Keyston. Practically the whole of these losses was in dicots, although at Keyston 5 species of grass also declined in frequency (Table 2). Despite the initial differences between the 2 sites, the greater loss of species at Ickleton meant that after 2,4-D the vegetation structure and species richness at the 2 sites were similar.

Interactions between maleic hydrazide and 2,4-D

The effects of MH and 2,4-D in mixture were additive and hence the greatest reductions in species richness occurred in plots treated with both chemicals. Both grasses and dicots were significantly reduced.

Effect of cutting

The single cut in June had no significant effect on the total number or frequency of grass or dicots or on the mean effect of the chemicals.

TABLE 2

The number of species significantly (P< .05) decreasing (-) or increasing (+) relative to the controls in response to MH or 2,4-D.

	Grasses -	Grasses +	Dicots -	Dicots +	Total -	Total +
MH at Ickleton	5	0	16	2	21	2
MH at Keyston	5	0	8	4	13	4
2,4-D at Ickleton	0	1	26	1	26	2
2,4-D at Keyston	5	0	13	0	18	0

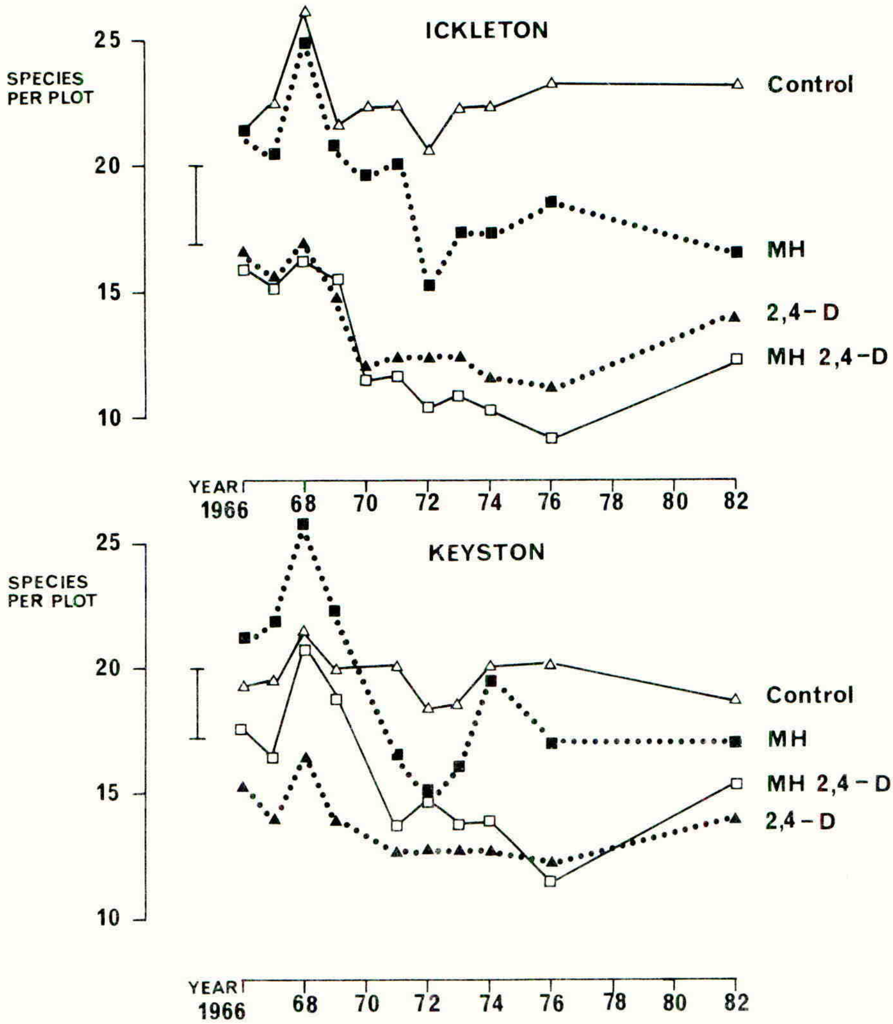

Fig. 1. Effect of chemical treatments on species richness between 1966 and 1982. (Bars show 5% LSD for differences within years).

Effect of chemicals on species composition

After 4 years of treatment with MH the vegetation at both sites consisted of a uniform sward dominated by a mixture of the grasses Festuca rubra, Poa spp., Arrhenatherum elatius and Elymus repens, together with 2 dicots, Plantago lanceolata and Convolvulus arvensis (Table 3). Although grasses were the principal dominants of these swards, most of the common species were less frequent than in the controls; only Festuca rubra maintained or increased its frequency and there were large reductions in Dactylis glomerata and Festuca pratensis.

Most of the common dicots decreased in frequency when treated with MH. Losses were greatest for the tall umbellifers, Heracleum sphondylium

TABLE 3

Effects of maleic hydrazide (MH) and 2,4-D on individual species. Chemical effects shown relative to % frequency in the no chemical (control) treatments. Significant differences (P <.05) from control shown by *.

	ICKLETON					KEYSTON				
	Control	MH	2,4-D	MH+2,4-D	5% LSD	Control	MH	2,4-D	MH+2,4-D	5% LSD
Grasses										
Poa sp	79.9	-15.4*	+8.5*	+9.3*	7.26	76.7	-16.6	+8.1	+4.6	16.93
Festuca rubra	93.9	+3.2	-2.0	+3.4	4.77	48.2	+9.2	-15.8	-7.2	25.06
Elymus repens	60.5	-24.7*	-6.0	+5.9	18.56	80.2	+.8	+2.6	+7.3	11.38
Arrhenatherum elatius	86.9	-12.8*	-2.7	-41.6	7.87	53.4	-29.8*	-8.8	-37.5*	11.42
Dactylis glomerata	39.8	-22.5*	+3.4	-22.5*	8.84	47.6	-40.6*	-12.5*	-32.6*	10.78
Agrostis stolonifera	20.0	-13.8*	-.3	-16.1*	7.40	15.7	-9.1	-.6	+4.4	11.08
Festuca pratensis	-	-	-	-	-	38.1	-33.6*	+1.9	-33.7*	18.28
Trisetum flavescens	19.7	-.3	-1.8	-16.8*	8.07	-	-	-	-	-
Phleum pratense	5.2	-2.2	-2.7	-5.1*	3.65	9.1	-5.5	-7.5*	-6.7*	5.79
Alopecurus pratensis	-	-	-	-	-	13.7	-7.2*	-7.7*	-8.6*	6.65
Dicots										
Convolvulus arvensis	35.8	+7.2	-10.9	+5.0	12.00	22.4	+31.8*	+6.6	+10.7	24.24
Heracleum sphondylium	.3	-.3*	-.3*	-.2	.25	49.4	-28.7*	-38.6*	-40.3*	11.15
Anthriscus sylvestris	14.0	-13.2*	-9.5*	-13.5*	5.50	35.0	-32.0*	-14.2*	-26.2*	13.07
Achillea millefolium	36.3	-19.4*	-35.9*	-36.0*	12.71	2.1	-.4	-2.0	-2.1	2.76
Potentilla reptans	12.5	-8.2*	-12.4*	-12.4*	4.72	26.7	-24.3*	-26.6*	-26.3*	12.23
Plantago lanceolata	17.9	+33.4*	-17.8*	-17.6*	11.94	5.4	+43.4*	-5.3	-5.2	15.57
Cirsium arvense	6.6	-2.1	-6.2*	+.4	5.73	13.8	-.2	-12.6*	-5.3	5.71
Vicia sativa	15.9	-14.9*	-15.8*	-15.8*	8.51	-	-	-	-	-
Veronica chamaedrys	12.6	-4.4	-8.9*	-8.8	4.72	-	-	-	-	-
Ranunculus repens	1.4	-1.1	-1.4*	-1.4*	1.34	9.8	-1.8	-9.5*	-9.7*	7.94
Agrimonia eupatoria	7.6	-6.8*	-7.5*	-7.6*	3.62	-	-	-	-	-
Trifolium repens	1.0	-.7*	-1.0*	-.9*	.63	5.1	-3.3	-5.0*	-4.6	4.86
Centaurea nigra	5.3	-1.3	-5.3*	-5.0*	3.93	.5	+.7	-.5	-.5	.97
Tragopogon pratense	3.4	-2.3*	-3.4*	-3.4*	1.35	-.3	-.2	-.3	-.3	.41
Plantago media	3.1	-2.8*	-3.1*	-3.1*	1.97	-	-	-	-	-

and Anthriscus sylvestris. Other tall herbs such as Agrimonia eupatoria, Centaurea nigra and Tragopogon pratense also decreased along with some less tall species such as Achillea millefolium, Potentilla reptans and Vicia sativa. These losses amongst the dicots were partly offset by increases in Convolvulus arvensis and Plantago lanceolata which were found in over 40% of the quadrats.

The use of 2,4-D gave a sward dominated by the same grass species as in the MH treated plots with Dactylis glomerata and Alopecurus pratensis (Keyston only) also being common. Grasses were less affected by 2,4-D than MH and only Dactylis glomerata, Phleum pratense and Alopecurus pratense decreased at Keyston, whereas at Ickleton, Poa spp. actually increased. The 2,4-D had a greater effect on dicots and with the exception of Convolvulus arvensis at Keyston, all the common species, with frequencies over 2%, were reduced.

DISCUSSION

The effect of chemical sprays on plant communities can be divided into direct effects on the growth, survival and reproduction of individual species and indirect effects resulting from a change in the competitive environment due to changes in other species. In a field situation, where the response of individual species in monostands is not known, it may not be easy to differentiate between these effects but generally, direct effects become apparent more quickly, within weeks, whereas indirect effects may take many years to detect. The consequences of direct and indirect effects are not necessarily complementary, hence the elimination of all species by total herbicides such as paraquat may be followed by a phase of colonisation and growth in which species richness rises above previous levels. Such indirect effects provide the rationale behind the use of chemicals, including herbicides and growth retardants, in the interests of nature conservation (Marrs 1984).

The direct effect of 2,4-D on vegetation is the rapid death of susceptible dicots and a reduction in species richness. The spaces left by the death of these plants are mainly colonised by grass species spreading by means of a stolons or rhizomes. The time and space available for colonisation by dicots is short, whilst any that do establish are likely to be destroyed by spraying in succeeding years. Hence both the direct and indirect effects of 2,4-D favour the growth of grasses and the net effect is an overall impoverishment of the sward. At Ickleton and Keyston and in the studies of Willis and Yemm (1966), this process was characterised by an increase in the rhizomatous grass, Poa pratensis.

MH restricts cell division and extension growth, resulting in a suppression of plant growth and flowering. At recommended doses it does not normally permanently damage plants and changes in sward species composition are most likely to be due to indirect effects on the balance of competition between species. Even in simple communities, interactions between species are complex but despite this, there are considerable similarities between the results of our work at 2 sites in Cambridgeshire and similar work at Bibury in Gloucestershire (Yemm & Willis 1962, Willis & Yemm 1966, Willis 1972). At all 3 sites, there were decreases in most grass species and in tall herbs such as Anthriscus sylvestris and Heracleum sphondylium as the swards become dominated by the fine grass Festuca rubra together with high densities of some low growing herbs such as Plantago lanceolata and Convolvulus arvensis. The main difference between the 3 sites has been the period of time over which changes in species richness have taken place. Thus, whilst in our 2 experiments, significant declines in species richness were detected within 4 years of the start of treatment, at Bibury the decline has taken much longer (Willis pers. comm.).

The control of species richness in grassland habitats is achieved through the balance between the competitive exclusion of species, and the establishment of new species. In closed grass swards, seedling establishment is a particularly hazardous process and the availability of suitable regeneration niches is thought to play an important part in maintaining species richness (Grubb 1977). Within the framework of these general ideas we can interpret the effects of MH at different sites in terms of 3 phases.

First, a direct herbicidal effect of MH which creates gaps in the sward. Yemm and Willis (1962) found that the suppression of Anthriscus sylvestris and Heracleum sphondylium created such gaps but although at Ickleton and Keyston both these species decreased, there was no evidence of any herbicidal damage.

Second, naturally-occurring gaps and the gaps created by the MH are filled either by the spread of existing plants (mainly grasses) or by colonisation with new plants from seed. Because the vegetative spread of plants is inhibited by the MH, the gaps are available for colonisation for a longer period and seedling establishment is more likely to be successful. Ruderal species such as Veronica persica, Stellaria media and Geranium dissectum are particularly likely to invade (Willis 1972), but perennials such as Plantago lanceolata may also take advantage of the reduced competition from grasses. The effect of this colonisation is that initially, particularly on relatively species-poor sites such as Keyston, species richness increases. On richer sites, such as Ickleton, gaps are more likely to be colonised by species already present, with no net increase in species richness.

Thirdly, the magnitude of the direct effects on growth will vary between species and this may upset the competitive balance between species and result in a change in the dominance hierarchy. Depending on their growth form, these new dominants may provide a more or less favourable environment for the co-existence of less abundant species. Because MH is usually applied in early spring, when grasses tend to be more actively growing than dicots, this may favour the growth of the latter as, for example, is demonstrated by the increase in Convolvulus arvensis. The growth of Festuca rubra is also poorly controlled, perhaps because its fine leaves are not easily wetted by the chemical spray or because growth from underground rhizomes enables it to recover quickly. Hence, at Ickleton, Keyston and Bibury, Festuca rubra became a dominant component of the sward. It is a species which spreads to form a short turf with a thick mat of thatch and an extensive rhizome system, and provides an inhospitable environment for other species. In time, it may give rise to a clonal monotony broken only by species capable of regenerating vegetatively whilst the ruderal species which earlier invaded the open sward will disappear. Hence, following an initial phase of disturbance in which species richness may increase, in the longer term the development of a new competitive balance among the dominants may lead to a loss of species and an overall decline in species richness. MH also inhibits flowering, particularly in grasses, and in the long term this may reduce the seed bank and limit regeneration from seed.

In conclusion, the long-term effect of MH on species composition of a grass sward will depend on the growth form and life history characteristics of the species at any particular site. Where Festuca rubra is present it is likely that the increased dominance of this species will lead to a reduction in species richness, but other results are possible if other species assume dominance. Furthermore, with the new generation of growth retardants (eg mefluidide, paclobutrazol), with different modes of action in the plant, there may be qualitatively different effects on plant community structures.

ACKNOWLEDGEMENTS

Thanks are due to Mr V.F. Woodham and Mr. B. Veale, to the Diamond Shamrock Company for the supply and application of chemicals, to Cambridge County Council for cutting treatments and to all those who assisted in the management and recording of the plots over a period of 17 years.

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HERBICIDE EFFECTS ON FIELD MARGIN FLORA

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ABSTRACT

An evaluation programme to investigate the effects of herbicides and plant growth regulators on a range of field margin flora is being carried out at the Weed Research Division with financial support from the Perry Foundation. One experiment on 16 broad-leaved species with six herbicides is reported here with a summary of further results published elsewhere. The most damaging herbicide treatment, in terms of numbers of broad-leaved species affected, was mecoprop. Of all the species tested only the grasses *Bromus sterilis* and *Elymus repens* have not been significantly reduced in vigour by any herbicide treatment compared to the untreated control.

INTRODUCTION

In recent years the farming community has tried to react in a more sympathetic way to the needs of the countryside. The formation of Farming and Wildlife Advisory Groups (FWAGs) and the appointment of wildlife advisers has helped them to do so. However, the farming community remains largely unaware of the consequences of routine agronomic practices (e.g. straw burning, pesticide and fertiliser application) on the flora and fauna of adjacent habitats. Relatively little research on the effects of pesticide application to non-target plant species has been done.

Field edges are increasingly important in providing a variety of habitats on the farm which are capable of supporting many beneficial insects (Sotherton 1982) and nesting sites for birds (Rands 1982) as well as being floristically attractive in their own right. Non-agricultural features such as field margins can be useful and attractive areas on farms. Agrochemical operations in adjoining fields may decrease the value of such areas. A positive input from the farmer is needed to maintain diverse habitats which will sustain a variety of flora and fauna.

Herbicide treatments for the control of field weed problems are chosen on agronomic and economic grounds. There is no information to help a farmer choose between herbicide treatments on the basis that product (A) may be less damaging to non-target plant species at the field edge than product (B). In recent years there has been an increased incidence of *Bromus sterilis* (Sterile brome) as a field weed. This grass commonly inhabits field edges. Minimum cultivations, straw burning and the lack of a reliable herbicide treatment have allowed it to build up at the field edge, gradually spreading into the field proper (Froud-Williams *et al*. 1980). *B.sterilis* is competitive in cereal crops, so the fear that populations may build up in the field has led some farmers to use drastic measures to control the weed in the field edge. Failure to appreciate that the field edge cannot be considered in the same way as the field proper has led to unsuitable management methods being used. Often, these have not only increased the original 'weed' problem but have made future management of the field margin more difficult.

A project has been set up to investigate the relative susceptibilities of a wide range of field edge plant species to commonly applied herbicides. This information will be used to develop useful management techniques for field edges which will satisfy both environmental and agricultural requirements, for example the regulation of plant growth to prevent seed formation in potential weed species, or to encourage growth of desirable species.

A pot experiment programme was chosen to provide basic information on the susceptibility of a wide range of plant species to chemical treatments, allowing reasonable numbers of species and treatments to be handled. 31 broad-leaved species and 11 grass species, representing 25 families, have been treated. Most of the species are common field edge plants. They include plants which in certain situations are considered weeds. The inclusion of species about which much is known, helped to establish that damage to the treated plants was a result of herbicide treatment.

METHODS

In this paper one experiment from the programme is described. The experiment was treated on 5 June 1984. The species and growth stages of the sprayed material are listed in Table 1. Each species received a single application of each chemical at the recommended field rate, as listed in Table 2. Each treatment was applied using a laboratory pot sprayer calibrated to deliver a volume rate of 200 litres ha^{-1}. Treatments were replicated twice. A field margin might be expected to receive a dose of herbicide from a field application ranging form zero up to field rate with accidental spraying. Pot-grown material which was unaffected by a treatment at field rate would not be expected to be affected under field conditions.

TABLE 1

Species and growth stages at treatment (5/6/84)

Species	Growth stage/height
Achillea millefolium	mature rosette
Anthriscus sylvestris	8 leaves
Carduus acanthoides	mature rosette
Conium maculatum	6 leaves
Cirsium arvense	10 cm
Convolvulus arvensis	pre-flowering
Geranium pusillum	flowering
Hypericum perforatum	3 branches
Lamium album	flowering
Ranunculus repens	flowering
Rumex obtusifolius	13 leaves
Rumex sanguineus	20 cm
Silene alba	flowering
Trifolium repens	pre-flowering
Vicia tetrasperma	4 branches
Urtica dioica	22 cm

TABLE 2
Herbicide treatments applied to a range of field margin flora

Herbicide	Product (Tradenames)	Rate kg (a.i.) ha^{-1} (kg (a.e.) ha^{-1}	Formulation
mecoprop	Compitox Extra	2.40	K salt
ioxynil+bromoxynil	Deloxil	0.76	ester e.c.
chlorsulfuron	Glean DF20	0.02	wettable powder
clopyralid	Format	(0.20)	amine salt
isoproturon	Arelon Liquid	1.88	dispersion liquid
diclofop-methyl	Hoegrass	1.14	e.c.

Plants were either grown on from field material or raised from seed. A permanent stockbed of the selected species was set up to provide plant material for subsequent experiments.

The assessment adopted was a simple visual score of the vigour of treated plants compared to the untreated control plants (Table 3). This enabled plants with very different growth rates and habits to be compared equally, so that susceptibility and potential selectivities between species could be assessed. The assessments were carried out at weekly intervals following spraying, for six weeks for annuals and 15 weeks for perennials.

TABLE 3

Criteria by which vigour of plants was visually assessed following herbicide treatment.

0 =	dead
1 =	moribund, not all tissue dead
2 =	live, some green tissue, further growth unlikely
3 =	gross inhibition of growth, recovery unlikely
4 =	slight inhibition of growth
5 =	obvious growth defect, epinasty
6 =	slight growth defect, wilting, chlorosis
7 =	colour difference, yellowing or darkening
8 =	slight detectable growth difference
9 =	indistinguishable from untreated control

RESULTS

The results from the experiment are shown as vigour scores at five weeks (Table 4) and 15 weeks (Table 5) after treatment. Several species were senescing naturally at 15 weeks and are therefore not included in Table 5. The most susceptible species are at the top of each column.

TABLE 4. The susceptibility of field margin species to six herbicides at five weeks after treatment. Species in *italics* are significantly reduced in vigor compared to the unsprayed control. Mean score values in parenthesis 9 = control 0 = complete kill.

mecoprop		ioxynil + bromoxynil		isoproturon		clopyralid		diclofop-methyl		chlorsulfuron	
C.acanthoides	**(0.0)**	***C.acanthioides***	**(0.0)**	***A.millefolium***	**(0.0)**	***C.acanthoides***	**(0.0)**	***C.maculatum***	**(8.0)**	***G.pusillum***	**(1.0)**
R.repens	**(0.0)**	***C.maculatum***	**(4.5)**	***C.arvense***	**(0.0)**	***V.tetrasperma***	**(0.0)**	***H.perforatum***	**(8.0)**	***A.sylvestris***	**(2.0)**
S.alba	**(0.0)**	***L.album***	**(5.0)**	***R.sanguineus***	**(0.0)**	***C.arvense***	**(1.0)**	***S.alba***	**(8.0)**	***R.repens***	**(2.0)**
C.maculatum	**(1.0)**	***R.sanguineus***	**(6.0)**	***U.dioica***	**(0.0)**	***T.repens***	**(2.0)**	***A.sylvestris***	**(8.5)**	***U.dioica***	**(2.5)**
V.tetrasperma	**(1.0)**	***C.arvense***	**(7.0)**	***R.repens***	**(1.5)**	***A.millefolium***	**(3.0)**	A.millefolium	(9.0)	***A.millefolium***	**(3.0)**
C.arvensis	**(1.5)**	***R.repens***	**(7.0)**	***C.maculatum***	**(2.5)**	***U.dioica***	**(3.0)**	C.arvense	(9.0)	***C.arvense***	**(3.0)**
A.sylvestris	**(2.5)**	***A.sylvestris***	**(7.5)**	***S.alba***	**(2.5)**	***A.sylvestris***	**(4.5)**	G.pusilium	(9.0)		
R.obtusifolius	**(3.0)**	***A.millefolium***	**(8.0)**	***H.perforatum***	**(3.5)**	***C.maculatum***	**(5.0)**	R.repens	(9.0)		
U.dioica	**(3.0)**	***S.alba***	**(8.0)**	***A.sylvestris***	**(6.5)**	***R.repens***	**(5.0)**	R.sanguineus	(9.0)		
A.millefolium	**(4.0)**	***U.dioica***	**(8.0)**	V.tetrasperma	(7.5)	***R.sanguineus***	**(5.5)**	U.dioica	(9.0)		
C.arvense	**(4.0)**	G.pusillum	(8.5)	G.pusillum	(8.5)	***H.performatum***	**(7.0)**				
R.sanguineus	**(4.5)**	H.perforatum	(9.0)			***S.alba***	**(7.0)**				
T.repens	**(4.5)**	R.obtusifolius	(9.0)			R.obtusifolius	(8.0)				
G.pusillum	**(5.5)**	T.repens	(9.0)			G.pusillum	(8.5)				
H.perforatum	**(6.5)**	V.tetrasperma	(9.0)			L.album	(9.0)				
L.album	(8.0)										
LSD treated x control	1.23		0.54		1.83		1.03		0.31		2.0
LSD between species	3.69		2.09		4.50		3.97		N.S.		N.S.

N.S. = no significant difference.

TABLE 5. The susceptibility of field margin species to six herbicides at fifteen weeks after treatment. Species in *italics* are significantly reduced in vigor compared to the unsprayed control. Mean score values in parenthesis 9 = control 0 = complete kill.

mecoprop		ioxynil + bromoxynil		isoproturon		clopyralid		diclofop-methyl		chlorsulfuron	
C.acanthoides	(0.0)	*C.acanthoides*	(0.0)	*A.millefolium*	(0.0)	*A.millefolium*	(0.0)	S.alba	(5.5)	*A.sylvestris*	(1.0)
C.maculatum	(0.0)	*C.maculatum*	(1.5)	*C.arvense*	(0.0)	*C.acanthoides*	(0.0)	A.millefolium	(8.5)	*C.arvense*	(2.5)
S.alba	(0.0)	*V.tetrasperma*	(4.5)	*U.dioica*	(0.0)	*C.arvense*	(0.0)	C.maculatum	(8.5)	*A.millefolium*	(4.0)
C.arvense	(1.0)	*L.album*	(6.5)	*S.alba*	(1.5)	*T.repens*	(0.0)	H.perforatum	(8.5)	*U.dioica*	(5.0)
V.tetrasperma	(1.0)	*H.perforatum*	(7.0)	*C.maculatum*	(2.5)	*V.tetrasperma*	(0.0)	A.sylvestris	(9.0)		
U.dioica	(3.0)	A.sylvestris	(8.0)	*R.sanguineus*	(3.0)	*C.maculatum*	(5.0)	C.arvense	(9.0)		
R.sanguineus	(3.5)	A.millefolium	(9.0)	*H.perforatum*	(4.5)	*R.obtusifolius*	(5.5)	R.sanguineus	(9.0)		
C.arvensis	(3.5)	C.arvense	(9.0)	A.sylvestris	(8.5)	*S.alba*	(5.5)	U.dioica	(9.0)		
A.millefolium	(4.5)	R.sanguineus	(9.0)	V.tetrasperma	(8.5)	*U.dioica*	(5.5)				
A.sylvestris	(6.5)	R.obtusifolius	(9.0)			*H.perforatum*	(6.0)				
H.perforatum	(8.5)	S.alba	(9.0)			A.sylvestris	(8.0)				
L.album	(8.5)	T.repens	(9.0)			R.sanguineus	(8.0)				
R.obtusifolius	(9.0)	U.dioica	(9.0)			L.album	(8.0)				
T.repens	(9.0)										
L.S.O. treated x control	1.84		1.42		2.52		1.45		N.S.		3.27
L.S.O. between species	5.16		5.11		4.02		5.24		N.S.		N.S.

N.S. = no significant difference.

Data from other experiments (Birnie 1984, 1985) have shown effects on a further range of grasses and dicotyledonous species. A summary of species markedly affected by herbicides is given in Table 6.

TABLE 6

Species seriously affected by herbicides, as shown by a score rating of 0 - 4 at the end of the assessment period.

Treatment	Species	
mecoprop	Carduus acanthoides	Brachypodium sylvaticum
	Conium maculatum	Agrostis stolonifera
	Silene alba	
	Galium aparine	
	Sisymbrium officinale	
	Vicia tetrasperma	
	Urtica dioica	
	Plantago lanceolata	
	Alliaria petiolata	
	Rumex sanguineus	
	Ranunculus repens	
	Cirsium arvense	
ioxynil + bromoxynil	Carduus acanthoides	
	Conium maculatum	
	Veronica persica	
	Alliaria peteolata	
isoproturon	Achillea millefolium	Agrostis stolonifera
	Cirsium arvense	Arrhenatherum elatius
	Urtica dioica	Brachypodium sylvaticum
	Silene alba	Poa trivialis
	Conium maculatum	Poa pratensis
	Ranunculus repens	Lolium perenne
	Rumex sanguineus	
	Leucanthemum vulgare	
clopyralid	Achillea millefolium	
	Carduus acanthoides	
	Cirsium arvense	
	Trifolium repens	
	Vicia tetrasperma	
	Plantago lanceolata	
	Leucanthemum vulgare	
chlorsulfuron	Galium aparine	
	Sisymbrium officinale	
	Myosotis arvensis	
	Anthriscus sylvestris	
	Cirsium arvense	
	Achillea millefolium	
	Geranium pusillum	
diclofop-methyl		Lolium perenne
		Arrhenatherum elatius
		Dactylis glomerata
		Festuca rubra
flamprop-M-isopropyl		Arrhenatherum elatius
		Dactylis glomerata

DISCUSSION

The results presented here and elsewhere (Birnie 1984, 1985) do not necessarily reflect the situation that would occur in the field, since herbicides, especially soil-acting compounds, may produce greater effects on pot- than field-grown material. It is probable, therefore, that plants which survived an application of a chemical at the doses used would survive similar applications in the field.

Species which were affected under the experimental conditions may also be affected in the field. The severity of that effect will depend on factors such as dose of chemical received, growth stage of the plant, weather conditions at time of spraying and whether the plant is an annual or perennial species. Some perennial species recovered from the single application of chemical, e.g. Rumex species treated with ioxynil+bromoxynil. Those species which have an underground storage organ, e.g. rhizome or tap root, may recover from herbicide applications (Bailey 1980), if the chemical used is not readily translocated throughout the whole plant. However, transient scorch or deformity may not be acceptable where the visual appearance of field edge plants is important. Annuals, even if they are susceptible, may survive to set viable seed. This will depend on the growth stage of the plants at the time of spraying.

CONCLUSIONS

Broad-leaved weed herbicides

Of the chemicals tested so far, mecoprop damaged the greatest number of species. This chemical is widely used in agriculture, either in mixture with other herbicides or on its own. Incorrectly applied, mecoprop is also known to cause ear deformities in cereals (Leafe 1956), and some cases of herbicide damage to broad-leaved crops, e.g. oilseed rape, are attributed to vapour drift of this herbicide (Eagle & Caverly 1981). In the light of the number of species affected, drift and vapour drift of mecoprop may pose a significant threat to field margin floras.

The other broad-leaved herbicides tested, ioxynil+bromoxynil, clopyralid and chlorsulfuron, were more limited in the numbers of species they affected. Given that increased herbicidal activity usually occurs in pot experiments these results suggest that few species would be affected from accidental contamination in the field.

Grass weed herbicides

With the exception of isoproturon, the grass weed herbicides were restricted in activity to the grass species. Of the species tested, B.sterilis and Elymus repens are the only grasses which were not significantly affected, compared to the untreated control by any of the herbicide treatments. Although few grass species actually died, several were restricted in growth, particularly by diclofop-methyl. This effect may be useful in a management situation where suppression of grass growth is desirable. The ability to manipulate grass growth could be a useful tool if competition between broad-leaved species and grasses is limiting diversity and growth.

ACKNOWLEDGEMENTS

We would like to thank the Perry Foundation for their financial support for the project and staff of the Weed Research Division for help and advice.

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