SESSION 3A

CEREAL CROP MANAGEMENT TECHNIQUES: EFFECT ON WEEDS AND WEED CONTROL

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GROWING PRACTICES - AN AID OR HINDRANCE TO WEED CONTROL IN CEREALS

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ABSTRACT

The development of cereal production systems over the last century and the part played by herbicides is described. Modern cereal production has increased the need for effective weed control owing to the breakdown of traditional rotations, non-ploughing techniques, earlier drilling, increased fertiliser usage and new varieties. It is concluded that modern herbicides have largely met the challenge of changing husbandry or indeed their availability has permitted such changes. However, there are still some technical problems remaining to be answered. The current surplus of cereal production within the European Economic Community may lead to changes which will result in less herbicide in general being used. However, the availability of effective herbicides provides the farmer with the flexibility to grow the maximum area of the cereal crops most suited to his soil and climate.

INTRODUCTION

Farmers have always responded to outside pressure on their farms and this is reflected in the area of cereals grown in England and Cambridgeshire over the last century or so (Table 1). 1875 marked the end of what was known as the "Golden Age" of farming when the cereal acreage in the arable east, long regarded as the granary of England, was virtually half the area under tillage and permanent pasture. Subsequently the cereal area declined but with the second world war, the 1947 Agriculture Act and the introduction of guaranteed prices, the area of cereals gradually increased from the low point reached in the 1930's. After joining the Common Market in 1973 and the world price increase of that year, the economic returns from cereals were very high and this, coupled with forecasts of world shortages of food (FAO, 1962), resulted in the continuing increase in the area of cereals (Table 2).

Together with the steady increase in cereal area over the last few decades have come dramatically increased yields (Table 3), so much so that the 1960's forecast of a food shortage now seems a long-distant memory. Naturally, everyone is aware and concerned that not by any means is the whole of the world's population fully fed.

These increases are due to many factors including plant breeding, mechanisation of the crop, field drainage, artificial fertilisers and pesticides. This paper deals with the role of herbicides in this story of technical success.

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TABLE 1

Percentage of land in crops, fallow and permanent pasture devoted to cereal production, 1875-1985 (UK Ministry of Agriculture, Fisheries and Food, 1987)

Year	Cambridgeshire	England
1875	45	28
1935	33	17
1965	55	34
1975	59	36
1985	64	40

TABLE 2

Area of cereals, oilseed rape and total tillage in England and Wales (in '000 ha) (UK Ministry of Agriculture, Fisheries and Food, 1987)

Year	Wheat(1)	Winter Barley	Spring Barley	Rape for Oilseed(1)	Total Tillage
1973	1,114	1873(2)		14	4,154
1977	1,054	1941(2)		55	4,173
1978	1,236	1866(2)		64	4,237
1979	1,347	576	1,279	74	4,285
1980	1,413	721	1,108	92	4,315
1981	1,458	790	1,042	125	4,360
1982	1,620	828	886	173	4,401
1983	1,645	837	807	218	4,404
1984	1,865	917	573	257	4,462
1985	1,816	929	574	272	4,519
1986	1,903	891	556	276	4,532

(1) Virtually all autumn sown
(2) Winter and spring barley not recorded separately

TABLE 3

Average yields (tonnes/ha) of wheat and barley in Great Britain, 1885-1985 (Home Grown Cereals Authority, 1986)

	1885-1894	1935-1944	1945-1954	1955-1964	1965-1974	1975-1984
Wheat	2.035	2.335	2.622	3.598	4.183	5.561
Barley	1.984	2.143	2.473	3.261	3.740	4.394

THE ROLE OF HERBICIDES IN THE DEVELOPMENT OF THE MODERN FARMING SYSTEMS

In 1875, rotations were balanced and based on the need to "weed and feed" crops. The purpose of the break crops was to clean or provide the opportunity to hand weed the land and/or produce nitrogen residues. In addition, farmyard manure was used to feed crops. Green forage crops, temporary clover leys, beans and peas were all a significant feature of farms in the arable east (Table 4). Potatoes accounted for a relatively low proportion of the area. Rotations were strict and this meant that crops were frequently grown which were not ideally suited to the land or climate.

The steady introduction of fertilisers from outside sources and eventually artificial fertilisers reduced the need for break crops with nitrogen rich residues. However, rotational farming continued in a less strict form until the 1950's. Since then there have been dramatic changes in cropping owing to the introduction of effective herbicides.

The first organic herbicides were introduced in the late 1940's and their immediate impact was on the cereal crop. By 1960, a large proportion of the cereal acreage was sprayed.

TABLE 4

Percentage of land in crops, fallow and permanent pasture devoted to specific crops, Cambridgeshire (UK Ministry of Agriculture, Fisheries and Food, 1987)

Crop	1875	1975	1985
Cereals	45	59	64
Green forage	13	1	0.25
Temporary leys	8	3	1.5
Permanent pasture	19	9	7
Beans and peas	8	3	3
Potatoes	2	5	4
Sugar beet	-	9	9
Oilseed rape	-	1	5

Although during the 1950's the need for a rotation was reduced, the complete spectrum of weeds, particularly those encouraged by autumn sowing of the crop, could not be controlled. There often remained a need to sow a significant proportion of the area to spring cereals (which were and are potentially lower yielding than autumn sown cereals) and other spring sown crops. However, with better drainage on heavy soils and improvements in machinery, there was an increased need for herbicides to control the weed species encouraged by autumn sown cereals. Mecoprop was introduced in 1957 and could control *Galium aparine* (cleavers) and *Stellaria media* (common chickweed). In 1958, barban was introduced for the control of the growing menace of *Avena fatua* (wild-oats). Tri-allate, which also controls *A. fatua*, was introduced in 1964 and like barban, it also had some effect on *Alopecurus myosuroides* (black-grass). This was being noted on heavy land with rotations which contained a relatively high proportion of autumn sown cereals. This weed was and is effectively controlled by herbicides of the urea group. Chlortoluron was introduced in 1971 and isoproturon in 1975. These herbicides, along with earlier introductions of terbutryn (1968) and methabenzthiazuron (1968), provided effective control of Poa species. These herbicides, along with later introductions such as difenzoquat (1974) and the esters of N-arylalanines for the control of A. fatua, allowed the intensive growing of autumn sown cereals. The broad-leaved weeds such as the Veronica spp. (speedwells) and G. aparine (cleavers) were controlled by bromoxynil (1971) and ioxynil (1970), usually in mixtures with mecoprop. Glyphosate was first introduced in 1974 and was recommended post-harvest of cereals for the control of Elymus repens (common couch). The introduction of the pre-harvest recommendation (O'Keeffe 1980), in many ways completed the control of the major weeds which were occurring in continuous winter cereals, by the use of herbicides and without the need to adjust crop husbandry specifically for weed control. For many weeds there have been more recent and sometimes more effective introductions not mentioned in this paper. This ability to control weeds has enabled farmers to grow crops most suited to their resources. Heavy land farming has been revolutionised by the fact that continuous autumn sown cereals can be grown. Much of the yield increase of such rotations has come, not just from the use of higher potential autumn sown crops but by avoiding the need for spring sown crops and late sown autumn crops, the establishment of which can lead to damage of the soil structure. Other pesticides, especially fungicides, have also played their part in the evolution of current farming systems.

However, there are some weeds which are still difficult to control with herbicides in autumn sown cereals. These weeds have been encouraged by agronomic practices over the last ten years; such as earlier drilling, minimum tillage, increased specialisation and less herbicide application in the spring to autumn sown crops. Examples include volunteer cereals, volunteer potatoes, Bromus sterilis (barren brome), Bromus commutatus (meadow brome) and Cirsium arvense (creeping thistle).

USE OF HERBICIDES IN CEREALS

Historical data on the use of herbicides in cereals is difficult to obtain. Recent usage is recorded in Table 5 and indicates that herbicide products per unit area increased significantly in winter wheat and winter barley during the period 1977 to 1982. Much of this increase is explained by the greater use of soil applied herbicides for the control of A. myosuroides and the Poa species which were encouraged by the increasing adoption of continuous autumn sown crops (Moss, 1978). Additional information suggests that the area sprayed against A. myosuroides has increased further since 1982 (Farmstat, 1987).

THE CHALLENGE TO HERBICIDES FROM MODERN AGRONOMIC PRACTICES

There is no such thing as a typical rotation. However, the strongest challenge to herbicides tends to come in a monoculture of autumn sown crops where many annual grass weeds as well as autumn germinating broad-leaved weeds are encouraged. A further boost is given to certain weeds by the adoption of minimum tillage, "earlier" drilling dates and high nitrogen rates. Modern wheat varieties are short strawed and often do not produce a significant canopy and so, in theory, are less competitive to weeds.

This does not suggest that all problems are related to such rotations and very short rotations have led to problems with volunteer crops eg weed beet, groundkeeper potatoes and volunteer cereals which are an increasing hazard in the cereal crop itself.

TABLE 5

Use of herbicides in cereals in England and Wales, 1977-1982 (Sly, 1981; Sly, 1986)

		1977	1982
Number of herbicide products/ha:-			
	all cereals	1.39	1.96
	winter wheat	1.54	2.32
	winter barley	1.21	1.92
	spring barley	1.38	1.43
Percentage of winter wheat and winter barley area receiving:-			
	tri-allate	4.7	5.8
	chlortoluron	4.3	24.2
	isoproturon	11.5	22.6
	linuron/trifluralin	-	11.8

Owing to commercial competition, the cost of herbicides recommended for cereals is relatively lower than for other crops. In addition, annual broad-leaved weeds are easier to control in a monocotyledonous crop such as cereals. Therefore, cereals are now commonly looked upon as the "cleaning" crop of the rotation. This is particularly so for the control of *E. repens*, *G. aparine* and *Viola arvensis* (field pansy).

Continuous autumn sown crops

One marked aspect of the traditional rotation was that crops had varying drilling dates, particularly autumn, spring and late spring and therefore, had complete crop canopies occurring at various times of the year. This meant that any one weed species was denied the opportunity to take advantage of a favourable environment and gain dominance.

The opposite applies with continuous autumn sown crops. Weeds which share the same growth cycle as winter cereals and oilseed rape are encouraged. The prime example of this is *A. myosuroides* on heavy soils, *Poa annua* (annual meadow-grass) on light soils and *Poa trivialis* (rough meadow-grass) on the heavy soils in the north and west of Great Britain. *A. fatua* can also be encouraged by this rotation, owing to the fact that a significant proportion of the plants can be established in the autumn. High levels of control are required annually to contain these weeds (Cussans & Moss, 1982).

Not surprisingly, autumn-germinating annual broad-leaved weeds are also encouraged by this system. *V. arvensis*, *G. aparine* and the *Veronica* spp. are now very significant weeds in winter cereals (Chancellor and Froud-Williams, 1984).

Non-ploughing techniques

The area of winter cereals, established by non-ploughing techniques, increased dramatically in the 1970's. This further encouraged the small seeded grasses which emerge usually from the top 5 cms of soil (Cussans *et al*, 1979). Perennial grasses are encouraged by direct drilling.

Minimum tillage, as opposed to no soil disturbance, will encourage annual broad-leaved weeds in the short term. However, with the use of effective herbicides, the seed banks of some species will become exhausted in the layer of disturbed soil. The annual broad-leaved weeds which tend to be encouraged by minimal tillage include *G. aparine*, *S. media*, *Veronica persica* (common field-speedwell), *Geranium* spp. (the cranesbills) and *Lamium* spp. (dead - nettles.) Annual broad-leaved weeds which withstand the ploughing process are those which have prolonged seed dormancy and can form significant seed banks in the soil. Examples of this are *Papaver rhoeas* (common poppy), the *Polygonum* species and the brassica weeds such as *Sinapis arvensis* (charlock) and volunteer oilseed rape. All of these can be controlled in winter cereals by the older herbicides MCPA, dichlorprop or mecoprop, provided that the weeds are small at the time of application. Hence, minimum tillage has encouraged the very pernicious weed *G. aparine* and some other broad-leaved weeds which until recently have been difficult to control reliably. Herbicide introductions over the last five years have meant that all annual broad-leaved weeds in cereals can be controlled adequately.

"Early" drilling of autumn sown cereals

Traditionally, sowing of autumn cereals was around mid-October but now cereals are usually drilled in southern and central England in late September to early October and August drilling is not uncommon in Scotland. This practice may not lead directly to a yield increase but there is a large indirect benefit: by avoiding drilling too late for optimum yield and by avoiding possible consequent damage to soil structure due to poor weather conditions. These indirect benefits have played a very significant part in the increase in average yields over the last few years. The better and more even establishment of autumn sown crops from earlier drilling and drainage may lead, at times, to a reduced establishment of weeds in the spring and summer.

Significant emergence of most autumn germinating weeds usually starts in early September and continues to mid-November. In general, the earlier a crop is drilled in this period, the more weeds will establish within the crop. With many annual grass weeds, this results in a higher standard of control being required (Moss 1985a) and with annual broad-leaved weeds, there is a need for emphasis on control in the autumn.

Earlier sowing has resulted in new annual broad-leaved weed species occurring in winter cereals. Both *Lamium purpureum* (red dead-nettle) and *Geranium* spp. are typical late summer germinators and are also favoured by minimum tillage. They were first noted as being significant weeds in oilseed rape, which is normally sown at the end of August, but are now significant weeds in early sown cereals. Once again, recently introduced herbicides mean that these weeds can now be controlled effectively.

Early sowing has contributed to two fairly intractable weed species. B. sterilis has little innate dormancy and will germinate once conditions of moisture and light are met. However, the lack of dormancy and its inability to emerge from depths of over 12.5 cms means that it can be controlled by ploughing. If the weather is dry between seed shedding and the establishment of a winter cereal crop by non-ploughing techniques, the weed can very effectively establish its position. Therefore, the problem is exacerbated by early drilling and minimal tillage. B. sterilis has proved very difficult to control reliably with herbicides alone: it has caused farmers to resort to cultural control or a combination of both. However, very recent trials suggest that there may be a herbicide in development which will give reliable control (Rule, 1987).

Cirsium arvense (creeping thistle) is of increasing importance in some parts of the country, particularly where early sown winter cereals share a rotation with spring sown broad-leaved crops, on the lighter soils in the eastern counties. One of the indirect reasons for this expansion of infestation is the earlier drilling of winter cereals. The crops are now often too advanced in the spring for the application of "hormone" herbicides, such as MCPA and mecoprop, which are still some of the most effective herbicides for the selective control of this weed (Davies & Orson, 1987). The control of this weed in cereals is proving to be very difficult indeed, particularly if conditions do not favour the pre-harvest applications of glyphosate.

Winter cereal varieties

New cereal varieties have progressively produced less straw over the last few decades. This progression to shorter varieties has probably led to wheat being less competitive to weeds. This is confounded by the fact that higher nitrogen rates are now used, which produce more leaf area on the individual crop plants, and the better establishment of crops achieved in recent years. Therefore, definitive conclusions of the relative competitiveness of the crop to weeds, for example now as opposed to forty year ago, are very difficult to draw. It is interesting to note, however, that farmers have observed that the plant growth regulator chlormequat, applied immediately prior to the first node detectable stage of winter wheat, does reduce the crop's ability to compete with weeds. Some "organic" farmers have requested plant breeders to produce longer straw varieties in order to help stifle weeds in a system which does not use herbicides which have been produced from organic chemistry.

Andersson (1986) demonstrated that crop canopy can have a major influence on annual broad-leaved weed control but he adjusted this by seed rate and row width rather than by crop height. Moss (1985b) produced data on the competition of A. myosuroides in varieties of winter barley and wheat with different straw height. He concluded that taller wheats withstood competition better than shorter wheats, although differences in competitive ability were not related simply to either crop height or tillering capacity. Like Andersson, he noted that high crop seed rates gave the crop a competitive advantage over low seed rates.

The swing from the more competitive winter barley to winter wheat (Table 2) may not have aided weed control measures.

Fertiliser

The average nitrogen usage on winter wheat increased dramatically from 74 kg/ha in 1975 to 192 kg/ha in 1985 but now appears to be stabilising (Agricultural Development and Advisory Service, 1986).

Thurston (1959) reported that in a pot experiment the dry matter yield of *A. fatua* and *Avena sterilis* sub sp *ludoviciana* (winter wild-oat) responded to increased nitrogen in the same manner as winter wheat and winter barley but more rapidly than spring barley. Visual observations of ADAS straw incorporation trials, where rates of nitrogen have been evaluated, suggest that *B. sterilis* responds more to nitrogen than does winter wheat (Lord, 1987).

Recent experimental work in Germany (Pulcher-Haussling & Hurle, 1986) indicates that all the annual broad-leaved weeds, which were present in a field trial, responded more in dry weight to nitrogen than did the winter wheat. Among these weeds were the nitrophilic and competitive weeds *G. aparine* and *S. media*. In the same trials, *A. myosuroides* also responded more to nitrogen than did the winter wheat. The experimental workers concluded from their observations that broader spectrum weed control was required because of the increased capacity of surviving weed species to compensate for poor control.

This data, although limited, suggests that weeds respond to nitrogen at the same or increased rate of dry matter as cereals. This increase almost certainly means that the higher rates of nitrogen used have led to the requirement for more effective weed control and perhaps a wider spectrum of control.

CONCLUSIONS

The increase in yield of cereals over the last thirty years has been a great technical success. Efforts have been made to allocate the role of specific factors in this yield increase (Silvey, 1981). However, the reasons have been far too complex to pinpoint responsibility on one particular factor. Increased field drainage, mechanisation, better varieties, fertilisers as well as pesticides, have all played a role.

It is easy to underestimate the part played by herbicides. As well as the direct role of protecting the yield of the current crop, they have allowed, with fertilisers, specialisation of cereals to land most suitable for their production. With fungicides and insecticides, herbicides have allowed earlier drilling of winter cereals, resulting not only in the great majority of the crop being drilled at the optimum time but also in the indirect benefits to soil structure. The role of herbicides is most amply demonstrated on the heavy soils in the east of England, where farming systems and the yield potential of crops have been transformed. In fact, for many farmers, the cereal crop is now looked upon as a cleaning crop, where weeds difficult to control in the other crops can be controlled cheaply and effectively. However, some problem weeds still exist.

All industries have to live in a range of "climates"; economic, ethical, technical, political etc. In each of these climates, the agricultural industry, in this country and much of the world, is under pressure. Food surpluses in the more developed countries are likely to lead to more economic pressures, as well as weakening the political strength of the industry. The use of pesticides in general is being questioned by an increasingly larger proportion of the population of this country and there is more demand for "organically" grown food. "Ethical issues" are also leading to an increase in the number of vegetarians (Gallup 1986). This is an important issue for the cereal grower, as between 40-50% of UK cereal production is used for animal feed (Home Grown Cereal Authority, 1986). Production of meat from cereals is an inefficient process and so a drop in demand for meat consumption would not be compensated for by an increase in human consumption of cereals.

There are technical pressures on herbicides which are beginning to come to the fore. The resistance of _A. myosuroides_ is the most dramatic of these. It is perhaps the first real technical challenge to be encountered, which questions the systems of continuous autumn grown cereals established by minimum tillage. Therefore, the problem posed is whether the current systems of production could be sustained if there were sufficient demand.

The organic farming movement claims that modern farming methods, relying on pesticides and chemical fertilisers, are not sustainable. This may or may not be true. However, the same question must be asked of the organic movement, which often relies on cereal seed grown with the use of pesticides and which often imports a significant proportion of plant nutrients from outside the farm. Also, true organic food production itself may not be sustainable in other ways. On arable organic farms, there appears to be an acceptance that the maximum area of an arable farm to be devoted to cereals should be approximately 50%. It is usually suggested that the other 50% should be devoted to grassland if the soil is not suited to vegetable production. Meat production is already in surplus within the EEC.

It is for the very reason of the inflexibility of "organic" farming that herbicides were first used. Whatever happens in terms of future demand for products from temperate regions, the availability of effective herbicides provides the farmer with the ability to grow the maximum area of cereal crops demanded and those which are most suited to his soil and climate. In this context, herbicides are often an underestimated resource which should be used wisely and with care.

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STRAW DISPOSAL TECHNIQUES AND THEIR INFLUENCE ON WEEDS AND WEED CONTROL

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ABSTRACT

Straw disposal affects weeds and their control directly and indirectly. Straw burning kills many seeds and reduces dormancy of the survivors. The indirect effects of straw disposal are mainly due to changes in tillage system associated with straw disposal. Shallow stubble cultivations appear to be beneficial in stimulating germination of brome grasses (*Bromus* spp.) and volunteer cereals so that the seedlings may be killed before establishing the next crop. In contrast stubble cultivations have a lesser effect on the germination of wild oats (*Avena fatua*) and black-grass (*Alopecurus myosuroides*). The choice of mouldboard ploughing or shallow tine cultivation systems also has a powerful effect on weed populations. Non-ploughing regimes favour brome grasses and black-grass so strongly that they may be impracticable without straw burning. The need for an integrated approach is stressed and population modelling is proposed as a useful adjunct to experimentation.

INTRODUCTION

The period between maturation of one cereal crop and establishment of the next is a vital one for weed populations. Large numbers of seeds are produced which may be shed before harvest, removed in the grain, or remain in the field with the straw and chaff fraction. During the period after harvest high natural mortality of seeds has been observed. Birds and small mammals take many seeds. Some germinate prematurely or lose dormancy and die without producing a seedling. Wilson & Cussans (1975) found two periods of heavy loss of wild-oat seeds (*Avena fatua*), from the stubble in autumn and during major periods of germination in the spring.

There have been surprisingly few studies of maturation of weed seeds either alone or relative to the maturation of crops. Wilson (1970) described the course of maturation and shedding of wild-oats in a number of crops in Oxfordshire and Cambridgeshire and Moss (1983) has made similar observations for black-grass (*Alopecurus myosuroides*). There is substantial variation between sites as well as between species. The grass weeds tend to shed their seeds before harvest except in the case of early harvested winter barley crops. In contrast, cleavers (*Galium aparine*) tends to shed its seeds late so that grain from late harvested winter wheat crops may be heavily contaminated.

A change in the straw disposal technique may have a major influence on the eventual outcome of all these processes, either directly or as a result of the tillage regime which may be changed as part of the straw disposal method. This paper reviews the subject, with special reference to the grass weeds, wild-oat and black-grass.

THE EFFECTS OF STRAW BURNING ON WEED SEED SURVIVAL

Direct effects

Straw burning generates very high temperatures, although these vary with quantity and moisture content of straw and with wind speed. The distribution of the straw, e.g. in swathes, spread or chopped, will also influence temperatures and the proportion of the ground affected. Within a thick swathe the straw may burn very fiercely, generating a peak temperature of over 700°C at ground level and over 1000°C 15 - 20 cm above the soil surface. Wilson & Cussans (1975) found temperatures at ground level beneath burning swathes reached an average peak temperature of 500°C and a temperature over 200°C was maintained for 1 - 2 min on average. Moss (1980) recorded rather lower temperatures beneath straw. It is comparatively easy to measure the effects of temperature on seed survival in a laboratory oven and Table 1 shows some data for black-grass (Moss 1980).

TABLE 1

Time required in an oven to reduce germination of black-grass seeds by over 90%

	Time (s)	
Temperature (°C)	Dry seed	Imbibed seed
100	300	300
150	60	300
200	40	50
300	10	30
400	10	10
500	5	5

The temperature/time relationships are broadly similar for wild-oat although with this species moist or imbibed seeds seemed to be just as vulnerable to heat as dry seeds. These laboratory records have been confirmed by results in field experiments. Wilson & Cussans sampled seeds from the surface of plots on four occasions and the results are shown in Table 2.

TABLE 2

Viable seeds of wild-oat on the soil surface (thousands/m^2) 1 week after burning

	Sept	Oct	Nov	Dec
Burnt stubble	2.94	2.58	2.45	1.17
Unburnt stubble	4.34	3.34	3.15	1.43

The data in Table 2 show the substantial effect of burning and the extent of natural seed losses which may occur if stubbles are left undisturbed for long periods. Some seeds, possibly the most recently shed fraction which had had least time for self burial, may have been most vulnerable both to burning and to natural losses. The loss due to burning recorded in September (32%) was substantially higher than that recorded in

December (18%). These data were calculated to integrate both the area beneath the swathes and between swathes, where straw burning had no observable effect. In the areas immediately below the swathe, the effect of burning was substantial (68% kill) although, as above, the effect declined during the autumn to 49%. Moss (1980) recorded a 94% reduction in black-grass seed numbers in October following burning of 4.2 t/ha of straw. Thus, this weed was more affected by rather lower temperatures than was wild-oat. The amount of straw, and thus the temperature, was very important. Five times as many plants were recorded in spring after burning 2.1 t/ha of straw as after 6.3 t/ha.

Indirect effects of straw burning

Those seeds which are not killed outright may be modified in their behaviour by burning. The most common observation has been a loss of innate dormancy. Wilson & Cussans (1975) determined viability and dormancy of wild-oat seeds removed from the soil surface beneath the straw swathes (Table 3).

TABLE 3

Viable wild-oat seeds/m^2 collected from beneath straw swathes

	Sept	Oct	Nov	Dec
Burnt plots				
Non-dormant	786	570	108	22
Dormant	947	861	850	678
Unburnt plots				
Non-dormant	75	248	301	0
Dormant	5393	3229	2519	1398

At the time of the first assessment, 55% of the seeds which survived burning were dormant in contrast to 99% on the unburnt plots. Burning decreased total viable seeds by 68% but increased the numbers of non-dormant seeds by about ten-fold. These data also show that there was a natural loss of dormancy of the surface seeds, with time, on unburnt plots and this was associated with loss of total viable seed numbers. Moss (1980) recorded similar but less striking effects on blackgrass, a species with rather less pronounced seed dormancy (Table 4).

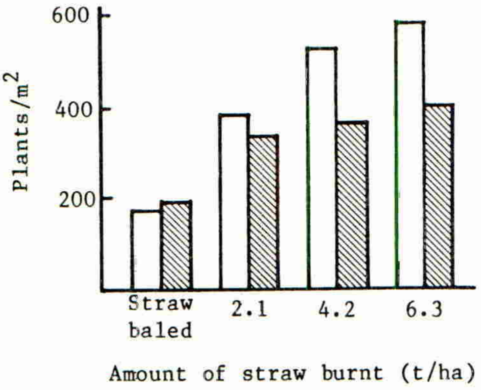
These results show that seeds which survived on the surface or when buried at 2 mm germinated more rapidly than those more completely protected from the burn even though the absolute number of seedlings was reduced due to kill of seeds.

These data, to some extent, confound kill of seeds with speed of germination. They may also combine the results of direct and indirect effects on the seeds. Moss also placed some seeds on the soil surface after straw treatment had been concluded. Figure 1 shows that more plants were produced on soil where straw had been burnt and that this effect increased with increasing amounts of straw.

TABLE 4
Germination of black-grass seeds buried at different depths in the soil prior to straw burning

Depth of seeds during burning (mm)	% germination at		% of total germination after 2 weeks
	2 weeks	18 weeks	
Surface	3	4	75
2	25	53	47
5	16	63	25
10	15	57	26
No burning	17	65	26
S.E.	±1.5	±2.2	±3.0

FIGURE 1
The number of black-grass plants in direct-drilled winter wheat in autumn 1977 (open bars, S.E.± 30.7) and in spring 1978 (hatched bars, S.E.± 8.9) when the seeds were applied after burning.



There appear to be important phenomena involved in the effects of burning on seeds, which are complex and for which we have no really satisfactory explanation. At least two elements are involved; the reduction of innate dormancy by the physical effects of burning, and some effect on the environment such that more plants establish after burning than on unburnt soil, even with seeds which have been protected from the direct effect. This direct effect on seed dormancy may be a damage response. The technique of pricking seeds with a sharp needle to break dormancy is consistently successful although we still do not fully understand how it works. It seems likely that the stimulus to germination by burning is of a similar nature.

The effects on the soil environment are even less clearly understood and can only be the subject of conjecture. It is possible that soil physical conditions are improved in some way; even a small improvement in tilth could result in better contact between seeds and soil moisture on the surface of untilled soil. Alternatively, it may be that decaying straw residues on unburnt plots affect seedling development and burning removes this constraint (McCalla & Haskins 1964, Lynch & Harper 1977). The blackening produced by burning increases temperature at the soil surface during the day and reduces it at night and this may be significant. Finally, and least likely, there may be some stimulatory effect of the gaseous products of combustion. The smoke produced by burning straw contains ethylene and carbon monoxide in sufficient concentration to have plant growth regulatory effects on some species (Imanishi 1983).

In summary, straw burning has major effects on weed seed survival. The effect on seedling numbers may be an imperfect reflection of the seed mortality which has occurred because of the effects on seed dormancy. The death of seeds is always beneficial from the agricultural point of view but the reduction in seed dormancy by burning has a mixture of beneficial and deleterious effects. When burning is followed by a spring sown crop and/or where total kill of seedlings is possible, the stimulation of seedling emergence adds further to the depletion of the soil seed bank and is thus entirely beneficial. With autumn sown crops, particularly with the modern tendency to sow very early, the situation is not so clear cut. The weeds which emerge early in the life of the crop are the most competitive and stimulation of early germination thus has dangers. Burning cannot therefore be considered in isolation from the other husbandry practices.

THE EFFECTS OF STUBBLE CULTIVATIONS

One of the traditional techniques in arable farming areas has been the shallow cultivation of cereal stubbles after harvest, several weeks before the main primary cultivation which, traditionally, would have been mouldboard ploughing. The objectives were: disruption of the rhizome system of perennial weeds; stimulating seeds of annual species to germinate and improved quality of the eventual burial of surface trash and vegetation.

The subject had become almost academic with the advent of improved herbicides for the control of perennial weeds. However, the need to incorporate straw has revived interest. There has been a belief that shallow admixture of straw accelerates decomposition and may aid final burial. It is therefore relevant to review the effects of these cultivations on weeds.

TABLE 5

The influences of straw burning and stubble cultivation on emergence of wild-oat seedlings in Autumn 1972. (a) Total seedling emergence/m^2. (b) Seedling emergence as % of the viable seeds available in September.

	Stubble cultivated		Stubble uncultivated		Mean
	(a)	(b)	(a)	(b)	(a)
Straw burnt	350	11.9	102	3.5	226
Straw not burnt	141	3.2	31	0.7	86
Mean	246		67		

Wilson (1972) and Wilson & Cussans (1972, 1975) showed that most losses of wild-oat seeds were from undisturbed stubbles. Cultivation had the effect of protecting seeds from this phenomenon. Stubble cultivations (in this work, rotary cultivation to a depth of 8 cm) did indeed stimulate some seeds to germinate but it was not sufficient to cause a significant wastage of the soil seed bank. Table 5 taken from Wilson & Cussans (1975) illustrates this point.

One of us (S.R.Moss) recorded the effects of straw burning and stubble cultivations as part of a population dynamics experiment. There were all combinations of +/- burning and +/- stubble cultivation. Straw (3 t/ha) was burnt on 19 August 1982 and cultivations with a Machio power harrow to a depth of 5 cm were done on 23 August. On 20th August soil samples were taken to a depth of 5 cm and seeds of black-grass and volunteer wheat surviving burning were extracted and numbers of viable seeds determined. The numbers of plants of black-grass and wheat were counted on 1 October before drilling the next crop, on 15 October. Table 6 shows the numbers of seeds and Table 7 show the effects of burning and shallow tillage on the autumn germination.

TABLE 6

Viable seeds/m^2 in the soil on 20 August, 1 day after burning

	Burnt plots	Unburnt plots
Black-grass	8100	17500
Volunteer wheat	43	223

TABLE 7

Number of black-grass and volunteer wheat plants/m^2 on 1 October and their number as a percentage of the total number of viable seeds present in the soil on 20 August

	No stubble cults Plants				Stubble cults to 5 cm Plants			
	Black-grass		Wheat		Black-grass		Wheat	
	/m^2	as %	/m^2	as %	/m^2	as %	/m^2	as %
Burnt	2760	34	13	30	4570	56	26	60
Unburnt	6640	38	57	25	7200	41	150	67

These data show that stubble cultivations do have a stimulatory effect on seedling emergence. This was greater with wheat than with blackgrass. Although cultivation stimulated some black-grass seeds to germinate this was not reflected in a greater diminution of the seed bank in the following June (mean black-grass seeds/m^2; after cultivation = 3780, no stubble cultivation = 3420). These results challenge the traditional practice of shallow cultivation to stimulate germination of seedlings which could be killed before sowing the next crop. It appears that black-grass and wild-oat both show substantial natural mortality if left on the surface of undisturbed stubble. Shallow tillage prevents this loss of seeds so that the "fatal" germination which it undoubtedly stimulates is of little practical value. The stimulation of germination of shed grain and barren brome (Bromus sterilis) may be of more practical value but even this would be weather dependent and would not fit into the modern practice of early sowing.

THE EFFECTS OF PRIMARY TILLAGE

One of the major consequences of the current interest in straw incorporation has been the added stimulus to the revival of mouldboard ploughing. Tillage practice changed in the 1960s and 1970s from ploughing towards simplified systems, mostly based on tine cultivation. A small proportion of our winter sown crops was established by direct drilling but this never increased to more than 5 or 10% of the area. Non-ploughing techniques probably reached a peak towards the end of the 1970s when they became the majority practice. Since then, sales of ploughs have almost doubled and simple roadside surveys suggest a substantial increase in the ploughed area.

Soil inversion by ploughing is known to have a major effect on the weed flora. The subject has been reviewed extensively (Cussans 1976, Cussans *et al*. 1979) and we need not review all the evidence here. Some weed species can be characterised as "long cycle" species notably *Polygonum aviculare*(knotgrass), *Sinapis arvensis* (charlock) and *Papaver rhoeas* (common poppy). Seeds produced by such plants have marked dormancy and great longevity. In any one season, plants can be produced only by the (often small) proportion of the seed bank which has been released from dormancy and is in a suitable position in the upper layers of the soil to germinate successfully. Such "long cycle" weeds appear to be well adapted to mouldboard ploughing. Annual inversion of the surface soil buries newly shed seeds and thus protects them at a time when they would be unlikely to germinate. Ploughing in subsequent seasons brings these seeds back towards the soil surface. Physical abrasion, exposure to light and aeration help to release a proportion of the seeds from dormancy and their positioning in the upper soil layers makes successful seedling emergence more likely.

In marked contrast, the grass weeds and a few broad-leaved species (notably cleavers) are "short cycle" species. They produce seed with relatively weak dormancy and comparatively short life span. Barren brome seeds generally only persist for one year whilst even wild-oat and black-grass have a maximum life span of six to ten years compared with 50 or 60 years for many of the "long cycle" species. Burial of freshly shed seeds by mouldboard ploughing prevents these "short cycle" plants from exploiting their seed producing capacity because few seedlings will establish successfully if the seeds germinate at depth. When the land is reploughed, short cycle species cannot benefit if insufficient seeds remain viable when brought back towards the surface to increase the population.

Some species are intermediate in behaviour and appear equally well suited to inversion and non-inversion tillage systems. Common chickweed (*Stellaria media*) is a good example. These responses have been characterised by Pollard, *et al*.(1982).

These are generalisations and they cannot be considered in isolation from the herbicides available. Some weeds are so easily controlled that they do not create a problem even when favoured by the husbandry system. Others, notably cleavers, brome and black-grass, are difficult to kill with herbicides so that they may be a problem in any system but a major threat in minimum tillage regimes. Even with these caveats there can be no doubt that the choice between ploughing and some other form of soil mixing for straw disposal will have a major influence on weed populations.

Unless or until improved herbicides are developed, we believe that straw incorporation systems which do not involve mouldboard ploughing, at least on a rotational basis, are too vulnerable to black-grass and, especially, to barren brome to be viable in the long term. Short term results may be satisfactory and it may be possible to keep clean fields free from infestation by rigorous hygiene. However, these are very common weeds and if they do become established the population increases in such systems are likely to outstrip the capacity of current herbicides to contain them.

EFFECTS OF STRAW DISPOSAL ON HERBICIDE EFFICACY

Some tillage systems require a higher standard of herbicide performance than others so that the effects of cultural practices and herbicide availability cannot be considered in isolation. Unfortunately, some herbicides are less active in minimum tillage systems because they are adsorbed by carbonised straw residues, with consequent reduced efficacy. The subject was reviewed in depth by Moss (1984). This problem remains one of the major causes of poor herbicide performance today. (J.H. Orson pers. comm.).

Some tine cultivation programmes can leave large quantities of straw on the soil surface and herbicide performance may be reduced in these conditions. This appears to be due to a "thatching effect" whereby spray which is intercepted by surface straw reaches the soil by wash off too slowly to exert maximum effect, or is partially degraded before reaching the appropriate level in the soil. Further studies are in progress on this topic.

THE NEED FOR INTEGRATED APPROACHES

We have seen that straw burning is beneficial, by killing seeds, but also harmful, in reduced tillage systems, by increasing herbicide adsorption. The practice of straw chopping and incorporation presents us with another paradigm. Straw chopping in contrast to burning allows weed seeds to survive but may be beneficial if it encourages a return to mouldboard ploughing. Quite clearly, an integrated approach is needed because so many factors are involved.

In our research group, we have tried to resolve this by a combination of carefully observed field experiments, detailed studies on individual aspects of the problem and modelling to achieve a holistic approach. One basic use of such a model is to calculate the theoretical performance required from a herbicide to maintain a static weed population. This sets a basic requirement for a management regime. The approach has been described by Cussans & Moss (1982) for blackgrass and by Cussans (1975) and Wilson, Cousens & Cussans (1984) for wild-oats. Table 8 shows the values calculated for blackgrass for four management systems.

These calculations give a good indication of the relative importance of the factors under consideration. They suggest that the herbicides currently available are more than adequate to contain black-grass in a ploughing regime, even where straw is incorporated. In contrast direct drilling or very superficial cultivation systems require a standard of weed control which is attainable but towards the upper limit of what is possible. Figure 2, based on the same model, shows the long term outcome if herbicide

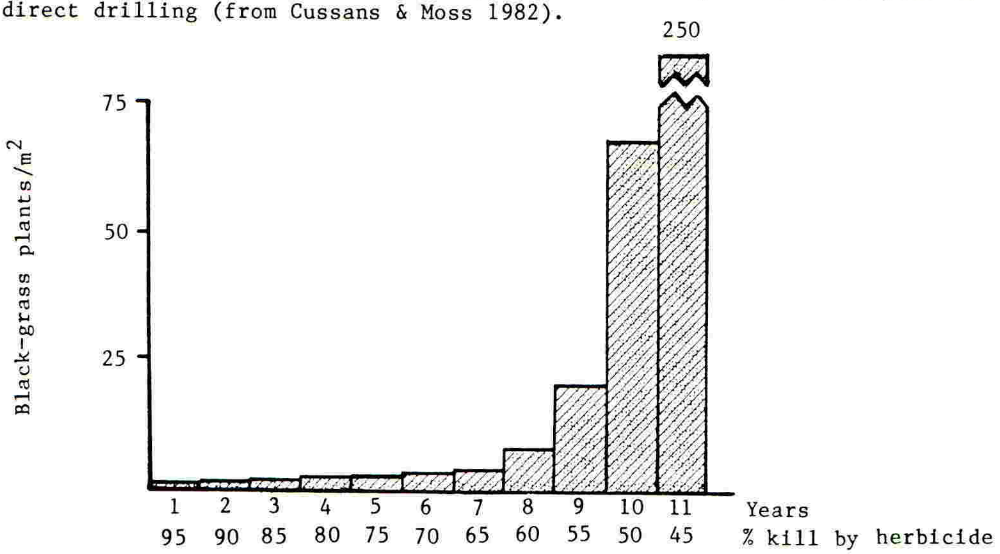
TABLE 8

The annual percentage kill by herbicides needed to maintain a static population of black-grass (from Cussans & Moss 1982)

	Straw burnt	Not burnt
Ploughed	50	65
Direct drilled	88	92

performance were to decline from an initial kill of 95% by 5% for each year of direct drilling. In this situation the effect would not be noticeable at first but builds up exponentially until the system breaks down completely after about seven years. This model is not truly predictive but many farmers and experimenters have observed a similar progression. This model was also used as the basis for a proposal that ploughing should be introduced on a rotational basis. Mouldboard ploughing every five or six years would maintain a static population even if the other years were direct drilled with a decline in herbicide performance of 10% per year.

FIGURE 2
A model for black-grass populations on direct drilled land which assumes kill by herbicide to be 95% initially, but declines by 5% for each year of direct drilling (from Cussans & Moss 1982).



CONCLUSION

This apparently simple subject involves considerable detail of seed biology and herbicide behaviour. Any change in husbandry and certainly the massive changes associated with potential straw disposal methods will result in changes in the weed flora and its control. There is a danger that the choice of method will be made on short term considerations whereas the weed problem, which may ultimately destroy some potential systems, requires long term study. Soil scientists should be more aware of this and involve weed scientists at an early stage in their deliberations.

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THE INCIDENCE AND CONTROL OF BROMUS COMMUTATUS, B. STERILIS AND ALOPECURUS MYOSUROIDES UNDER DIFFERENT STRAW MANAGEMENT REGIMES ON A HEAVY SOIL.

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ABSTRACT

Straw disposal other than by burning, increases the risk of grass weed infestation, particularly meadow brome (Bromus commutatus), barren brome (Bromus sterilis) and blackgrass (Alopecurus myosuroides). If straw burning is to be restricted in the future, the problem of dealing with these and other grass weeds must be addressed.

This paper describes work carried out at Boxworth since 1980. The use of currently available herbicides alone for control of grasses was inadequate and often costly. However, an integrated approach using herbicides and additional measures such as deeper cultivation or ploughing, later sowing or straw burning was more successful. Particularly good control of bromes and blackgrass was obtained in systems which included the development herbicide UK234, but some other materials also gave promising results.

To date there has been no significant interaction between the straw disposal method used and the herbicides tested.

INTRODUCTION

During the past decade two grass weeds, barren brome (Bromus sterilis) and meadow brome (Bromus commutatus), have complicated the choice of cultivation methods and herbicides for autumn sown cereals on a heavy chalky boulder clay soil at Boxworth. (ADAS R & D 1980). Continuous autumn cereals, minimum tillage systems and dry autumns have collectively been implicated in the increasing brome grass problem (Froud Williams et al 1981). Several herbicides commonly used for the control of blackgrass (Alopecurus myosuroides) and wild oats (Avena fatua or Avena ludoviciana) have some activity against brome grasses, notably triallate, isoproturon, metoxuron and methabenzthiazuron + chlorsulfuron (ADAS R & D 1981). However control of severe infestations has invariably been inadequate, expensive and frequently uneconomic particularly when a sequence of herbicides has been necessary. Consequently it was concluded that modifications of husbandry and cultivation practices were necessary to supplement the use of herbicides. Possible methods considered were

a) Straw burning: Boxworth results over a four year period showed that effective burning reduced populations of barren brome and especially the later maturing meadow brome by 78-99 per cent compared with numbers of these weeds after straw chopping and soil incorporation (ADAS R & D 1983, 1984).

b) Ploughing deeper than 12-15cm: at this depth or deeper both barren brome and meadow brome will germinate but having no innate dormancy will fail to emerge. (Froud Williams et al 1984, 1986).

c) Other relatively deep cultivations: these have similarly tended to keep populations of brome grasses lower than after direct drilling or minimum tillage (ADAS R & D 1980).

d) Late sowing: severe infestations of grass weeds have been reduced to much more modest levels by delaying sowing until mid October. For example, a delay in sowing from 23 September to 14 October in 1986, reduced meadow brome incidence by at least a factor of three.

e) Rotational changes: graminicides used in winter oilseed rape and field beans are effective against brome grasses. Also spring cropping, although somewhat unpopular on heavy soils in wet seasons does facilitate the reduction of grass weeds.

Experience at Boxworth since 1982/83 indicated that the main hazard to be overcome in the absence of straw burning was the increased risk of grass weeds. Therefore as part of the overall project a trial was started in the season 1985/86, to study grass weed problems and to evaluate new herbicides or combinations of existing herbicides which might deal with a broader spectrum of grass weeds including brome grasses and blackgrass.

MATERIALS AND METHODS

The herbicides and straw disposal methods employed in 1985/86 are presented in the tables of results (tables 1,2 and 3). Winter wheat (cv Norman) was drilled on 16.10.85. Straw disposal methods included burning in swathes or after spreading, baling, or straw chopping. All ash or straw residues were incorporated into the soil by a shallow 10-12cm tined cultivation. Commercial formulations of isoproturon, metoxuron, methabenzthiazuron + chlorsulfuron, triallate + metoxuron were applied pre emergence on 25.11.85 (triallate on 14.11.85). Two cyanazine treatments pre emergence on 25.11.85 were followed in spring by either metoxuron or isoproturon on 12.3.86. UK234, a development herbicide, was applied either pre emergence on 14.11.85 or post emergence on 12.3.86.

Two further trials to study the control of meadow brome in winter wheat (cv Brock) were laid down at Boxworth in the 1986/87 season:-

a) On a site where straw disposal methods had been compared since 1983/84 and where an increase in brome grass had occurred in minimum tillage systems.

b) On a second site where straw was chopped and incorporated, and various herbicides tested for their efficacy.

Treatment details and results available to date are given in tables 4 and 5.

Analysis of variance was by Genstat. Standard errors of difference (sed) shown are applicable for horizontal, interaction (hi) or vertical (v) comparisons.

RESULTS

The control of meadow brome and barren brome in 1985/86 is given in tables 1 and 2. All herbicides gave excellent control of blackgrass regardless of the method of straw disposal and therefore no details are presented. Yield data is given in table 3.

Results obtained in the trials which commenced in autumn 1986 are given in tables 4 and 5. At the time of writing, harvesting has not been completed.

TABLE 1.

Meadow brome infestation, (heads m^2) assessed in early July 1986.

Herbicide (autumn except where stated)	kg ai/ha	straw burnt:- in swathe	spread	straw:- baled	incorporated
1. NIL control		0.93	2.78	88.9	284.0
2. isoproturon	2.5	0.46	1.83	62.5	420.1
3. metoxuron	4.37	0.46	2.17	41.7	210.4
4. methabenzthiazuron					
+ chlorsulfuron	2.45	0.02	1.37	74.3	137.4
5. triallate	2.25				
+ metoxuron	4.37	0.34	1.90	63.2	238.9
6. cyanazine	2.25				
+ isoproturon	2.5	0.17	0.59	3.5	16.0
7. cyanazine	2.25				
+ metoxuron	4.37	0.00	0.24	2.1	6.9
8. UK234	1.5	0.00	0.10	27.8	91.7
9. UK234, spring	1.5	0.00	0.15	0.0	2.1
	sed:	hi ± 0.973		hi ± 62.65	
		v ± 0.745		v ± 63.85	

TABLE 2.

Barren brome infestation (heads m/^{2}) assessed early June 1986.

Herbicide (autumn except where stated)	kg ai/ha	straw burnt:- in swathe	spread	straw:- baled	incorporated
1. NIL control		0.17	0.63	116.0	125.7
2. isoproturon	2.5	0.32	1.05	38.2	139.6
3. metoxuron	4.37	0.00	0.17	10.4	109.9
4. methabenzthiazuron					
+ chlorsulfuron	2.45	0.07	0.07	18.7	84.0
5. triallate	2.25				
+ metoxuron	4.37	0.00	0.12	84.0	16.0
6. cyanazine	2.25				
+isoproturon in spring	2.5	0.00	0.05	2.8	33.3
7. cyanazine	2.25				
+ metoxuron in spring	4.37	0.00	0.07	0.7	11.1
8. UK234	1.5	0.02	0.32	5.6	34.7
9. UK234 in spring	1.5	0.00	0.07	0.0	2.8
	sed:	hi ± 0.293		hi ± 57.27	
		v ± 0.285		v ± 56.50	

TABLE 3.

Yield of grain (t/ha @ 15% moisture content) in 1985/86.

Herbicide (autumn except where stated)	kg ai/ha	straw burnt:- in swathe	spread	straw:- baled	incorporated	mean
1. NIL		6.55	6.94	5.77	4.58	5.96
2. isoproturon	2.5	7.08	7.01	6.27	4.83	6.30
3. metoxuron	4.37	7.02	6.96	7.09	5.72	6.70
4. methabenzthiazuron + chlorsulfuron	2.45	6.77	7.19	6.91	5.87	6.66
5. triallate + metoxuron	2.25 4.37	6.89	7.37	6.66	6.66	6.89
6. cyanazine + isoproturon	2.25 2.5	6.88	7.09	6.82	6.02	6.70
7. cyanazine + metoxuron	2.25 4.37	7.14	6.97	6.64	6.35	6.78
8. UK234	1.5	6.93	7.13	7.07	6.97	7.03
9. UK234, in spring	1.5	6.98	7.53	7.28	7.31	7.28
	sed:	hi ± 0.381		v ± 0.301		± 0.15

TABLE 4.

Crop establishment and grass weed infestation assessed in July 1987.

Herbicide	kg ai/ha	plants m^2 16/3	total grass weeds m^2 16/3	meadow brome weeds m^2 22/6	grassweed score 0-10 (where 10 =severely infested)
0. No herbicide		246.5	48.0	305.9	6.3
1. UK234 post em 19/11	1.5	261.3	3.1	40.9	2.0
2. UK234, late post em 12/3	1.5	246.5	38.2*	33.0	2.8
3. cyanazine pre em 15/10 + cyanazine + isoproturon 12/3	2.25 0.875 1.1	260.0	26.2#	140.3	4.3
4. cyanazine pre em 15/10	2.25	231.5	29.3	159.0	5.2
5. triallate + metoxuron 6/11	2.25 4.37	267.5	24.9	220.7	5.0
6. diflufenican + isoproturon 12/3‡	1.69	246.5	32.9*	251.6	6.0
7. pendimethalin 15/10	1.98	208.4	46.7	271.5	6.2
8. pendimethalin isoproturon 6/11	1.32 1.24	263.5	32.4	170.7	5.8
9. imazamethabenz 6/11	0.50	249.8	30.7	171.5	5.7
sed:		± 18.01	± 14.23	± 78.89	-

* no effect of spring herbicide at this stage: similarly #

‡ not recommended for spring application: total ai quoted.

TABLE 5.

Meadow brome infestation (heads/m²) assessed in June, 1987.

Treatment	No herbicide	+ UK234 (applied on 13/3/87)
Straw burnt:-		
5cm tines	22.0	1.9
Straw incorporated:-		
15 cm tines	158.0	20.7
10cm tines	98.9	6.6
5cm tines	598.0	302.0

DISCUSSION

1. 1985/86 trials.

Straw burning alone gave over 99 per cent control of meadow and barren brome (tables 1 and 2) and yields were improved by 15 or 32 per cent (0.98 t/ha and 2.17 t/ha) compared to baled or straw incorporated areas respectively, where no herbicide was used (table 3).

The use of the development herbicide, UK234, effectively controlled all grass weed present, most notably where straw was not burnt and increased yields by up to 2.73 t/ha or 60 per cent, giving similar levels of yield from all methods of straw disposal.

Cyanazine applied pre emergence in the autumn followed by isoproturon or metoxuron in the spring at recommended rates of application also gave good reductions of brome grasses and blackgrass, with good yield increases. This occurred despite up to 60 per cent crop thinning due to inadequate planting depth or consolidation of the seedbed where straw residues remained. All other herbicides with the exception of isoproturon alone, tended to reduce brome grass populations but visually this control would have been judged inadequate. Nevertheless all materials other than isoproturon significantly increased yields ($P = <.05$) where straw was not burnt. Where straw was burnt, yield differences between herbicides were not quite statistically significant at that level of probability (table 3).

2. 1986/87 trials.

Both trials at Boxworth showed good control of meadow brome by UK234 with reductions of 87-89 per cent (tables 4 and 5). A useful reduction of meadow brome also resulted from cyanazine particularly when followed by a second application of cyanazine + isoproturon at recommended (lower) rates in the spring. No crop damage resulted from cyanazine following adequate depth of sowing and thorough rolling before treatment.

Spring herbicide applications in 1987 were all delayed by adverse weather conditions, and by the time spraying was possible meadow brome had begun to tiller and elongate. Therefore, although the date of spraying was similar to 1985, the percentage control of meadow brome was not quite as good as in 1986. This may be due to the fact that in 1986 the early March spray closely followed a prolonged cold spell throughout February and the brome grasses were much less forward than in 1987.

These trials have again shown that control of brome grass by herbicides normally used for the control of blackgrass and wild oats is usually in adequate. The use of deeper cultivations or ploughing, which have often given considerable control or prevention of severe infestations of grass weeds, involve extra cultivation costs and crop establishment difficulties in dry seasons on heavy soils. Late sowing, which has also been beneficial for grass weed control, has attendant risks which might be acceptable only on a limited area. Straw burning is the one husbandry factor that has shown very good control of brome grasses, particularly meadow brome. However, current public antipathy towards this method of straw disposal is increasing. It is therefore of considerable economic and environmental importance that the search for an efficient and cost effective broad spectrum grass weed herbicide, or combination of herbicides and cultivation methods is found to solve this major problem associated with autumn cereals on heavy land.

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OPTIMISING CHEMICAL CONTROL OF ALOPECURUS MYOSUROIDES ON MINERAL SOILS WITH A STRONG TENDENCY TO ADSORB SOIL APPLIED HERBICIDES.

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ABSTRACT

Six field trials were carried out during the 1986 harvest year to evaluate the control of black-grass (*Alopecurus myosuroides*) using selected herbicides alone, or in sequence, on mineral soils with a strong tendency to adsorb certain soil applied residual herbicides.

None of the chemicals used alone gave reliable control but chlorsulfuron plus metsulfuron-methyl used sequentially with diclofop-methyl gave 94%-96% control. Tri-allate used sequentially with chlorsulfuron plus metsulfuron-methyl gave 90% control and 94% control when used sequentially with diclofop-methyl.

Chlorsulfuron plus metsulfuron-methyl appeared to be least affected by adsorption as the Kd of soils increased. While this product can form an important first link of a sequential approach to black-grass control on high Kd soils, its use may impose cropping or rotational constraints which the grower may not find acceptable. In these situations, sequences based on tri-allate or isoproturon followed by diclofop-methyl could be considered.

INTRODUCTION

Black-grass continues to be one of the most troublesome annual grass weeds of winter cereals. The consistent trend over the past five years to sow winter wheat and barley earlier in the autumn, often established by minimum cultivations, has tended to sustain high black-grass populations and necessitate high levels of chemical control (Cussans, 1982).

Problems often arise as a result of particular husbandry practices. One recent example is the shallow incorporation of burnt straw residues in the top soil. This practice is particularly associated with heavy soils, which are difficult to plough and subsequently produce a satisfactory seedbed. On these soils reduced tillage techniques lead to an increase in the organic matter content of the top 7.5cm of soil. While there is an improvement in soil structure over time, the build up of highly adsorbent burnt straw residues leads to a reduction in the efficacy of residual herbicides such as chlorotoluron and isoproturon (Moss 1984).

To maintain the very high level of control necessary to contain black-grass under these agronomic conditions, herbicides which have mainly foliar activity or are less strongly adsorbed by the burnt straw residues, must be used. There is also a need to have effective sequences for grass weed control, since germination may be protracted. The present study investigated the use of tri-allate, chlorsulfuron plus metsulfuron-methyl or diclofop-methyl alone or in sequences in field trials on highly adsorbent mineral soils.

Tri-allate has mainly vapour activity and while highly lipophilic (strongly attracted to organic matter) is not entirely dependent on movement in soil water for its activity. Diclofop-methyl has mainly foliar activity and chlorsulfuron plus metsulfuron-methyl are moderately polar weak acids and are repelled by the overall negative charge of the soil surfaces and consequently are less strongly adsorbed (Nicholls, 1987).

This paper presents data from 6 ADAS field trials carried out during the 1986 harvest year.

MATERIALS AND METHODS

Trials were conducted in commercially grown winter wheat with naturally occurring infestations of black-grass. The sites were in the ADAS Eastern (Denny Abbey, Odell and Poppylots), South East (Pitstone and Stoke House) and South West (Charfield) Regions. Sites known to have a long history of minimal cultivations were chosen. For example at Pitstone, shallow surface cultivations had been practised for 12 years. The Kd (chlorotoluron) value for each site was determined in the laboratory and the values indicated that the performance of most residual herbicides would be reduced. (The higher the figure the more adsorbent the soil to most residual herbicides). Earlier work has suggested that a value above six, marks the transition between normal and reduced herbicide performance (Moss, 1984).

Site and application details are given in table 1 and treatment details are included in tables 2 and 3.

Table 1 Site and application details

	Timing	S1	S2	S3	S4	S5	S6
Soil texture		SCL	SCL	ZCL	CL	ZCL	ZCL
Organic matter %		4.9	N/A	7.1	5.1	6.3	6.3
Kd (chlorotoluron)		8.2	11.6	16.5	16.5	9.1	6.2
pH		7.9	N/A	7.6	7.3	7.2	7.3
Cultivar		Galahad	Avalon	Norman	Avalon	Avalon	Mission
Pre-emergence	a	7/10 1985	17/10 1985	26/09 1985	4/10 1985	11/10 1985	17/10 1985
Post-emergence	b	16/12	12/12	13/11	7/11	15/11	29/11
Post-emergence	c	10/03 1986	12/03 1986	14/03 1986	1/05 1986	18/04 1986	19/04 1986
Crop GS (Zadoks)	b	13	12	13	12-13	12-13	12-13
	c	13	13	22	30	30	30
Black-grass size	b	3 lvs	2 lvs	3 lvs	1-2 lvs	1-2 lvs	1-2 lvs
	c	3 lvs	3 lvs	4 lvs	3 lvs to 3 to 4 tillers	3 lvs to 2 to 3 tillers	2 to 3 tillers

KEY: S1 = Denny Abbey S3 = Poppylots S5 = Stoke House
S2 = Odell S4 = Pitstone S6 = Charfield

All treatments were applied by an Oxford Precision Sprayer in a total volume equivalent to 200 litres of water/ha. Spraying Systems Teejet 8002/11002 nozzles at the appropriate working pressure were used.

Materials were tested alone or in sequence, normally a pre-emergence treatment followed by an early post-emergence application. Isoproturon alone was also used in the spring when soil and climatic conditions were favourable. Due to the wet late spring, applications were very delayed on certain sites.

All trials were of the complete randomised block design with at least 3 replicates. Black-grass control was assessed on the basis of head length (m/m2) or panicle mortality /m2.

RESULTS

The control of black-grass, assessed on the basis of panicle mortality/m^2 given by the treatments tested is presented for all sites in table 3. Additionally for the Eastern Region sites of Denny Abbey, Odell and Poppylots the control of black-grass head length (m/m^2) is presented in table 2. Treatments are abbreviated to CMM (chlorsulfuron + metsulfuron-methyl) and DFM (diclofop-methyl).

DISCUSSION

Tri-allate alone gave on average 62% control, a figure lower than would normally be expected (typically in the range 80 to 90%) on non-adsorbent soils. Chlorsulfuron plus metsulfuron-methyl (CMM) performed particularly well alone pre-emergence or early post-emergence on the 3 Eastern region sites. These soils have a naturally high clay content. The normal structure of aggregates and clods would lead to a large spreading of the herbicide due to retention in small pores within aggregates and only slow diffusion into the main water channels (Nicholls, 1987). There was a slight tendency for pre-emergence CMM applications to give higher control of black-grass heads. This confirms earlier observations (Flint, 1985).

Diclofop-methyl (DFM) applied post-emergence performed as expected on most sites except at Poppylots, where very severe frosts for 2 nights after application may help to explain the failure to control black-grass.

The benefits of a sequence of herbicide treatments or the tank-mixture of materials with different adsorption properties is clearly shown in table 3. The most consistent result was achieved with a pre-emergence application of CMM followed by the full or half rate of DFM applied early post-emergence.

Earlier experiments (Upstone, 1982) indicated the effectiveness of chlorsulfuron in shortening the length of black-grass panicles compared with other residual herbicides. On the Eastern Region sites, black-grass head length (m/m^2) was measured as well as panicle number/m^2. The results from these sites (table 2) support the findings of Upstone et al, and highlight that under the difficult conditions for annual grass weed control on these highly adsorbent soils, those treatments which have the maximum effect on head length and therefore seed return are preferable.

The relationship between soil organic matter and soil adsorption is presented in Figure 1 (Nicholls, 1987). To compare the results achieved under laboratory conditions with those in the field, the weed control data (mortality of black-grass heads/m^2) for tri-allate alone, CMM alone (a) pre-emergence, (b) post-emergence and isoproturon alone (b) early post-emergence, or (c) in spring, are presented in Figure 2. There is a general trend for CMM to be least affected by adsorption as Kd increases. This is particularly so for the Poppylots site (Kd 16.5). However at the other very high Kd site, Pitstone, the performance of CMM is generally less satisfactory. IPU performed more effectively on this site at both timings. However CMM pre-emergence gave the level of control expected for a herbicide which is not normally recommended alone for black-grass control. The lower level of control of all products at Pitstone is partly explained by an important spring flush of black-grass in early February, at a time when the level of herbicide persisting in the soil would have been on the decline.

The results shown in Figure 2 confirm that CMM is one of the herbicides less affected as Kd increases. It could therefore be used as the first and very useful part of a sequential treatment for black-grass control. On certain soils and in some years it may not be necessary to have a follow up treatment.

The results presented indicate that CMM in association with DFM can achieve the high levels of control required to contain black-grass on soils which exhibit a strong tendency to adsorb soil applied herbicides. The use of either one of these materials alone is less reliable. From a practical point of view there may be the possibility to reduce herbicide cost by using a lower dose of DFM after CMM. However timing the DFM application will be critical and weeds should be no larger than the 1 to 2 leaf stage.

Of particular concern is the effect of CMM on the rotation. Its use may impose certain restrictions in cropping which the grower may not be prepared to accept. In this situation sequences based on tri-allate or isoproturon followed by DFM are preferred. The need for a contact specific graminicide capable of controlling black-grass at later stages than DFM is needed. With current herbicide developments this may happen in the next 2 to 3 years. Also the problem of adsorption may become less widespread due to the increased area of intensive cereals which is now annually or rotationally ploughed.

ACKNOWLEDGMENTS

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Table 2 % control of black-grass head length m/m²

Treatment	kg a.i. per ha	Timing	S1	S2	S3	Mean
Untreated control; head length m/m²			24.7	98.7	51.3	48.2
tri-allate	2.25	a	64.2	69.7	36.4	57.8
tri-allate (fb) chlorsulfuron + metsulfuron-methyl	2.25 0.02	a a	98.3	97.0	96.7	97.3
tri-allate (fb) diclofop-methyl (tm) bromoxynil + ioxynil	2.25 1.14 0.57	a b	98.1	100	53.0	83.7
chlorsulfuron + metsulfuron-methyl	0.02	a	96.3	97.0	84.1	92.5
chlorsulfuron + metsulfuron-methyl (fb) diclofop-methyl	0.02 1.14	a b	99.4	95.4	99.8	98.2
isoproturon	2.5	b	90.2	16.6	97.4	68.1
isoproturon (tm) chlorsulfuron metsulfuron-methyl	2.5 0.02	b	98.4	97.8	98.1	98.1
isoproturon (tm) diclofop-methyl	2.5 1.14	b	n/a	94.0	96.2	95.1
diclofop-methyl (tm) bromoxynil + ioxynil	1.14 0.57	b	94.1	0.0	99.9	64.7
diclofop-methyl (tm) chlorsulfuron + metsulfuron-methyl	1.14 0.02	b	98.6	5.0	99.6	67.7
isoproturon	2.0	c	75.8	19.4	43.0	46.1

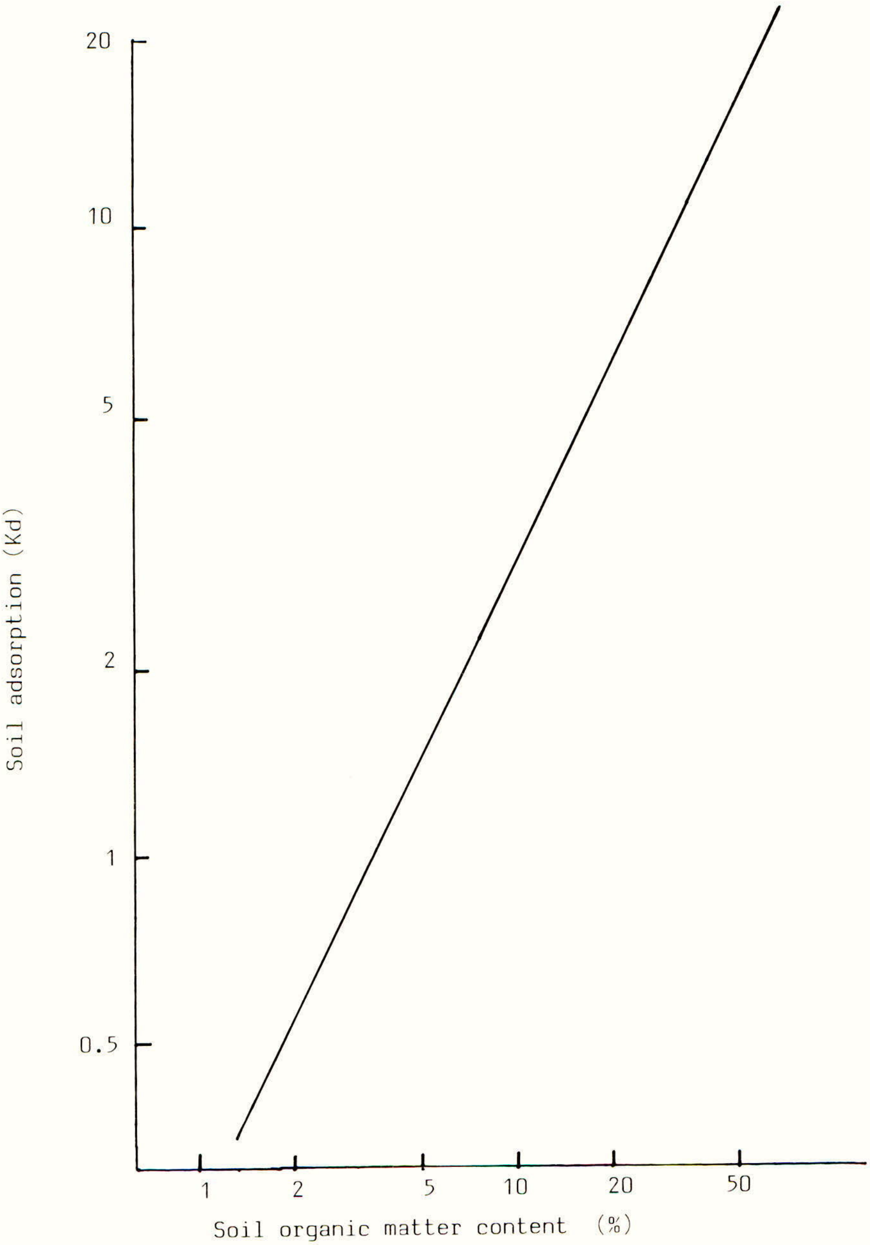
fb = followed by
tm = tank-mixed with
a = pre-emergence
b = post-em. (autumn)
c = post-em. (spring)
S1 = Denny Abbey
S2 = Odell
S3 = Poppylots

Table 3 % Control of black-grass heads/m^2

Treatment	kg a.i. per ha	Timing	Sites S1	S2	S3	S4	S5	S6	Mean
Untreated control; heads/m^2			316	793	1043	357	468	470	574.5
tri-allate	2.25	a	75.0	82.0	36.0	42.0	63.0	72.0	61.7
chlorsulfuron + metsulfuron-methyl	0.02	a	96.0	84.0	96.0	62.0	72.0	68.0	79.7
tri-allate (fb) chlorsulfuron + metsulfuron-methyl	2.25 0.02	a a	98.0	96.0	96.0	67.0	93.0	91.0	90.2
tri-allate (fb) chlorsulfuron + metsulfuron-methyl	2.25 0.02	a b	98.0	92.0	96.0	84.0	54.0	85.0	84.8
tri-allate (fb) diclofop-methyl (tm) bromoxynil + ioxynil	2.25 1.14 0.57	a b	98.0	00.0	53.0	75.0	96.0	98.0	86.7
chlorsulfuron + metsulfuron-methyl (fb) diclofop-methyl	0.02 1.14	a b	99.0	00.0	95.0	76.0	97.0	96.0	93.8
chlorsulfuron + metsulfuron-methyl (fb) diclofop-methyl	0.02 0.57	a b	99.0	97.0	94.0	-	-	-	96.7
isoproturon (tm) chlorsulfuron + metsulfuron-methyl	2.5 0.02	a	-	97.0	-	50.0	96.0	91.0	83.5
isoproturon (tm) chlorsulfuron + metsulfuron-methyl	2.5 0.02	b	99.0	98.0	99.0	78.0	99.0	70.0	90.5
chlorsulfuron + metsulfuron-methyl	0.02	b	95.0	93.0	96.0	22.0	76.0	47.0	71.5
isoproturon	2.5	b	91.0	97.0	26.0	82.0	53.0	72.0	70.2
diclofop-methyl (tm) bromoxynil + ioxynil	1.14 0.57	b	95.0	99.9	0.0	56.0	80.0	72.0	67.2
diclofop-methyl (tm) chlorsulfuron + metsulfuron-methyl	1.14 0.02	b	99.0	00.0	6.0	80.0	95.0	87.0	77.8
isoproturon	2.0	c	88.0	50.0	6.0	67.0	66.0	66.0	57.2

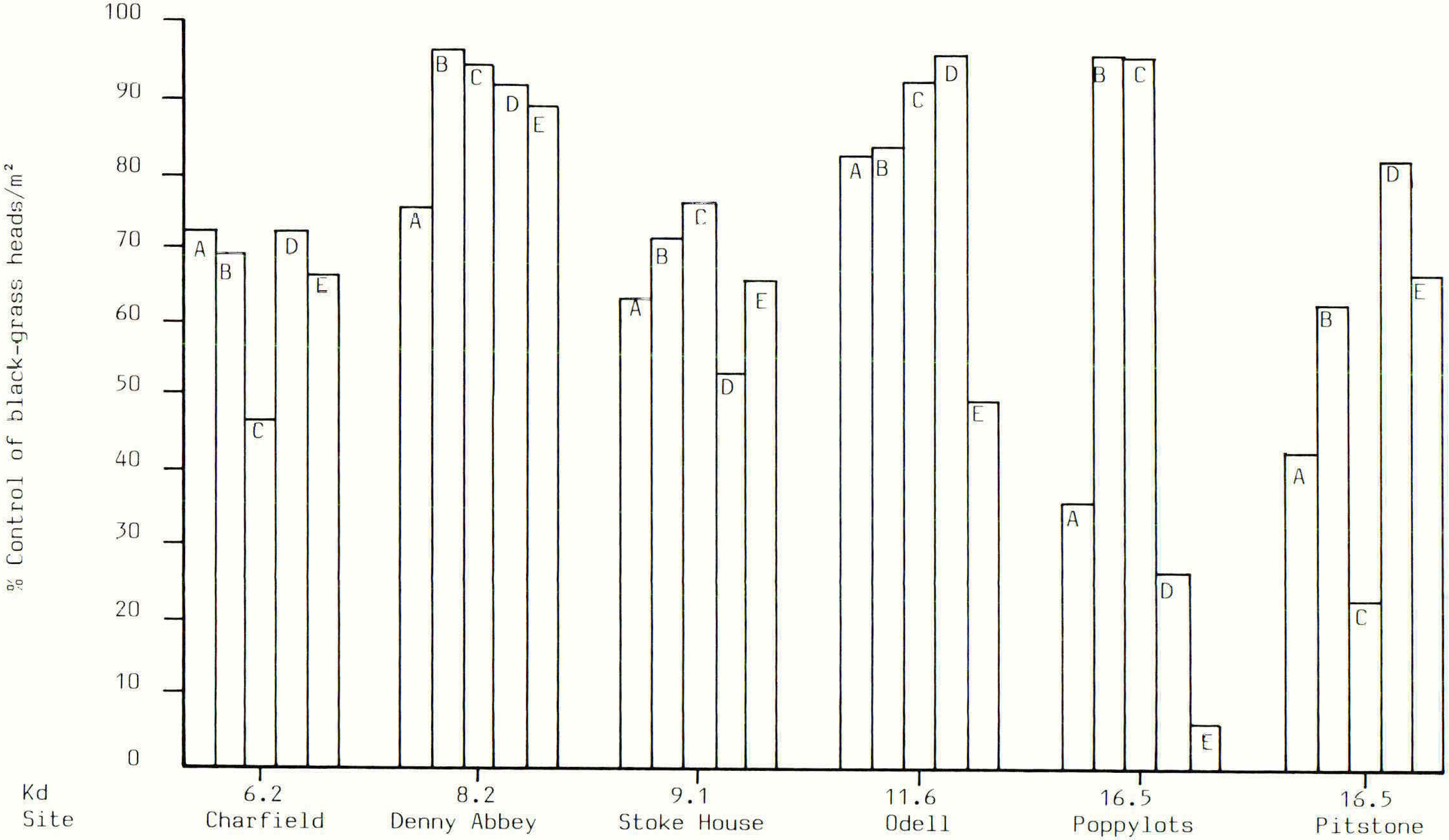
fb = followed by
tm = tank-mixed with
a = pre-emergence
b = post-em. (autumn)
c = post-em. (spring)
S1 = Denny Abbey
S2 = Odell
S3 = Poppylots
S4 = Pitstone
S5 = Stoke House
S6 = Charfield

Figure 1 - Adsorption of fluometuron as a function of soil organic matter



(Source, Nicholls 1987)

Figure 2 Effect of Kd on herbicide efficacy



Key A = tri-allate alone.
B = chlorsulfuron + metsulfuron-methyl (pre-emergence).
C = chlorsulfuron + metsulfuron-methyl (post-emergence, autumn).
D = isoproturon (post-emergence, autumn)
E = isoproturon (post-emergence, spring).

THE INFLUENCE OF SOWING DEPTH ON THE TOLERANCE OF WHEAT AND THE SUSCEPTIBILITY OF *ALOPECURUS MYOSUROIDES* AND *AVENA FATUA* TO CHLOROTOLURON AND ISOPROTURON

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ABSTRACT

A series of pot experiments tested the influence of sowing depth on the tolerance of wheat, wild-oat (*Avena fatua*) and black-grass (*Alopecurus myosuroides*) to chlorotoluron and isoproturon. Deeper planting protected wheat from damage by isoproturon but less by chorotoluron. Wild-oat was damaged less by both herbicides, but especially by isoproturon, when sown deeper but sowing depth did not alter the susceptibility of black-grass to either herbicide.

All shoot weights were decreased by sowing deeper, in the absence of herbicide.

These results are discussed with reference to the route of herbicide entry into the plant, soil moisture, and herbicide adsorption and mobility in the soil.

INTRODUCTION

The substituted urea herbicides chlorotoluron and isoproturon are widely used for the selective control of grass weeds in cereal crops (Sly, 1984). However, weed control is sometimes unsatisfactory (Flint, 1985) and crop damage has occasionally occurred (Tottman *et al*., 1975).

The major site of uptake of these herbicides is via the roots; foliage entry and subsequent translocation is a small component of uptake (Blair, 1978). The selectivity of some soil-acting herbicides depends on the herbicide reaching the roots of weeds but not those of the crop (Walker, 1980). Both chlorotoluron and isoproturon are readily metabolised to herbicidally inactive products by herbicide-tolerant cultivars of wheat and barley (Ryan & Owen, 1983). Despite this evidence of innate selectivity, the implication from the manufacturers' recommendations that the seed should be well covered (Anon. 1987) is that depth protection is important in enhancing the crop-safety of these herbicides.

Experiments were undertaken to investigate how planting depth affected the tolerance of wheat to chlorotoluron and isoproturon and whether weed control was reduced when wild-oat or black-grass develop from seeds deeper in the soil.

MATERIALS AND METHODS

Plant material

Seeds of wheat, wild-oat (*Avena fatua*) or black-grass (*Alopecurus myosuroides*) were sown at various depths (see Tables 1-6) in pots of sandy loam soil from Broom's Barn Experimental Station (Experiments 1-3) or from Weed Research Organisation, Oxford (Experiments 4-6). Three cultivars of wheat were used : Avalon, which is known to be tolerant to chlorotoluron, and Slejpner, which is sensitive (experiments 1-3) and Fenman (experiment 4).

Pots used were 9 cm diameter (experiments 5-8), 10 cm (experiment 4) and 18 cm (experiments 1-3). Fertiliser was added as required.

Herbicide treatment

Chlorotoluron was applied pre-emergence to the surface of pots containing wheat (experiment 1), wild-oat (experiment 5) and black-grass (experiment 6), and post-emergence to wheat (experiment 2). Isoproturon was applied pre-emergence to wheat (experiment 3), wild-oat (experiment 5) and black-grass (experiment 6), and post-emergence to wheat (experiment 4). Post-emergence applications were made when the plants sown at 25mm depth had three emerged leaves (GS13). Treatments were replicated four (experiments 1-4) or six times (experiments 5 & 6).

Commercial formulations of chlorotoluron and isoproturon were applied, at rates indicated in tables, using a laboratory sprayer fitted with three 8003 'Teejet' nozzles spaced at 50 cm delivering approximately 250 l/ha (experiments 1-3). For experiments 4-6, a laboratory sprayer fitted with a single 'Teejet' nozzle was used, either an 8001 delivering 250 l/ha (experiment 4), or an 8002E delivering 420 l/ha (experiments 5-6). All applications were made at a pressure of 210 kPa.

Environments

In experiment 4 plants were kept in a Vötsch controlled environment room where conditions were 16/10°C, 55/86 % r.h. day/night. A daylength of 14 h was provided by cool white fluorescent plus tungsten lamps giving a mean irradiance of 95 Wm^{-2}. For all other experiments plants were kept in the glasshouse at 20-25°C for experiments 1-3 or 15 - 20°C for experiments 5-6. In the latter two experiments supplementary light was supplied to give a minimum daylength of 14 h.

Weighed amounts of water were applied directly to the soil in experiment 4 to give the required moisture regimes. In the other experiments soil moisture was maintained at approximately field capacity throughout the duration of the experiments by watering over the soil and foliage.

Assessments

Plants were cut at soil level and dry weights (experiments 1-4) or fresh weights (experiments 5-6) are given in the tables of results. Data were subjected to analysis of variance and standard errors are given as appropriate.

RESULTS

The deepest planting (75 mm) reduced the dry weight of Avalon more than Slejpner plants (Tables 1 & 2). As expected, Slejpner was more sensitive than Avalon to chlorotoluron applied either pre- or post-emergence. Since the interaction between cultivars, dose and depth was not significant, only weights for each cultivar averaged over four chlorotoluron doses are presented for each depth (Tables 1 & 2). Data show that the greatest damage to Slejpner tends to result from the shallowest and deepest sowings.

TABLE 1

The effect of depth of sowing on the activity of chlorotoluron applied pre-emergence to two cultivars of wheat (mean of 4 doses*); harvested 27 days after sowing (experiment 1).

Cultivar		Dry weight/plant (mg) Depth of sowing (mm)					
		6	12	25	50	75	SED
Avalon	untreated	98.6	147.0	120.4	128.2	66.1	24.1
	treated*	96.1	107.1	103.5	86.7	55.1	8.3
Slejpner	untreated	109.1	127.5	119.4	120.3	39.8	22.4
	treated*	48.7	74.9	76.7	73.8	22.4	8.7

* 0.87, 1.75, 2.75, 3.5 kg ai/ha

TABLE 2

The effect of depth of sowing on the activity of chlorotoluron applied to two cultivars of wheat at GS 12-13 (mean of 4 doses*); harvested 15 days after treatment (experiment 2).

Cultivar		Dry weight/plant (mg) Depth of sowing (mm)					
		6	12	25	50	75	SED
Avalon	untreated	208.0	218.0	214.0	290.0	144.0	39.2
	treated*	153.8	174.8	185.8	210.6	121.7	19.9
Slejpner	untreated	296.0	213.0	242.0	244.0	170.0	54.9
	treated*	101.9	134.4	120.4	112.6	76.5	13.6

* 0.87, 1.75, 2.75, 3.5 kg ai/ha

In experiment 3 the interaction between cultivar, dose and depth was also not significant and so the weights of the two cultivars were meaned (Table 3). This table shows that plants sown deeper were generally less damaged by isoproturon than were those sown shallower.

TABLE 3

The effect of the depth of sowing on the activity of isoproturon applied pre-emergence to wheat*; harvested 28 days after sowing (experiment 3).

	Dry weight/plant as % of untreated Depth of sowing (mm)				
isoproturon (kg ai/ha)	6	12	25	50	60
0.75	74.3	104.8	111.9	91.8	109.1
1.5	37.4	62.3	103.5	92.7	92.7
2.1	39.3	33.6	75.1	102.1	85.7
SED			11.3		

* averaged for two cultivars Avalon & Slejpner

Fenman sown at 50 mm depth was significantly less damaged by isoproturon than at 25 or 12 mm depth at all three soil moistures (Table 4), whereas at 12 mm sowing depth damage was least at 60% field capacity. Sown at either 25 or 50 mm depth the degree of damage was less at 100% field capacity than at lower moistures.

TABLE 4

The effect of soil moisture and sowing depth on the activity of isoproturon (2 kg ai/ha) applied to wheat cv. Fenman at GS 13; harvested 17 days after treatment (experiment 4).

	Dry weight/plant as % of untreated Moisture (% field capacity)		
Depth of sowing (mm)	100	80	60
12	35.0	29.1	47.2
25	58.2	42.8	48.2
50	91.7	65.6	63.6
SE		3.33	

Wild-oat plants were heaviest grown from seed sown at 12 mm and lightest at 50 mm (Table 5). When treated pre-emergence with chlorotoluron at 0.25 and 0.5 kg ai/ha, shallow planting (6 mm) resulted in greater damage than other depths (Table 5). There was also a trend of less damage to wild-oat from isoproturon applied pre-emergence which resulted from deeper sowing (Table 5).

TABLE 5

The effect of depth of sowing and chlortoluron or isoproturon applied pre-emergence on growth of wild-oat; harvested 37 days after sowing (experiment 5).

		Fresh weight/plant (g) Depth of sowing (mm)			
Treatment	kg ai/ha	6	12	25	50
untreated		1.15	1.31	1.18	0.59
chlorotoluron	0.125	1.14 (99)	1.30 (99)	0.92 (78)	0.76 (129)
	0.25	0.64 (56)	0.93 (71)	1.05 (89)	0.66 (110)
	0.5	0.14 (12)	0.30 (23)	0.57 (48)	0.40 (68)
isoproturon	0.125	0.30 (26)	0.84 (64)	0.87 (74)	0.57 (95)
	0.25	0.05 (5)	0.21 (16)	0.53 (45)	0.41 (69)
SED			0.145		

% of untreated in brackets.

TABLE 6

The effect of depth of sowing and chlorotoluron and isoproturon applied pre-emergence on growth of black-grass; harvested 37 days after sowing (experiment 6).

		Fresh weight/plant (mg) Depth of sowing (mm)			
Treatment	kg ai/ha	6	12	25	50
untreated		233	249	230	100
chlorotoluron	0.125	128 (55)	158 (63)	133 (58)	67 (67)
	0.25	74 (32)	92 (37)	56 (24)	27 (27)
isoproturon	0.125	37 (16)	63 (25)	62 (27)	52 (52)
	0.25	12 (5)	47 (19)	24 (11)	23 (23)
SED			26.8		

% of untreated in brackets.

Black-grass grew less well from seed sown at 50 mm than at shallower depths (Table 6). At the doses tested, there was little effect of planting depth on the susceptibility of blackgrass to chlorotoluron or isoproturon applied pre-emergence (Table 6).

DISCUSSION

Previous studies (Blair, 1978) have indicated that the activity of chlorotoluron and isoproturon applied post-emergence results mainly from entry from the soil rather than through the foliage. The affect of these two chemicals on wheat, wild-oat and black-grass will therefore depend upon the innate tolerance of the plants to the herbicides and the relationship between herbicide location in the soil profile and the site of entry into the plant.

Black-grass (Naylor, 1970) and, to a less extent wild-oat, produces roots near the soil surface soon after germination and emergence (Hoshikawa, 1969). They are likely, therefore, to have roots in contact with the herbicide whereas wheat, generally sown deeper (2.5-3.5 cm), does not produce roots in the surface zone until plants have at least 3 leaves. In the case of chlorotoluron, even the susceptible wheat cultivar showed no marked evidence of being protected by deeper sowing. In contrast, there do appear to be differences in susceptibility of cultivars to both pre- and post-emergence isoproturon depending upon depth of seeding. This implies either differences in the mobility of these chemicals in the soil or in the susceptibility of the different cultivars to isoproturon compared with chlorotoluron. We are unable to differentiate between these factors on the basis of these experiments.

The trends in the response of plants to increasing depth of planting appear domed particularly in Tables 1 and 2. These trends could be investigated further with additional statistical tests. Shallow sowing may result in better contact between the roots and the herbicide whereas deeper sowing may produce weaker seedlings (Tables 1 and 2) which may then reduce the capacity of the plant to metabolise the herbicide.

Mobility of herbicides in the soil will be influenced mainly by adsorption onto soil particles. In strongly adsorptive soils, deeper sowing may give more protection from herbicides. In Broom's Barn soil (experiments 1-3) adsorption of isoproturon is low (Kd 0.5-1.0) and isoproturon can move rapidly down the soil profile in the field (Blair & Martin, unpublished). Begbroke soil (experiments 4-6) is more adsorptive (Kd approx. 2.0) but we have no comparative field measurements of movement. Other factors which affect adsorption, such as the presence of burnt straw residues (Nyffeler & Blair, 1978), would also affect availability and, potentially, movement of the herbicide and hence might increase any protection from deeper planting.

Distribution of soil moisture can influence both root development and availability of many herbicides (Blair, 1985). It seems possible that the results in Table 4 may be due to an experimental anomaly. The watering regime, whereby small quantities of water were added daily to restore a 10 cm plant pot to 50% field capacity, resulted in uneven distribution of water through the soil profile (Blair, unpublished). Thus the moisture content in the upper layers, where the herbicide is concentrated, would be very much higher than the average for the whole pot.

Sowing depth is an important mechanism of selectivity between crop and weeds with some other herbicides (Holly, 1976). For the substituted ureas there is a metabolic basis of selectivity between cereals and black-grass or wild-oat (Ryan *et al*. 1981). However, under the particular conditions of the experiments described depth of planting increased the safety of isoproturon to wheat. In this respect our results support the manufacturers' recommendation that wheat should be covered by soil to a depth of 12-25 mm. Further studies are required to clarify the response under different conditions and to explain the apparently greater influence of planting depth on the tolerance of wheat, wild-oat and black-grass to isoproturon than to chlorotoluron.

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THE INFLUENCE OF WEATHER ON THE PERFORMANCE OF FLUROXYPYR AND MECOPROP AGAINST CLEAVERS (GALIUM APARINE)

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ABSTRACT

Cleavers (Galium aparine) infestations in winter wheat were treated with fluroxypyr ester and mecoprop salt in two field experiments. Applications were made on seven dates in spring 1987. Fluroxypyr gave better control than mecoprop and appeared to be less affected by temperature although poor results were recorded on plots where weeds were vigorous and the crop thin. The best results from mecoprop, or fluroxypyr in a thin crop, were obtained when the soil temperature at 10cm exceeded 8°C but fluroxypyr, aided by strong crop competition, gave excellent control at temperatures as low as 4°C.

An examination of meteorological records for the last 10 years indicates the opportunities for successful use of the two herbicides. The lower temperature threshold for fluroxypyr would have allowed its application an average of 26 days earlier than mecoprop.

INTRODUCTION

Cleavers (Galium aparine) remains a major weed of cereals in the UK. It is fiercely competitive (Wilson, 1986) and not readily controlled with herbicides (Lovegrove, et al., 1985; Orson, 1985). Mecoprop has long been a valuable control measure but results have been variable, particularly when applied in winter or early spring. The more recently introduced fluroxypyr (Paul et al., 1985) has generally given better control of G.aparine but as with mecoprop, winter applications have sometimes produced poor results (Lutman & Lovegrove, 1987).

The object of these experiments was to compare cleavers control by the two herbicides in early and late spring weather conditions and to test the hypothesis that soil temperatures at 10cm might provide a useful guide to optimum spray timing.

MATERIALS AND METHODS

Field experiments

Two field experiments were conducted, one at Boxworth Experimental Husbandry Farm and the other at Broom's Barn Experimental Station. Brimstone winter wheat, contaminated with cleavers seed, was sown on 30 September and 17 November at Boxworth and 2 October and 5 December at Broom's Barn in 3 replicate blocks. Fluroxypyr ester (Starane* 2 herbicide) and mecoprop K salt (Iso-Cornox** 57) were applied at 200g and 2.4kg a.i./ha respectively, to sub-plots on 7 dates from early March to late April 1987. At least 2 sub-plots in each block were left unsprayed. The two experiments were sprayed whenever possible on the same day; 5, 24, 30/31 March, 6, 13, 15 and 24 April. Sub-plots were 3m x 6m at Boxworth and 2m x 9m at Broom's Barn. Treatments were applied in 200-220 litres of water/ha using hand-held sprayers. The second and third treatments were followed by light rain within an hour or two of spraying but quantities were small and unlikely to have reduced herbicide efficacy.

At Boxworth a mixture of diquat and paraquat was sprayed to kill weeds that had germinated before the second drilling and clopyralid was applied overall in December to remove volunteer field beans. Chlormequat was applied to the early drilled plots at both sites in April to prevent lodging.

Populations of between 12 - 40 cleavers plants/m^2 were established at Boxworth and 20 - 50 at Broom's Barn . At Boxworth these included indigenous as well as drilled cleavers and germination was virtually complete by the first spray treatment with only a few seedlings emerging much later. At Broom's Barn germination continued up to the third spray date particularly on the late drilled plots. The plants at Broom's Barn grew more slowly and did not reach the size of the larger plants at the first spray date at Boxworth until the last spray date, some 7 weeks later. Treatments thus spanned weed growth stages from early cotyledons up to plants 250mm high (Lutman & Tucker, 1987).

The crop on the early drilled plots reached "first node detectable" (Tottman, 1987) by the fourth spray date at Boxworth, by the fifth at Broom's Barn and were at "second node detectable" on the last spray date at both sites. The second drilling on both sites was made in poor soil conditions in a very wet autumn and crop establishment was thin and uneven. By the last spray date the plants had reached "ear at 1cm".

At Boxworth, weed control was assessed in mid-July by estimating % cleavers cover in 5 x 0.25m^2 quadrats and multiplying this by the average height of the weeds to give an index of weed bulk in each plot. At Broom's Barn plant counts in m^2 fixed quadrats were made prior to each spray treatment and again in early July, when plant dry weights were also measured.

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* Starane is a trademark of The Dow Chemical Company

** Iso-cornox is a trademark of Schering Agriculture

Percentage control of cleavers was calculated from the bulk index data for Boxworth and the dry weight measurements for Broom's Barn, each compared with the unsprayed plots. The data was transformed, log(x+1000) for Boxworth and log(x+10) for Broom's Barn, to meet the requirements of a normal distribution before statistical analysis. After such transformations the statistical significance of the many possible comparisons among the data is not easily summarised for presentation. Differences of less than 10% should be interpreted with care although smaller differences among the higher levels of control, particularly at Boxworth may be significant. Differences between the sites have not been analysed but all the other comparisons mentioned in the text are significant ($P<0.05$).

Weather records were taken from permanent meteorological sites within a few hundred yards of each experiment and supplemented with records taken on site with electronic data loggers and from local standard meteorological stations.

Relative humidity recorded at 9.00am was lowest (65% r.h.) on the last spray date, a hot and dry day in late April. Rain fell frequently through March and the first half of April at both sites and soil moisture deficits remained below 10mm until the week of the last spray treatment when they reached approximately 25mm.

RESULTS

The results are presented in Figures 1 & 2, together with the 10cm soil temperatures at each site. In these two field experiments fluroxypyr gave better and more consistent control of cleavers than mecoprop. Mecoprop was most affected by treatment timing and early treatments often gave poor results. Fluroxypyr also gave some poor results, applied to vigorous weeds in a thin crop in March and early April, when temperatures were low.

Fluroxypyr gave excellent control (better than 95%) on the early drilled plots at both sites; only the first spray timing, in early March, at Boxworth gave less satisfactory results than later treatments. Control was very poor at the first spray timing on the late-drilled plots at Boxworth but improved with later treatments and reached nearly 100% on the last 3 spray dates. The late March treatments of mecoprop generally gave poor control, often less than 50%, but subsequent applications were more successful and the latest, towards the end of April, gave virtually 100% control on all plots. The first application of both herbicides gave much better control at Broom's Barn than at Boxworth.

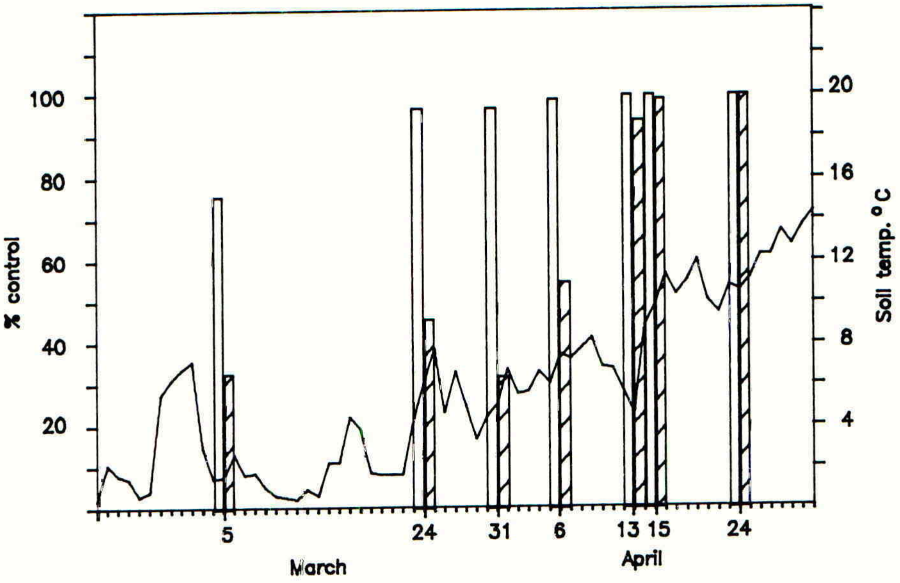
Control generally improved with later treatment and increasing soil temperature. Both herbicides gave complete control on all plots when the soil temperature exceeded 8°C, as it did on the last two spray dates. On the early drilled plots fluroxypyr gave 95% or better control on both sites at temperatures down to 4°C but mecoprop was not so effective. At Broom's Barn both herbicides performed quite well (80-90% control) on the first spray date when the soil was little more than 1°C.

Examination of the 10cm soil temperatures at Boxworth over the last 10 years (1977-86) indicates some difficulty in identifying the beginning of a steady rise. A subsequent fall in temperature is more likely after reaching a threshold of 4°C than one of 8°C. 4°C has been reached between 19 March and 14 April and 8°C between 19 April and 12 May over the 10 year period.

Figure 1. Control of cleavers in wheat with fluroxypyr and mecoprop at Boxworth Experimental Husbandry Farm

—— 9.00am soil temperature at 10cm, ▯ fluroxypyr, ▨ mecoprop

a) Late September drilled plots



b) Mid November drilled plots

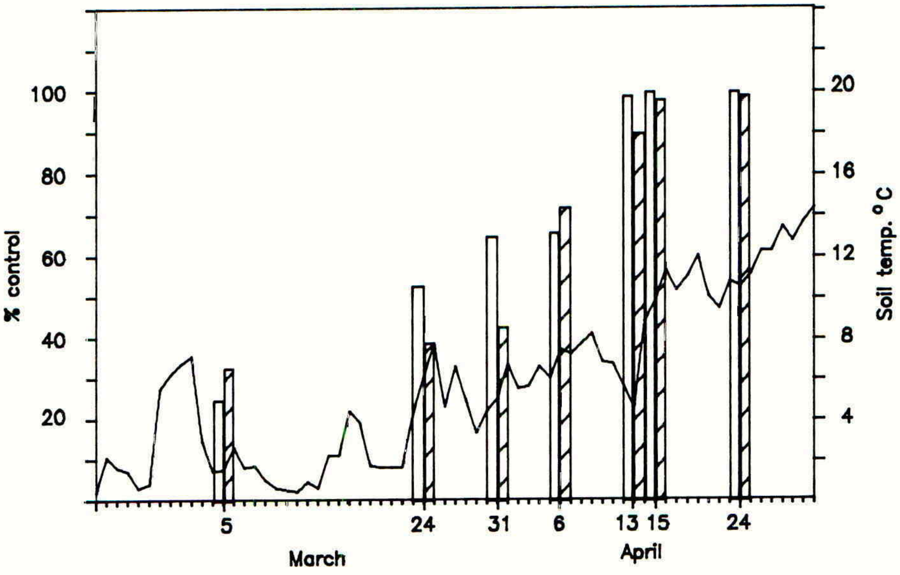
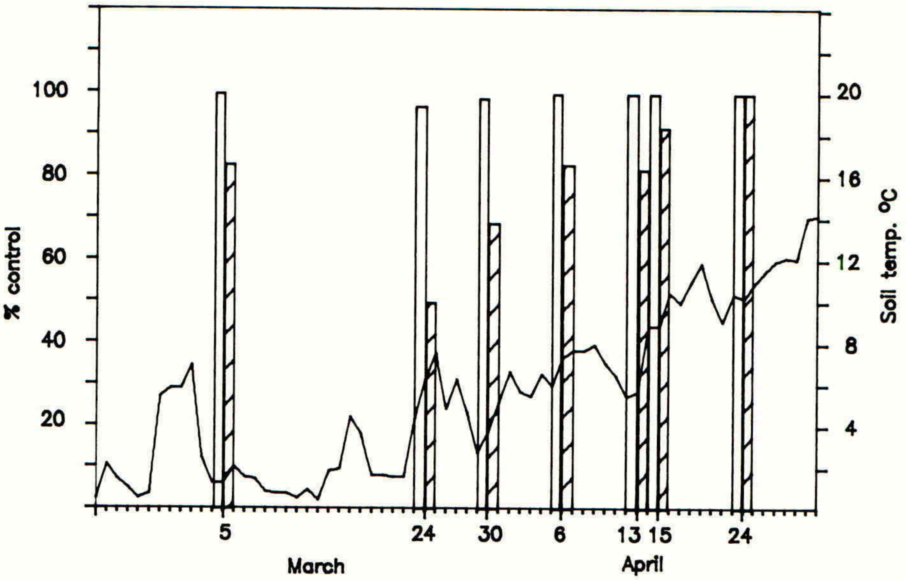


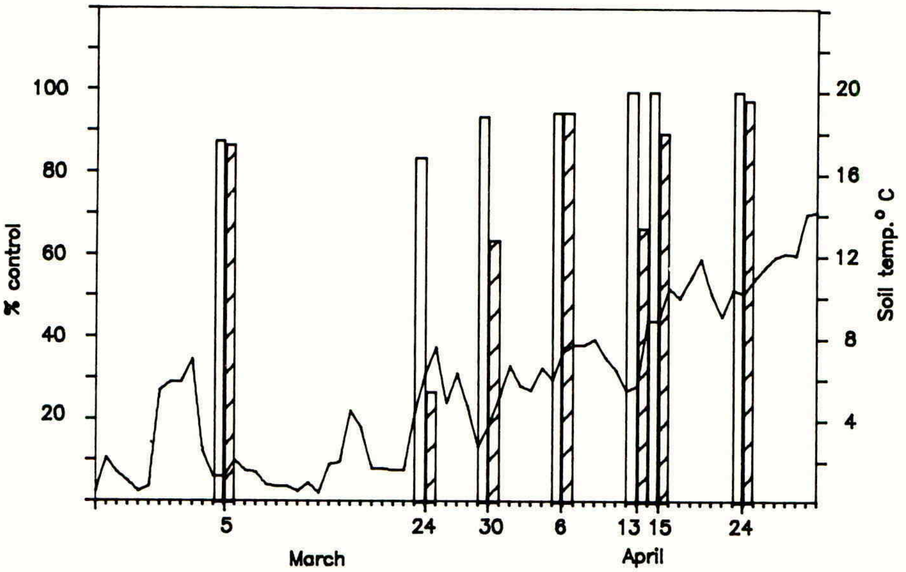
Figure 2. Control of cleavers in wheat with fluroxypyr and mecoprop at Broom's Barn Experimental Station

— 9.00am soil temperature at 10cm, ▯ fluroxypyr, ▨ mecoprop

a) Early October drilled plots



b) Early December drilled plots



The lower temperature threshold for fluroxypyr would have allowed spraying for cleavers control to begin an average of 26 days earlier.

Both herbicides controlled cleavers over a wide range of growth stages. The very large cleavers plants at the last time of spraying at Boxworth were completely killed. Similarly, a high level of control was achieved by the early treatments on the late drilled plots at Broom's Barn when the cleavers were in the cotyledon stage. The number of subsequent germinators observed on adjacent control plots implies that the herbicides killed all the cleavers plants present at spraying and also some that had not then emerged.

The crop on the later drilled plots at both sites was thin (averaging only about 60% ground cover in July). On these plots at Boxworth, where the cleavers were most vigorous, the earlier fluroxypyr treatments gave poor control. Mecoprop treatments at the same times gave consistently poor results and were not apparently affected by the level of crop competition.

DISCUSSION

Herbicide performance is strongly influenced by weather and soil conditions. Each of the factors that contribute to the outcome of a herbicide treatment, for example, retention, uptake, metabolism, translocation, recovery from injury and crop competition, may be affected by different factors and in different ways. It is not surprising, therefore, that the results of field experiments comparing herbicide treatment timing are sometimes difficult to interpret and it may be that the interactions are too complex to allow a simple conclusion.

Temperature is the most obvious factor that might influence herbicide activity and an analysis of field observations by one of the authors, for advisory purposes, has suggested that mecoprop salt can be expected to give good results when the 9.00am soil temperature at 10cm has been at least 6°C for 2-3 days and appears to be rising steadily. In these experiments control of cleavers generally improved with later treatment and increasing temperature. Both herbicides gave complete control on all plots when the soil temperature exceeded 8°C, as it did on last two spray dates. Although the temperature exceeded 6°C on the 4th spray date at both sites, it subsequently dropped and at Boxworth fluroxypyr gave poor control on the late-drilled plots and mecoprop was poor on plots of both drilling dates.

The soil temperatures were similar on both sites throughout the experiments despite the differences in soil type. The most difficult observation to explain is the efficacy of the earliest treatment at Broom's Barn when the same treatment at Boxworth in very similar conditions gave poor results. Application was preceded by a short spell of warmer weather but followed by a fortnight of cold and frost. Fluroxypyr is taken up and translocated rapidly at higher temperatures (Sanders et al., 1985) but this may be delayed without affecting the ultimate result in very cold conditions. It is possible that subtle differences in temperature between the two sites, sometime after application, may have altered the herbicide's activity by affecting the relative speeds of its degradation and translocation to its site of action. However, in practice it would seem safer to conclude that herbicide performance is more variable at low temperatures.

Soil measurements, recorded daily at 9.00am at a depth of 10cm, have been chosen as a useful and practical summary of the plant's exposure to changes in temperature. Equally appropriate might have been an average of daily maximum and minimum temperatures. Herbicide performance may be influenced by variation over a shorter time scale than is encompassed by these measurements. If so, it would be difficult to formulate practical recommendations to take advantage of such differences.

The size of the cleavers at the time of treatment did not appear to be important. On various occasions, complete control of cleavers was achieved at any stage of growth from early cotyledons through to plants 250mm high. Indeed, there was some evidence of the herbicides killing plants that had not yet emerged at the time of treatment.

Relative humidity appeared to play little part in determining herbicide activity. In general, foliar herbicides perform best when applied in humid conditions (Coupland & Caseley, 1981). In this instance, excellent control was achieved on the last spray date when humidity levels were lowest.

In general, the crop and weeds were less vigorous on the lighter soil at Broom's Barn and the cleavers proved fairly susceptible whenever they were sprayed with fluroxypyr. At Boxworth, results were better with fluroxypyr on the earlier drilled plots for which the most likely explanation is the better establishment, growth and competitive ability of the crop, although the indigenous cleavers may have been inherently more tolerant of the herbicide. Cleavers plants have a notorious ability to recover from severe herbicide injury. Vigorous crop competition must play an important role in limiting this recovery and hence is likely to enhance herbicide performance in the field.

Such limited field experimentation does not allow firm conclusions about the factors that determine herbicide efficacy. There are, however, several pointers to factors that might have been important in these trials. To achieve the very high levels of kill needed to provide commercially acceptable control of cleavers with mecoprop, spraying cannot be confidently advised until the soil temperature reaches 8°C. Although good control can often be achieved before this, the risk of a subsequent decline in temperature brings a chance of failure. Such high temperatures were not reached until the crop was in the "second node detectable" stage. Although the main competitive effect of cleavers occurs later (Wilson *et al*., 1985), crop tolerance of the herbicide is reduced. Fluroxypyr can be used safely at advanced growth stages and it performed best at the later spray dates. However, providing the cleavers plants were growing in a healthy competitive crop, very good control was achieved from treatments in late March when soil temperatures were around 4°C. The consequent increase in the number of potential spraying opportunities may be of value when large areas have to be treated in a wet and windy spring.

Future field experimentation might concentrate on a more detailed examination of soil temperatures in relation to herbicide efficacy, involving more spray dates or a more careful comparison of crop densities. In either case, growth analyses of weeds and crop is likely to help interpretation of the results. An alternative might be to examine temperature effects in a controlled environment, although it is clear from these experiments that in the field such effects will be strongly modified by crop competition.

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