CHAPTER 8

Cultural Control

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The increase in wild oat populations in recent decades has been popularly attributed to two factors; widespread dispersal of seeds and cultural practices favourable to the growth of this weed. However, for technical or economic reasons, many of the cultural changes during this period are not readily reversible, eg increasing intensity of cereal growing or replacement of reaper-binders by combine harvesters.

Nonetheless, a continuing and careful review of the effects of cultural practices upon wild oat populations is necessary if we are to devise systematic approaches to control. The literature on these cultural effects has been reviewed under six major headings: effect of harvesting date; effects of post harvest operations; effects of spring cultivations and sowing date; crop competition as an agent of control; rotations; and roguing. Seventy-four published references were used in the preparation of this chapter. Many others were scrutinised but omitted, mostly because they duplicated other work or added little to it.

One general principle can be argued although it has not been discussed fully by any of the authors reviewed. It appears that cultural techniques are generally more applicable to containment of low weed populations than to reduction of high populations. An example of this is to be found in the work of Gram in Denmark which was cited by Storhaugen (1961). Gram compared four rotations over a four year period and Table 8.1 gives an indication of the results.

Table 8.1 *The effect of four years of annual cultural treatments on wild oats (from Gram, cited by Storhaugen 1961).*

Rotation	Wild oat populations/m² 1947	1951
4 yrs barley–no roguing	105	211
4 yrs barley–hand rogued	105	21
2 yrs barley–2 yrs pasture	109	39
1 yr barley–3 yrs roots	112	9
barley, roots, barley, roots	113	73

In this experiment all the cultural treatments prevented population increase of *A. fatua* but only two reduced populations to less than 20% of the initial level in 1947. These two treatments, hand roguing and roots grown for 3 years out of 4, would not be applicable where the initial weed density was high.

If this general principle is accepted, it does not necessarily mean that cultural measures are totally inapplicable where *A. fatua* populations are high. In such densely infested areas, however, cultural methods need to be integrated with the use of herbicides.

EFFECTS OF DATE OF HARVESTING

An early crop harvest may result in seeds being removed before natural shedding has commenced or, in extreme cases, before the seed has matured sufficiently to be effectively viable. A number of authors have studied the relative rates of maturity of crop and weed in this context. Dunn (1955) suggested growing cultivated oats and harvesting as green feed before seeds of *A. fatua* mature. Thurston (1959b) stated that where a heavily infested pea crop was cut for silage before *A. fatua* seeds had shed, the viable seeds in the top 15 cm were reduced by one third in the following year. Gummesson (1972b) showed that green forage harvested before *A. fatua* plants had shed their seeds gave almost as good a control of *A. fatua* as a fallow. After three years of green forage the reserve of viable *A. fatua* seeds in the soil was almost exhausted and only scattered plants occurred after this. Continuous green forage, although effective as a method of control, is unlikely to fit into a farming system. Banting (1969) referred to the early cutting of a crop for green feed as a useful control measure, but one that is often inconvenient for the farmer.

Wilson (1970a) studied the extent of shedding of *A. fatua* in various winter and spring sown crops before they were harvested. The extent of shedding was related to the subsequent contamination of the straw. A winter-sown barley crop harvested on July 17, when 16% of the wild oat seeds had shed, resulted in 669 seeds/kg straw (11,600 seeds/bale); in contrast, a spring sown barley crop harvested on August 18 when 94% of the seeds had shed returned nine seeds/kg straw (140 seeds/bale). It was concluded that the straw from any infested cereal crop is likely to contain wild oat seeds. Thurston (1969) and Petzold (1958, 1959) showed that the later harvest associated with the combine harvester compared with the binder allowed the shedding of a considerably higher proportion of seed prior to harvest. Petzold showed that of 27 weed species studied, *A. fatua* shed the highest percentage of seeds to the ground before harvest. Metz (1969) advocated an early harvest accompanied by an efficient collection of chaff during harvesting, so that the maximum numbers of seeds could be collected and removed from the field. On cereal plots 66% of the *A. fatua* seeds were shed before harvest and 20% during harvest; 7.5% were accounted for in the cereal grain and 2.5% in the straw and chaff. It would seem that when cereal crops are grown to maturity, a high proportion of the seeds will be removed from the field only with extremely early harvests.

EFFECT OF POST-HARVEST OPERATIONS

STRAW BURNING

The burning of straw, a measure generally advocated for the destruction of wild oat seeds, should be undertaken as soon as possible after harvest (Holroyd 1972c), before the seeds are able to propel themselves by their awns into the surface layers of the soil (Hill 1972). There is little information on the numbers of seeds and the proportion of the total seeds destroyed by burning. Hill suggested that an application of paraquat before burning would give a more complete burn of the straw and the stubble between the straw swathes. There is relatively little published information on the temperatures achieved under burning straw, and on the response of viable seeds to different heat levels. Hopkins (1936) found that viable seeds were capable of withstanding 115°C for 15 minutes. Wilson and Cussans (1975) recorded average maxima of about 500°C beneath burning straw swathes and noted that temperatures in excess of 200°C were maintained for between one and two minutes. In this experiment the initial effect of straw burning was to reduce the numbers of seeds on the stubble by about one third, but the difference between burnt and unburnt plots progressively declined during the autumn on plots which were not cultivated.

Increased germination and emergence of seedlings where straw burning has broken dormancy of seeds is reported. Viel (1963) recorded wild oat seedlings present in January on plots which had been subjected to various treatments after harvest in mid August. Fewest seedlings had emerged where straw was not burnt and the plots were ploughed after harvest, and most on plots where the straw was burnt. Burning without cultivation resulted in more seedlings than where the burnt stubble was cultivated. This contrasts with the result obtained by Wilson and Cussans (1975). In this work both burning and stubble cultivation increased autumn emergence of *A. fatua* seedlings. Where burning and cultivation were combined many more seedlings were produced.

It seems likely that dormancy is broken only on a small proportion of the total number of viable seeds present when the straw is burnt. Thurston (1958) found that straw burning stimulated germination of *Avena fatua* in a badly infested field, but that 10 dormant seeds remained in the soil for every one that germinated in the burnt areas. This was confirmed by Wilson and Cussans (1975) who reported that, at most, the autumn seedling emergence only accounted for about 12% of the available viable seeds.

The long term effect of annual straw burning seems slight. Kidd (1972) observed that land which had been growing cereals continuously for many years and the straw burnt, continued to remain heavily infested. In a long term experiment at Boxworth Experimental Husbandry Farm (Whybrew 1964), straw was either carried off or burnt after harvest, annually from 1957 to 1964. Burning generally resulted in more seedlings in the autumn; Table

Table 8.2 *The effects of six yeqrs of stubble treatments on autumn emergence of* A. fatua *seedlings and on numbers of mature plants of* A. fatua *at harvest (after Whybrew 1964).*

	1958	1959	1960	1961	1962	1963	1964
	Seedlings/m² in late autumn						
STRAW BURNT							
Stubble untouched	6.45	0.22	3.52	1.22	2.51	5.38	
Stubble rotary cultd	8.58	1.51	7.09	3.88	26.67	110.51	
Stubble ploughed	0.26	0.22	3.01	2.51	6.03	39.32	
STRAW REMOVED							
Stubble untouched	0.65	0.60	1.67	3.66	0.86	3.66	
Stubble rotary cultd	6.76	2.63	3.95	2.08	7.03	39.61	
Stubble ploughed	0.43	0.16	1.44	2.22	3.07	10.84	
	The effects of burning, as % increase in autumn seedling numbers						
BURNING v REMOVAL							
Stubble untouched	892	−63	111	−67	192	47	
Stubble rotary cultd	27	−43	79	86	279	179	
Stubble ploughed	−40	38	109	13	96	263	
	Plants/m² at harvest						
STRAW BURNT							
Stubble untouched	1.23	0.54	1.06	1.64	8.6	11.5	70.6
Stubble rotary cultd	1.75	1.21	2.03	6.06	37.3	50.7	226.0
Stubble ploughed	1.72	0.98	1.18	4.25	30.6	43.3	175.8
STRAW REMOVED							
Stubble untouched	2.09	1.06	1.89	3.22	15.5	21.3	122.0
Stubble rotary cultd	2.77	2.61	5.19	12.3	78.9	88.5	270.3
Stubble ploughed	2.12	1.84	2.61	8.80	45.0	69.2	183.0

8.2 shows that the stimulation of seedling germination after burning varied from year to year, 1960, 1962 and 1963 showing the greatest proportional increases. The effects of burning on percentage germination must have been greater than the effects on seedling numbers as shown. There were more plants at harvest on plots from which straw had been removed, implying a greater availability of seeds for autumn germination on these plots. The effect of straw burning upon the numbers of wild oats present at harvest was also variable from year to year and the graph shows that the net result of seven successive years of straw burning was relatively small.

STUBBLE CULTIVATIONS

Many reports refer to the influence of autumn cultivation of stubbles upon wild oat infestations. Reports from Canada and the North Central United States tend to favour autumn tillage (discing) in late September or early October to encourage germination of wild oats in the autumn. This often resulted in fewer wild oats in the following crops, in comparison with those where tillage had been carried out in the late autumn or early spring (McCurdy 1960c, Korven 1970).

In Britain, stubble cultivations stimulate only a small proportion of *A. fatua* seeds to germinate. Wilson and Cussans (1972) reported that after September cultivation of stubbles, those seedlings that germinated in the autumn were only a small proportion ($<5\%$) of those emerging on the same plots in the following spring. However, subsequent work (Wilson and Cussans 1975) showed that the proportion could be higher, particularly when straw was burnt. Whybrew (1964) observed that seedling germination following autumn cultivations was largely dependent upon the availability of moisture after harvest. In dry autumns fewer seedlings emerged than were expected on the basis of population trends.

In Britain, stubble cultivations have often been associated with increases in wild oat infestations in the following year. It was suggested (Charman 1972, Chesson 1972) that this may be due to the trend towards deeper cultivation, chisel ploughing or normal ploughing, bringing up deeply buried dormant seeds to the surface layers from which they can germinate. Thurston (1954) reported a survey of the incidence of *Avena fatua* and *Avena ludoviciana* in England and Wales, in which it was indicated that deep ploughing often increased the number of panicles per acre in infested fields.

In experiments reported by Wilson and Cussans (1972, 1975) increased infestations resulted from relatively shallow stubble cultivations. They concluded that the timing of cultivation was important in influencing subsequent infestations. Rotary cultivation in the early autumn resulted in a two to three-fold increase in *A.fatua* seedlings emerging in the following spring, compared with leaving the stubbles undisturbed until late autumn. Early (in comparison with late) autumn cultivation also resulted in a greater survival of viable seeds in the soil. These differences were associated with losses of viable seeds from undisturbed stubbles during the autumn months; losses which did not occur when viable seeds were mixed into the soil by cultivations. Other experiments (Wilson 1972) demonstrated a considerable and progressive deterioration in quality of seeds recovered from the soil surface during the autumn, while seeds which were cultivated into the soil were largely preserved during the autumn. Losses of viable seeds from the soil surface could be attributed to birds, rodents or microbial attack, but attempts to establish these as prime causes of seed losses were inconclusive.

Long term results of continued stubble cultivations were reported by Whybrew (1964). At Boxworth Experimental Husbandry Farm, between 1957 and 1964, rotary cultivation of stubble soon after harvest led to increased incidence of wild oats compared with stubbles left uncultivated during the autumn. Rotary cultivation was slightly worse than shallow ploughing of the stubbles carried out at the same time. The whole experiment was cross-ploughed in December or January each year (Tables 8.2, 8.3). From

Table 8.3 *Wild oat populations and yields of barley on a long term experiment comparing late sowing with early sowing of spring barley (after Whybrew 1964, Selman 1968)*

	Wild oats at harvest plants/m²		Barley yield quintals/ha (85% DM)	
	Early drilling	Late drilling	Early drilling	Late drilling
1958	1.95	0.07	36.6	31.1
1959	1.38	0.01	50.3	45.3
1960	2.33	0.02	51.0	39.5
1961	6.05	0.04	33.5	35.1
1962	36.00	0.04	46.4	47.4
1963	47.36	0.10	31.1	37.9
1964	174.62	0.18	25.2	37.4
1965	6.78* 1.47†		49.2* 39.7†	
1966	4.34* 8.58†		52.5* 43.9†	
1967	4.66* 10.05†		37.3* 41.8†	
1968	1.52* 1.35†		48.6* 21.0†	

*From 1965 plots previously subjected to early sowing were either treated with diallate (*) or sown late (†).

1965 control measures (spring applications of tri-allate and delayed sowing of the crop) were introduced (Selman 1968). It was thought that, with the increased germination resulting from stubble cultivations, a more rapid decline in wild oat populations would occur when measures were applied each spring to kill germinating wild oats. However, the population trends for each stubble treatment for 1965-67 showed very little difference between treatments, and barley yields showed no consistent advantage from stubble cultivation. The differential loss of surface and buried seeds during the autumn reported by Wilson and Cussans (1972) suggests that at the start of the control measures in 1964 greater numbers of dormant seeds would have been present in the soil on the plots which had received stubble cultivations since 1957.

The effect of depth of burying and frequency of cultivations on seeds of *Avena fatua* and *Avena ludoviciana* was demonstrated by Thurston (1961). Seeds were placed in the plough furrow at the time of ploughing at a depth of 15 cm and then either left uncultivated, or ploughed annually thereafter. Other seeds were harrowed into the top 5 cm of soil. With both species fewer seedlings emerged where seeds remained undisturbed than where seeds were brought to the surface by re-ploughing. With *A. fatua,* more seedlings arose from seeds harrowed into the top 5 cm than from seeds ploughed to a depth of 15 cm. The long term survival of viable seeds was greater on the ploughed plots particularly where the seeds remained undisturbed, with a maximum survival of 61 months. With *A. ludoviciana,* differences in survival were less obvious and a maximum of 33 months was recorded.

EFFECT OF SPRING CULTIVATIONS AND SOWING DATE

An important cultural means of controlling wild oats is to delay sowing the crop to allow wild oats to germinate and to be destroyed by cultivation. Van Dord and Heuver (1965) recommended sowing spring barley as late as possible, and cultivating as early as possible to stimulate wild oat germination. They suggested that cultivation should be carried out as frequently as possible, not only to kill the existing wild oat seedlings but also to stimulate more wild oat seeds to germinate. A long-term experiment at Boxworth Experimental Husbandry Farm (Whybrew 1964, Selman 1968) demonstrated that the cultivations associated with sowing barley in late April or early May effectively contained a wild oat population at a low level from 1958 to 1964, compared with the considerable increase in wild oats in barley sown in March, before the majority of wild oats had germinated (Table 8.3). In the first three years, early sown barley in the absence of significant numbers of wild oats outyielded late sown barley by an average of 7.3 quintals/ha. As the wild oats increased on the early sown plots, so did the yield difference in favour of late sowing. From 1965 onwards control measures were introduced on the previously early sown plots. Sowing barley in late April or early May was almost as effective in controlling wild oats as sowing in mid March and spraying with tri-allate. In each case there was a considerable reduction in wild oats accompanied by a big increase in barley yield. Yields of late sown barley were, however, approximately 9 quintals/ha lower than those of the early sown barley in 1965 and 1966. Selman concluded that late sowing could not be justified as a control measure for wild oats in spring barley because of reduced grain yields, if chemical treatment could properly be used as an alternative. The advantage of early sowing with tri-allate depended largely on achieving a good seedbed, allowing good incorporation of the tri-allate.

Thurston (1964c) demonstrated that early sowing of the crop restricted the growth and seed production of *Avena fatua* and *A. ludoviciana*, but pointed out that with early sowing, fewer seedlings are destroyed by seedbed cultivations. The germination period is so prolonged that delayed sowing is likely to be accompanied by unacceptable yield losses. With the earlier germinating *A. ludoviciana* a change from winter to spring cropping can be effective.

In Sweden delayed sowing of barley reduces yields because of the short growing season, and is only recommended with severe wild oat infestations (Gummesson 1968). A delay of at least two weeks is necessary for satisfactory control. Experiments in 1968 (Table 8.4) showed that wild oat

Table 8.4 *The effects on wild oats of tri-allate and delayed sowing (from Gummesson 1968).*

Treatment Dose of tri-allate and depth incorporation	Relative no. of wild oat plants	Relative weight of wild oat plants
Untreated	100	100
Delayed sowing	28	48
Tri-allate 1.6 kg/ha incorpd to 5 cm + delayed sowing	6	12
Tri-allate 1.6 kg/ha incorpd to 5 cm	25	24

control from delayed sowing was not as good as from chemical treatment, and the best control was obtained from combinations of delayed sowing and chemical treatment where sowing was carried out two weeks after spraying and incorporating tri-allate. The same author (Gummesson 1968) reported a long-term experiment which included delayed drilling of the crop each year for 5 years. It was found necessary to extend the delay period from 10 to 14 days to enable the wild oats to grow sufficiently to be killed by harrowing. The residual effect, as shown by the relatively low numbers of wild oats emerging in the year after treatment ceased, was comparable with that obtained after four successive years of tri-allate applications.

Many authors in Canada and the United States refer to cultivations associated with delayed seeding of wheat and barley as a practical control measure. Most of these authors refer to work in the 1950s before alternative chemical measures were available with the introduction of barban and tri-allate. Leggett (1955b) reported that delayed seeding was the most widely used method of control in Canada. He recommended a light cultivation in the early spring to stimulate the germination of wild oats, and delayed seeding to kill one or preferably two crops of wild oat seedlings. Sowing an early maturing variety of barley in the first week of June at a heavier seed-rate than normal and with an application of fertiliser gave the best results. Dunham (1955, 1956, 1957) found delayed seeding of wheat and barley the most effective control method, reducing wild oat infestations and increasing yields, particularly where delayed seeding was accompanied by an increased seed rate and application of fertilizer. One report refers to an early sown crop of barley in which rod weeding carried out as the barley was emerging reduced the wild oats by 50%, with no apparent deleterious effect on the crop. Korven (1961) reported the delayed seeding of wheat as a practical control measure in Saskatchewan. In one experiment, wheat sown at intervals between 5 and 16 May was infested by *Avena fatua* at harvest, but hardly any *A. fatua* was present in wheat sown on 18 and 23 May. He gave results of trials in each of 6 years showing increases in wheat yields. Delay in seeding varied from 15 to 23 days and yield increases from 1.7 to 9.5 quintals/ha were recorded. Shallow rod weeding carried out 4-6 days after seeding was found to be more effective in destroying seedlings than harowing.

Friesen (1964), reviewing weed control in cereals in Western Canada, stated that the basis of effective cultural control is the summer fallow. Fallowed land must be kept free of weeds by timely cultivations to conserve moisture effectively. Seeds of weed species, such as *Avena fatua,* with dormancy periods longer than one year, can survive one year's fallow and mature in the following crop, and if two or more crops are taken between fallowings the infestation almost always increased. Banting (1962) supported these conclusions and found that *A. fatua* could be grown out and destroyed by repeated fallowing for three years. Friesen states that pre-seeding cultivations to destroy at least one stand of weeds will enhance the weed control in the fallow season. In the drier areas cultivation and seeding are combined in one operation, while in the moister regions cultivations and seeding are carried out as separate operations to ensure better weed kill, but seasonal weather variations make this an unreliable weed control practice. In Western Canada the short growing season demands that wheat must be planted before the end of May, which largely precludes the use of the delayed seeding principle of weed control in wheat. But the delayed seeding of an early maturing variety of barley or oats can be effectively used to control *A. fatua* (Table 8.5).

Table 8.5 *Effect of delayed seeding on yields of barley and wild oat control in the Canadian prairie provinces, 1952-57 (from Friesen 1964).*

		Barley quintals/ha		Wild oats/m^2		
Location	No. of years	Normal seeding	Delayed seeding	Normal seeding	Delayed seeding	% control wild oats
Brandon	5	19.5	17.7	49	43	14
Melfort	4	16.5	22.0	60	13	93
Regina	5	16.5	9.2	41	32	28
Lacombe	5	22.6	26.2	184	55	84

Studies at a number of experimental farms have shown over 80% reduction in *A. fatua* by delayed seeding to an early variety of barley, but prolonged periods of wet, cool weather in the spring at Regina and Brandon greatly reduced the degree of control obtained. Friesen also states that the effectiveness of harrowing or rod weeding after seeding is greatly affected by seasonal conditions. Delayed sowing gave slightly better control of wild oats than normal sowing and barban, but the lower yields resulting from delayed sowing resulted in a slightly lower financial return than from normal sowing followed by an application of barban. These results are in agreement with the experience in the UK reviewed earlier.

CROP COMPETITION AS AN AGENT OF CONTROL

Many reports illustrate the susceptibility of wild oats to competition from crops. Factors that increase crop competition often militate against the growth and seed production of the wild oats.

One such factor, under the control of the farmer, is the crop seedrate. It is generally agreed that a high seedrate is necessary to give the maximum competition at a critical period when the wild oats are at an early stage of development. In Canada, Dunham (1956) and Molberg (1958) noted considerable reductions in the growth and seed production of wild oats where barley seed rates were increased from 75 to 150 and from 90 to 180 kg/ha respectively. McNamara (1972) noted that very low seeding rates for wheat in Australia induced rapid build-up of wild oats. Where the seeding rate was reduced from 45 to 22.5 kg/ha, the wild oats produced twice as many seeds; raising the seedrate increased the proportion of wheat seedlings to wild oat seedlings and reduced the number of wild oat seeds produced. In England, Selman (1970) showed that wild oats surviving at harvest from tri-allate and barban treatments were more than halved where the seedrate of barley (grown in 18 cm rows) had been increased from 101 to 157 kg/ha. Bate, Elliott and Wilson (1970) reported that doubling the seedrate of barley from 94 to 188 kg/ha more than halved the production of seeds by competing wild oats. In this work, reduction of barley row width from 20 cm to 10 cm also restricted wild oat seed production but was less effective than an increased seed rate.

Pfeiffer, Baker and Holmes (1960), in experiments on crop competition and barban dosage in relation to the control of wild oats, found that increasing the seedrate of barley from 47 to 376 kg/ha progressively reduced the weight of wild oat plants from about 830 to 240 g/m^2 and, where barban was also applied, from about 240 to 60 g respectively; where no barley was sown, weights of wild oat plants were, respectively, about 1700 and 480 g/m^2 without and with barban treatment. The capacities of barley and barban to reduce wild oat numbers appeared to be separate and additive; rates of barban which caused crop damage, even when temporary, resulted in heavier wild oat infestation at harvest than where lower but completely safe rates were used.

Pfeiffer and Holmes (1961) reported similar conclusions where barban was applied to cultivated oats grown in association with barley. In the absence of barban, increasing barley seedrate from 0 to 376 kg/ha led to a marked reduction in the fresh weight of oat shoots, the number of panicles and the number of spikelets per panicle. Barban applied at each seedrate caused a further reduction in fresh weight of between 70 and 80% at each seedrate. The absence of any interaction indicated that the effects of crop competition and the herbicide were simply additive. It was concluded that if wild oats react similarly to cultivated oats, then a marked reduction of the initial population could be achieved simply by increasing the seedrate of the crop.

Another factor affecting crop vigour is the nutrient status of the soil associated with applications of fertiliser. Reports tend to differ according to whether the crop responds better than the wild oats: if the crop receives the greater boost, the wild oats are suppressed to a greater extent than where no fertiliser is used. Thurston (1959a) demonstrated that, in growth analysis experiments in pots, wild oat seedlings were smaller than those of cultivated cereals in the early stages, but thereafter caught up the cultivated cereals because of their higher net assimilation rate. Addition of nitrogen to the soil affected the growth of the wild oats as it did that of the cultivated cereals, and the conclusion was that nitrogen fertiliser applied to an infested field would be unlikely to alter the balance between the yields of the crop and of the wild oats. The added nitrogen would not begin to affect the growth of the crop until after the seedling wild oats would have begun to catch up, and thereafter the crop and wild oats would respond alike. Pfeiffer and Holmes (1961) found a similar response to nitrogen where cultivated oats were grown in association with barley. Increasing rates of nitrogen led to similar increases in the individual shoot weights of both oats and barley. In the presence of barban their data were inconclusive, but Hoffmann *et al* (1960) found that increasing rates of fertiliser (NPK mixtures) markedly improved the degree of wild oat control with barban. Where no barban was used, wild oats and wheat benefited equally from the fertiliser. McBeath, Dew and Friesen (1970) found a similar response in both barley and wild oats to nitrogen in a growth chamber experiment. In a field experiment, with both barley and wild oats emerging together, barley was more responsive than wild oats to nitrogen in early growth and seed production. Reports from North America generally favour applications of fertiliser to increase crop vigour with resultant suppression of wild oats. Dunham (1956) and Molberg (1958) demonstrated a greater fertiliser effect with barley drilled at a high rather than a low seedrate. Little work is reported on the placement of fertiliser in relation to the relative response of crops and wild oats, but it is suggested (Pfeiffer and Holmes 1961, Hughes 1972) that combine drilling the fertiliser with the seed may result in selective suppression of the wild oats. Hughes warns against excess nitrogen which may cause lodging of the crop and so favour the wild oats.

Some reports indicate that the relative response of crops and wild oats to fertiliser varies with the crop species. Granström (1959a) reported that nitrogen favours wild oats more than cultivated oats, wheat, peas or linseed, but not barley, Bell and Nalewaja (1967) showed that wild oats competed more strongly for fertiliser than flax or wheat but less strongly than barley, and recommended fertiliser for barley crops infested with wild oats. In contrast Fryer (1959), visiting the Danish Weed Institute, reported that, of the cereals, barley had been found to be the least effective competitor with wild oats, and nitrogen had been found to boost the growth of the wild oats more than that of barley. Many reports refer to comparisons between crops for competitive ability against wild oats. Most suggest that spring barley is more competitive than other cereals (Leggett 1955b, Granström 1957, Bell and Nalewaja 1967). Chancellor and Peters (1970), comparing spring sown crops of barley, wheat and beans, showed that barley was the most competitive and allowed the least numbers of wild oat seeds to be produced. Wheat was slightly less competitive than barley, beans considerably less so. It was suggested that the differences between wild oats and cereals were related to the rates of early root growth and after 10 days barley was shown to have 2-3 times the root growth of wild oats, while the root growth of wheat only slightly exceeded that of wild oats. There was little difference in competitive ability between two cultivars of barley, Deba Abed of prostrate habit and Zephyr of upright habit, but the work by Thurston (1970) suggested that the former suppressed wild oats slightly more than the latter. Roebuck (1972) suggested that short-strawed cultivars may be more susceptible to competition. Other work suggests that wheat may be a better competitor than barley. Jones (1960) obtained better control of wild oats with barban in spring wheat than spring barley crops and attributed this to the greater competition offered by the wheat. Thurston (1962c) showed that barley was less tolerant of acid soils than wild oats and, under these conditions, wheat and rye were better competitors than barley.

Several authors emphasise the greater competition offered by winter sown crops which are well established when spring germinating wild oats emerge. North American workers (Harrington 1955, Wood 1955) recommended sowing autumn rye in late August or September, to smother the spring germinating wild oats. This would be especially useful in the Northern areas where the delayed sowing technique is not feasible. In England, Thurston (1956a) compared the effects of winter sown crops of rye, wheat, barley and spring barley on the establishment and growth of *Avena fatua*. Two years of these crops showed that *A. fatua* was controlled by a dense crop of autumn sown cereal irrespective of crop genus; winter wheat and winter rye were equally effective. Beyond a certain crop density, further increase in crop did not decrease the size of the wild oats. The heaviest crop did not completely suppress the wild oats. In the third year the whole experiment was sown to spring barley. More wild oat seedlings arose where winter wheat and winter rye had grown, and it was suggested that wild oat seeds had remained dormant under the winter sown crops, and subsequently germinated in the spring barley.

The competitive advantage of winter sown crops is considerably reduced if wild oats germinate with the crop and survive the winter. This is the case if *A. ludoviciana* is the predominant species, or if *A. fatua* becomes sufficiently well established and the winter remains mild. Holroyd (1972c) showed that mortality during winter decreased with age. *A. fatua* plants which had reached the three-leaf stage by mid December suffered only minor mortality ($<$20%) during the rest of the winter, whereas plants which had only one leaf at that time had much less chance of survival (mortality $>$70%). The larger and earlier emerged plants also produced the greatest amount of seed. Earlier sowing of winter crops allows larger wild oat plants to become established before the winter.

The depth at which the crop is sown can affect the rate of early establishment of the crop and thus influence the competitive balance between crop and wild oat. Shallow drilling of barley was advocated to get quicker early growth of the crop (Leggett 1955b, Harrington 1955, Long 1968). An experiment reported by Roebuck (personal communication) compared barley sown at two depths–shallow (1.5 cm) and deep (7.5 cm) After three weeks, the first leaf from the shallow sown barley was more fully expanded, and the second leaves more fully advanced than from the deep sown barley. After five weeks shallow sown barley had $4\frac{1}{2}$ leaves on the main stem and nearly 3 tillers, compared with 4 leaves and 1 tiller on the deep sown barley. This experiment was carried out in a weed free situation; the more rapid early growth of the shallow sown barley suggests that in the presence of wild oats, it is important to maintain a fairly shallow sowing depth, and so give the crop the maximum competitive advantage over the wild oats in the early stages of growth.

ROTATIONS

It is no longer reasonable to think of rotation wholly in the context of cultural control techniques. Many crops which were formerly cleaned by hand or mechanical cultivation are now dependent on the use of herbicides, although hand labour may be available to augment the chemical control. Crops such as sugar beet and peas may therefore still be valuable in rotation, as suggested by Thurston (1956a) and van Dord and Heuver (1965), but this owes more to the development of effective herbicides than to cultural methods.

Nonetheless, the principle of rotation is still widely accepted. The object is to reduce the cost and/or increase the efficiency of weed control over the whole farm by interspersing crops in which control is difficult or impracticable with crops in which a high degree of control can be attained. Just as this principle extends to the use of break crops cleaned by herbicide it may also be applicable in cereal monocultures. Selman (1970c) in a paper reviewed earlier, discussed the possibilities of rotation of herbicide use in successive spring barley crops. Rotational control techniques may be limited by economic or managerial factors. The break crop may not be very profitable or, in the case of some root crops, it may be profitable but restricted in acreage by shortage of labour or by contractual limitations.

In practice such managerial factors must be weighed against the efficiency of weed control in individual crops in the rotation and the overall requirements for weed control of the whole rotation. A rotation which successfully maintains the status quo in an area only lightly infested with wild oats must not be expected to bring about rapid amelioration of a very severe infestation. Research in this area involves carefully conducted and, usually, long-term experiments. There are, not surprisingly, some considerable gaps in the literature but some aspects have been studied in detail.

The most widely studied rotation, and the one most applicable to large areas of Northern Europe, is the use of grass leys in a predominantly cereal system. Complete prevention of wild oat seed return is quite practicable in a ley although a degree of good management is needed to prevent seeding in hay crops or re-importation of seed in cattle fodder. The absence of soil disturbance by cultivation appears to maximise the survival of buried viable seeds. This dilemma probably goes some way toward explaining some of the contrasting results which have been obtained. Harrington (1955) found that a rotation including a grass clover mixture down for 3 years left the fields almost free from wild oats. In Canada (Canada 1957) wild oats were not a problem if two or three years of grass and legumes were included in an 8-year rotation.

In contrast to this Gram (1956) found that a 3-year lucerne ley reduced a wild oat population from $109/m^2$ to only $35/m^2$; also, only 60% reduction in wild oats was recorded by Molberg (1958) after 3 years of bromegrass with a partial fallow in the final year.

Differing conclusions have been reached on the duration of the ley phase. For absolute elimination, long periods are essential and a Ministry Advisory leaflet (1961) advised that infested fields should be sown to grass for ten years. Mears (1965) found the best results were from a moderately long pasture phase of 6-8 years. Bullen (1966) reported very good results from a very long ley but noted that when a 5-year ley was ploughed it still produced 19,750 wild oat seedlings/ha.

This subject was studied at Rothamsted (Thurston 1961b). At one site, populations of 10.76 seedlings/m^2 were recorded before the land was put down to grass. When plots were ploughed up after 3 years 1.44 seedlings/m^2 were recorded; after 4 years, 0.72 seedlings/m^2 and, after 5 years, $0.83/m^2$.

At another site in Northampton a mixed population of *Avena fatua* and *A. ludoviciana* was monitored by assessing the population of viable seeds in the soil after varying intervals in grass. After $5\frac{1}{2}$ years in ley grass the viable seed population was estimated at $1235/m^2$ and finally in 1960, after $6\frac{1}{2}$ years in grass, there were over 494 viable seeds/m^2. These data were discussed by Thurston (1966) who noted that, in each case, there had been a considerable decrease in viable seed during the first year of the ley, 41% at one site and 86% at the other. Subsequent decreases in the seed reserves were much less and after 5 years there still remained enough seed to produce a significant infestation. It seems that, despite considerable variability, the rate of decline of seed reserves under grass is fairly constant at around 50% per annum. This illustrates an important principle: population differences which are similar in percentage terms may be very different in terms of their absolute magnitude and practical significance.

Thurston suggested that a given area of grass in a rotation would be best deployed as a greater frequency of one year leys rather than longer leys occurring less frequently in rotation. This remains the most carefully researched advice on this subject for UK conditions but suffers from the risks associated with an enlarged acreage of undersown cereals. These may be general problems of farm management or the more specific risk that an undersown barley crop containing a high wild oat population may allow significant seed shedding to top-up the soil seed reserves at the outset of the ley phase. Fortunately, it is now possible to spray undersown crops with chlorfenprop-methyl or to spray most varieties of barley with barban 3 days before undersowing grasses. Further development of flamprop-isopropyl and difenzoquat may extend the potential for control in undersown crops, and thence, the potential usefulness of short term leys in wild oat-infested land.

The ideal crop in rotation for control of wild oats is one in which maximum seedling emergence is combined with total elimination of seed shedding. The use of cereals cut green for forage has already been reviewed earlier and these appear to be ideal rotational crops. Similarly the root crops combine cultivations which may help to stimulate maximum seedling emergence with maximum opportunities for control by herbicides or by cultural means; inter-row hoeing and hand hoeing followed by hand pulling or roguing.

The work by Gummesson (1968) and by Wilson and Cussans (1975) suggests that where effective arable break crops are employed the persistence of many wild oat populations may be less than has commonly been believed; three years elimination of seed shedding may be sufficient to reduce numbers to a very low level.

ROGUING

It is rarely possible to eradicate wild oats without recourse to roguing (MAFF 1961). With a low density of wild oats it is possible to hand-rogue the plants to stop the build up of wild oat seed in the soil. Cherry (1968) estimated the maximum density at which roguing was practicable to be 500 wild oat plants/ac (1235/ha), the meticulous roguing of 200 plants/ac taking up to $1\frac{1}{2}$ hours. However, Holroyd (1972c) stated that, at maximum, 500 plants/ac could be rogued economically and 500 plants/h is the approximate rate of roguing. Elliott (1969) agreed that the maximum feasible density for hand roguing is 1 plant/10 yd^2 (1/8.4m^2), the cost of this being 10 shillings (50 new pence)/ac. Estimates of maximum density at which roguing is feasible must be, to some extent, subjective and influenced by other circumstances. Many farmers with large acreages consider one plant to 30 m^2 to be an absolute maximum, so the higher figures quoted above may be applicable only to relatively small areas.

Wild oats do not ripen evenly, Not only is there considerable variation between plants (Wilson 1970a) but on any one panicle shedding commences from the uppermost spikelets before the lower ones are mature (Thurston 1962c). Roguing must therefore start before shedding has commenced, usually in early July. A second roguing may often be necessary to remove the later plants. It is essential that the whole plant be pulled and removed from the field (Elliott 1969). Removal of only the panicles results in secondary tillers and further panicles being formed. These may not appear above the crop (Holroyd 1971). Even if the seed is stripped off the panicle when green, the seed can still ripen and be viable.

On the disposal of the wild oat plants after roguing (Elliott 1969, Holroyd 1971, MAFF 1961, Agriculture in Northern Ireland 1971), great emphasis is placed on the fact that the complete wild oat plant should be removed from the field and burnt. This is the best way of ensuring that the wild oat seeds will not germinate even if they are transported back into the field again. In any other method of disposal there is a possibility of wild oat seeds ripening, becoming viable and lying dormant until suitable conditions occur for germination.

It has been frequently observed (Thurston 1965, van Dord and Heuver 1965, Holroyd 1971) that when barban is used as a means of wild oat control in cereals, the wild oat plants that survive are stunted in growth yet still bear viable seed. This has the effect that no wild oat panicles show above the crop and that roguing (if carried out) is made difficult, as it is then necessary to search through the crop canopy for the wild oat plants and often many are missed. If seed bed conditions permit, tri-allate may be the better choice of chemical as the surviving wild oat plants have normal panicles which can be removed as the roguing gang moves through the field.

It was estimated that 100% control of wild oats was obtained by hand roguing in sugar beet (Canada 1959b). This serves to indicate that roguing is very much easier and more certain in some crops (notably non-cereal crops).

Chemical roguing–the direct application of a chemical to wild oat panicles with the object of rendering the seed non-viable–is now being developed. The chemical is applied by 'stroking' the panicle with a specially designed glove which is kept covered in a herbicidal foam. Chemical roguing is generally twice as fast as normal hand roguing as it does not involve the removal of the plant from the field (May 1972, Holroyd 1972). May (1972) also observed that treated seeds, although non-viable, appeared in the harvested grain. This will probably be unacceptable to the seed merchant who expects a sample free of *Avena* seed. By using one particular herbicide–glyphosate–prior to the 'milk' stage it is possible to prevent the development of any caryopses within the seed, making seed cleaning easy. Chemicals and methods used in chemical roguing are discussed on p. 208.