Weeds and Animal Productivity

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A weed has been defined as "a plant out of place". Thus all plants may be weeds, depending upon circumstances, and weeds may not necessarily be undesirable even when they are undesired. It is proposed to accept this definition of a weed for the purposes of this paper, but it does not appear to be entirely satisfactory since it merely shifts the difficulty of definition to the term "out of place".

Practically every environment in which an agricultural production process takes place contains vast numbers of organisms which are not an essential part of the process. The degree of environmental control necessary to eliminate them all would generally be very great and quite uneconomic in most circumstances.

So it is that, in particular circumstances, particular animals are labelled as parasites or pests and certain higher plants are described as weeds; the implications being that the production process would be better without them. Before money can be spent on their eradication, however, measurable benefit must be associated with their absence.

In the growing of grass, as in the growing of any other crop, if a species is required it will be sown or otherwise encouraged. If it is not required, it is a weed and the crop would be better without it: the question remains as to how much better. If the weed species is represented by very few plants, they can only be worth eradication if they are noxious (e.g. poisonous) or capable of giving rise to many more plants, by whatever means, or if they are carriers of disease (e.g. ophiobolus in cereals).

There is no doubt that as grassland production gains precision and is raised to very high levels, a situation can be envisaged in which a totally weed-free environment is desirable, though this is unlikely to be so without regard to cost. In the nearer future, apart from a category in which each individual plant is objectionable, weed species are likely to be tolerable or not according to their population density (i.e. frequency per unit area of land). A list of weeds of grassland would therefore place as most important those unsown or undesired plants most commonly present in considerable numbers. Such a list would always reflect the current situation, but it does not follow that those species listed as important weeds are currently limiting agricultural output from the land on which they occur. Nor, of course, does it follow that the grassland situations in which these weeds are important, are desirable now or will be relevant in the future.

This point is one of some importance. There is little to be gained from identifying and listing the important weeds of, for example, pastures sown to timothy (Phleum pratense) if this grass is not going to be grown in the future. There is, perhaps, even less to be gained from a study of the effects of such weeds in a timothy pasture which is managed badly even by current standards. These would seem to be the main dangers in deriving evidence of the importance of weeds from current practice but they are not, of course, too difficult to avoid.

There is an increasing body of evidence that the future choice of grasses for agriculture in the U.K. will be restricted to a very few species, notably perennial ryegrass (Lolium perenne) in regions where its survival can be guaranteed. There are, however, many situations where a pure legume sward or mixtures of grass and legume species may be required. If this general restriction to a relatively few species is to be the pattern, then it is already possible to specify some of the relevant situations, defined in terms of species and the management required to achieve high levels of output of digestible organic matter in a suitable form for animal feeding. With sufficient experience of such situations, it will clearly be possible to state the major weed problems. This may well be so now for perennial ryegrass under grazing conditions and the chief weed would probably be <u>Poa trivialis</u>: it may not be so for continuous cutting managements. Clearly, the method of defoliation may not only have a bearing on the choice of crop plant, it may also determine the major weeds. Of course, cutting and grazing differ in more than their actual method of defoliation and many facets of the presence of the animal may be important.

In principle, however, the way the crop is harvested (or by whom) does not affect the crucial question of whether at a particular time (e.g. in relation to sward establishment), or over the whole year, weeds are adversely affecting productivity.

Whether harvested by the animal directly or not, crop yield and nutritive value are important. The latter cannot therefore be allowed to vary greatly with harvesting method if it is ultimately to be consumed by the animal. It is true that grazing may allow much greater selection in what is actually eaten than occurs in the feeding of cut herbage or is possible where herbage is conserved, especially if this is dried, ground and pelleted. It is also true that the last process can greatly alter physical form before the animal is presented with the food and that conservation may change the nutritive value of the herbage conserved. It is rather unlikely, however, that these considerations would lead to the harvesting of a given crop at a different nutritive value (e.g. a different digestibility) for cutting as compared with grazing. It is reasonable, then, to consider the effect of weeds on the production of a given species of grass as operating on the same factors whatever the method of harvesting: these factors must be the major ones in the animal production process.

<u>Animal production from grass</u>

There are more different kinds of animal to be fed than there are products (such as milk, meat and wool). The nutrient requirements of sheep and cattle vary with their physiological states - whether they are growing, pregnant or lactating - and with the rate of performance that is desired. Now, it is possible that entirely different crops will be grown for these different animals, or the same crops may simply be harvested at different stages of maturity. There is certainly a minimum level of nutritive value, which may be expressed in terms of percentage digestibility, for example, that a crop must have if it is to sustain a given level of animal growth or milk yield. The object must be, of course, to grow and harvest as much material of this quality as is possible (or, more accurately, economic) per unit of land. In cutting systems, the further object must be to ensure that as high a proportion of the harvested crop as possible is eaten by animals. Whatever the system, it is desirable that the food consumed should be converted efficiently. In fairly simple systems this may depend chiefly on high rates of food intake leading to high rates of performance. Animal production always has an element of reproduction about it, however, and, in complete production systems there are breeding animals that, at times, only require to be maintained at the same body weight. The relevant point here is that it is far easier to achieve a high degree of utilisation (the proportion of what is grown that is harvested) by grazing with such animals than is the case with animals from which a high performance is required.* It should also be noted that harvesting a high proportion of what is present at the time of defoliation is not necessarily the same thing as harvesting much of what is grown. Harvesting, whether by grazing or cutting, is usually concerned only with net growth and the relationship between the amount grown and the amount that can be harvested is not well understood. The main factors affecting this relationship are herbage senescence and survival from one harvest to the next.

* These higher performing animals may come into the same category if their herbage diet is supplemented with other foods, including conserved herbage.

The major components of animal production from grass, therefore, are:

1. The quantity of herbage grown;
2. The quality of this herbage;
3. The quantity of digestible organic matter harvested;
4. The efficiency with which this quantity is converted to meat, milk or wool. For any given animal production process, this efficiency will depend upon the distribution of the digestible organic matter harvested, amongst the animal population, in such a way that the proportion used for production, as distinct from maintenance, is maximised.

The Effect of Weeds

Any effect of weeds on animal production must operate on one or more of the above components, especially on the first three: but an effect on one of them does not necessarily imply any effect on the others. Animal production may be affected in two main ways. Performance per head may be reduced if herbage quality (2) is adversely affected, and output per acre will be reduced if the quantity of D.O.M. harvested (3) is decreased.

Herbage quality

The presence of weeds cannot normally influence herbage quality unless they form part of the harvested crop. They may not do so, either because they are left ungrazed or because they occur below cutting height. In grazing systems, the extent to which weeds can be rejected depends in part on how selectively the animal can graze: cattle and sheep differ considerably in this. In cutting systems, if weeds occur above the cutting height they are bound to be harvested and it is unlikely that they can be separated thereafter. Once mixed with the harvested crop, they may reduce quality by being unpalatable (resulting in decreased food intake) or by being less nutritious (e.g. less digestible). If grazed, only the second is likely to be important.

The question of the relative digestibility of weeds and crop plants in grassland can only be posed of specific examples. One may be considered from a five-year sheep grazing experiment carried out at Hurley (Spedding, Betts, Large, Wilson and Penning, 1966). Self-contained sheep units were maintained at two stocking rates (3 & $4\frac{1}{2}$ ewes/acre/annum) and managed rotationally. As in most grazing systems, about one third of the dry matter produced was harvested for conservation. The original sward was perennial ryegrass (S.23) and white clover (S.100). The latter became unimportant as a contributor to production within one year.

Two main weed grasses occurred. *Agrostis* spp. quickly appeared in severely grazed plots and *Poa* spp. (first *P. annua* and then *P. trivialis*) followed. By the end of five years, at both stocking rates, the pasture contained up to 50% of *P. trivialis*. *Poa trivialis* produces some 25% less D.M. than S.24 under fertile conditions and *Agrostis tenuis* has been found to yield 20% less at several levels of fertiliser nitrogen, but mixtures with white clover gave similar gross yields whether the grass was S.24 or *Agrostis tenuis* (Green, 1965). It is worth considering, therefore, the apparent digestibility coefficients of such crop and weed grasses (Tables 1 to 3). It would require a considerable proportion of the animals' food intake to come from the weed grass for the mean digestibility to be depressed significantly.

The Quantity of D.O.M. Harvested

Herbage harvested by cutting still has to be fed to the animal, in one form or another, but the effect of weeds is unlikely to be large on this part of the process.

The most probable effects are (a) on the amount grown and (b) on the proportion harvested, both of which determine the quantity of nutrients actually eaten by

Table 1

Digestibility (in vitro) of grass species continuously grazed by sheep during a period (13.5.64 - 10.6.64) when flowering did not complicate the picture. The pastures were maintained, by adjusted stocking, at 3 levels of dry matter per unit area: Low (L), Intermediate (I) and High (H), varying from 2,500 to 4,500 lb. D.M./acre.

	D.M./acre category		
	L	I	H
Lolium perenne	80.2 - 67.0*	76.0 - 63.1	77.2 - 68.5
Dactylis glomerata	74.6 - 56.3	74.5 - 56.1	72.5 - 58.6
Festuca rubra	72.7 - 55.7	72.9 - 53.1	74.0 - 53.0
Poa trivialis	77.0 - 60.3	75.4 - 58.4	74.0 - 60.9

* % digestibility of organic matter, initial and final values for the period studied (given by Spedding, Large & Kydd, 1966) on samples taken to ground level.

Table 2

Digestibility of Lolium perenne and Poa trivialis grown together in a sward grazed rotationally by sheep. The values are in vitro digestibilities on material sampled to ground level from June to September, 1965.

	Date			
	2.6.65	15.7	26.8	30.9.65
Lolium perenne	77.7*	73.8	72.7	76.0
Poa trivialis	73.4‡	61.1	59.0	56.3

* S.E.'s range from ± 0.73 to ± 0.82

‡ S.E.'s range from ± 1.08 to ± 1.24

Table 3

Mean Digestibility (in vitro on the D.M.) of grass species based on 6 successive samples between 6.5.64 and 10.6.64, each sample taken after 3 weeks growth from plots irrigated and receiving a high level of fertiliser nitrogen (Green & Corrall, 1966);

Grass species	% Digestibility
Lolium perenne S.24	76.5
Dactylis glomerata S.37	72.6
Phleum pratense Canadian	75.6
" " S.51	75.4
" " S.232	76.1
Poa pratensis S.63	73.4
Poa trivialis Danish	76.5

animals. There are also many other factors operating on these two components, however.

(a) Weeds can only reduce the amount of crop grown by some kind of competition and this can only operate on a limiting resource. Thus, if incident light is not a limiting factor (because very little of it is used anyway or because of low density in the crop plant), competition for light is unlikely. It may be argued that, at most times, grass growth is limited by water or nitrogen. It is worth considering, particularly in relation to systems of the future, whether nitrogen will be used in such a way that weed grasses can use it wastefully, by competing with the crop plant, or in significant quantities.

There are times, of course, when the factor limiting growth is something like temperature: although weeds can hardly influence the issue at such times, relatively little of the total production may actually occur in these conditions.

Clearly, the greatest difficulty here is to decide when a weed is competing for resources and when it is simply occupying vacant space. If it can be said that, in some sense, a weed must be depriving its neighbouring crop plants of resources, then the same must be said of any crop plant substituted for it, unless the weed plant is much more vigorous (e.g. in some broad-leaved weeds). Whether it is competing or not, any benefit from its removal must come from that space being filled by more crop plant (i.e. that the weed is preventing some crop plant from growing there).

It is relevant to note that in recent studies on mixtures of perennial ryegrass and Poa trivialis, both in the U.K. (Kydd, 1966) and in New Zealand (Vartha, 1966), the total annual herbage production (of D.M.) has not been significantly affected over a wide range of proportions of Poa.

In practice, then, perhaps the most important question to ask is, if a weed is removed, will a crop plant fill the gap and how soon will it do so? This is similar to asking why the gap existed in the first place and why it was filled by the weed.

In short, in management systems that allow and encourage weeds, their removal will not necessarily increase herbage production. There are, however, critical times when weed eradication can have far-reaching consequences: the establishment phase of crop grasses is one such time.

(b) Many factors affect the proportion of the crop that is harvested: the upper limit is set largely by the animals' demand for food. If this is low relative to the quantity of herbage present, any factor which reduces the total amount of crop may actually increase the proportion harvested. Only at high grazing pressures can a high proportion of the crop be harvested by grazing; factors increasing or decreasing crop yield will thus have most influence where stocking rates are high in relation to the amount of herbage grown. This situation is not, of course, confined to absolutely high stocking rates or absolutely high herbage yields.

In practice, however, a substantial margin normally occurs between supply and demand at any one time. This is for two reasons. First, there is a strong element of insurance about it and, secondly, a margin may be required in order to ensure high individual food intake and animal performance. Where a combination of animals (e.g. ewes following lambs or rearing heifers following milking cows) is used to allow high individual performance of some animals whilst obtaining high utilisation with others, any reduction in total herbage production due to the presence of weeds will be reflected in reduced stock-carrying capacity. Since the needs of some of the animals are by definition low, it is unlikely that herbage quality would be so important, however, and the carrying capacity is likely to be that of the combined crop and weed yield.

Many examples of failure to benefit in grassland practice from methods of increased crop production whether by using nitrogen or a herbicide, can be traced to an inadequate stocking rate. It should be remembered, however, that there are many reasons why stocking rates may not be increased, varying from shortage of capital to problems of disease control.

If, under grazing conditions, the proportion of the crop that is not used remains substantial, and if weeds, or loss in crop production due to them, can be regarded as forming part of the unused portion, then a sizable weed content will be economically tolerable. Any attempt to assess the probable benefits of weed removal will need to take into account, therefore, not only the effect on crop yield but also the proportion being utilised by stock.

The argument must be somewhat different for systems based entirely on cutting, There is no reason to suppose that cutting harvests all the crop that is grown or all that is present on any one harvesting occasion. Nevertheless, it is probable that if less is grown, less will be harvested. Weeds are more likely to have an important effect, therefore, provided that they do, in fact, reduce crop yield significantly.

The Assessment of the Effect of Weeds

This can only be done for specific conditions but a general approach can be suggested, based on the foregoing discussion. This can be illustrated by a relatively simple example, if the following assumptions are accepted:

1. That percentage digestibility is the most useful single index of nutritive value (Blaxter, 1960);
2. That the production of herbage can be satisfactorily expressed in terms of digestible organic matter (D.O.M.)
3. That any special contributions of weeds (such as a high mineral content) are not significant or they would be included as crop plants and deliberately sown.

Then the percentage reduction in production of D.O.M. due to the presence of weeds in a grass crop

$$= 100 \left(1 - \frac{C_W D_c + W D_W}{C D_c} \right)$$

where $C \equiv$ D.M. production of weed-free crop grass
$C_W \equiv$ D.M. production of crop grass grown with weeds present
$W \equiv$ D.M. production of weed
$D_c \equiv$ Digestibility of crop
$D_W \equiv$ Digestibility of weed

If the calculation resulted in a negative value, it would suggest that the wrong crop plant had been selected.

Although overall yield of two sward constituents may exceed or fall short of the mean of the two, quite commonly it remains constant (Harper, 1964). Where this is so, $C = C_W + W$ and the weed content observed can be expressed as $\frac{W}{C}$.

Supposing such a case, where the weed content was 40% and its digestibility 60 compared with a crop of 70% digestibility, the percentage reduction in yield of D.O.M. would be

$$100 \left(1 - \frac{60 \times 70 + 40 \times 60}{100 \times 70} \right) = 100 - 94.3 = 5.7\%$$

Clearly bigger effects would follow from a reduction in total crop yield, so it is important to know whether or when this occurs.

⎡A more general equation can be stated as follows:

$$\% \text{ reduction in D.O.M. production} = \frac{100}{CD_c} \left(f_w D_c + W(D_c - D_w)\right)$$

where $f_w \equiv$ the effect of weeds on the total D.M. production, such that $C_w + W = C - f_w$: when $f_w > 0$ a reduction in total yield is implied; when $f_w < 0$, weeds have a beneficial effect.⎦

To translate any effect on herbage yield into an effect on animal production would then require the following further information:

1. The extent to which the weed was eaten by the stock;
2. The extent to which animal performance was dependent on the higher digestibility of the crop grass;
3. The degree to which the herbage was being utilised or would be utilised if weeds were removed.

If the weed was not eaten to any great extent, the effect on animal output would be related to the difference between the percentage utilisation and the weed content (as a percentage), assuming that the presence of weeds did not affect the percentage utilisation. If the weed was readily eaten and the mean digestibility of weed and crop was adequate for animal performance, then the effect on animal output would be related to the difference between the reduction in total herbage yield (as D.O.M.) and the percentage of the herbage not utilised.

Conclusions

By definition, a weed is not the plant of choice, thus it must be less desirable in some respects. This may be so to varying extents and it may be necessary to know to what extent the weed is less productive and in what way. It is further necessary to know whether, in given circumstances, weeds reduce the productivity of the crop. This information can only be obtained by experimentation and the latter cannot be contemplated for a wide range of plants and circumstances without regard to the best use of research resources. It is most needed for the major weeds, within the situations in which they are of greatest importance, provided that these situations are of major agricultural relevance now or in the future. It cannot be assumed that the effect of weeds on animal production will necessarily be of biological or economic significance, since the quantity of marketable products per unit of land may be unaffected even though detectable loss may occur at some stage in the system.

The more efficient the whole husbandry system becomes, however, the more likely is it that weeds will cause a significant reduction in animal productivity.

References

Green, J.O. (1965). Exp. Progr. Grassld. Res. Inst., Hurley, 17, 14 - 15.

Green, J.O. & Corrall, A.J. (1966). Unpublished data.

Harper, J.L. (1964). The nature and consequence of interference amongst plants. Genetics Today. Proc. XI Int. Congr. of Genetics, The Hague, Sept., 1963.

Kydd, D.D. (1966). Personal communication.

Spedding, C.R.W., Betts, J.E., Large, R.V., Wilson, I.A.N., & Penning, P.D. (1966). Productivity and Intensive Sheep stocking over a 5 year period. In preparation.

Spedding, C.R.W., Large, R.V. & Kydd, D.D. (1966). The evaluation of herbage species by grazing animals. Proc. Xth Int. Grassl. Congr., Helsinki.

Vartha, E.W. (1966). Of what significance is the presence of Poa trivialis in ryegrass pastures? Proc. N.Z. Grassl. Ass., 1965, 102 - 111.

WEEDS AND THE FARMER

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I think it will generally be agreed that the farmer who is concerned with both thinks in a very different way about weed control in grassland than he does about weed control in arable land. For evidence one need only look at the very different proportion of each that is sprayed each year. In short, the farmer is concerned very much more about the weeds in his arable crops and willing to go to much more trouble and expense to get rid of them.

There are several reasons for this. Arable weeds reduce yield, make no contribution to productivity and hamper harvesting. By contrast grassland weeds may not reduce yield - many of them do contribute to productivity and they do not, in any striking way, hamper harvesting. Examples of weeds which contribute to productivity on grazing land are *Plantago spp*. (plantains) *Taraxacum officinale* (dandelion) and nearly all grass weeds. Those which do not are more obvious - because they are disliked by animals they are left standing upright when all around them is grazed. They include *Rumex spp.* (docks), *Cirsium spp*. (thistles), *Senecio jacobaea* (ragwort), *Urtica dioica* (nettles), *Juncus spp*. (rushes) and one grass species in particular *Deschampsia caespitosa* (tussock grass). When grass is cut for conservation all species are harvested together; the problem of the weeds' contribution to productivity is then more obscure.

Another reason for the farmer's attitude to weed control in grassland is that the extra return from an arable crop due to removal of weeds can be ascertained by experiment and the value of this easily calculated to give the margin by which the benefit exceeds the cost. The same process in the case of grassland weeds is so involved that it is usually not attempted. Grass is only one input to a livestock enterprise involving several others, including the skill of the farmer as stockman. Between an increase in grass production and an increase in profit the way is long and difficult.

The farmer is also aware that for grassland weeds, unlike most arable weeds, indirect methods of control are available. By such changes in management as cutting instead of grazing or by using more fertiliser and increasing the stocking rate of the land, some weeds can be drastically reduced or eradicated. In many cases, this obviates the need for direct treatment of weeds.

Another factor is that many major grassland weeds are difficult to control selectively by herbicides. One may mention as examples *Rumex spp*. (docks), *Deschampsia caespitosa* (tussock grass), some *Juncus spp*. (rushes), *Equisetum spp*. (Horsetail) and weed grasses as a whole.

On most farms there has been up to now a considerable margin of under-utilisation of grassland. That is to say, the stocking density of grassland has been much lower than its existing productivity. The farmer has been aware of this to some extent, so that the incentive to increase direct production of grass has been weak.

Finally, in my view another reason for the farmer's attitude is that the case for weed control in grassland has never been put to him convincingly. Perhaps this is because the evidence to convince him is not yet available.

So far I have spoken of the farmer's attitude to grassland weeds, but in fact one can distinguish among farmers two views of the grassland weed problem. The "traditional" view is dying and the "economic" view is struggling to be born. The "traditional" farmer's reaction to weeds is primarily aesthetic. This is not surprising, as farming in the past was often thought of as an art, and not as a science or a business. The traditional farmer thinks of grassland weeds as ugly; to him they are an eyesore, they spoil the look of a good field. As evidence of this aesthetic theory, I would suggest that farmers dislike upright weeds, such as docks, thistles or rushes, which are very obvious, more than prostrate kinds such as creeping buttercup or plantains, which are less noticeable. Yet a prostrate weed like creeping buttercup, covering a large percentage of the ground, can be of more economic importance than a spectacular weed like docks, where a bad infestation may cover less than 5% of the ground. The traditional farmer's reaction to eyesore-weeds is to remove them, if possible, without regard to whether it will pay him to do so or not. Providing, of course, that the cost is what he regards as "reasonable". By this he usually seems to mean similar in cost to the spraying of a cereal crop, which is hardly a rational basis for deciding whether or not to spray grassland. The "economic" farmer's view of grassland weeds arises from his conception of farming as primarily a business, in which everything is judged according to its effect on farm income. His view of any technique or operation can be summed up as "What is the cost? What is the return?" I have said that this economic conception of grassland weed control is hardly yet born. The economic farmer is very much with us in other parts of farming; but until we are in a position to answer the question "What is the return?" we shall find it hard to interest him in grassland weed control.

I would like to discuss from the farmer's point of view the questions:- "What plants are weeds in grassland?" and "What effect to they have on productivity" In the case of sown grassland there is likely to be general agreement that any species other than those sown are weeds. If this is accepted, then there is little doubt that the major weeds of sown grassland are perennial grasses, especially Agrostis stolonifera (creeping bent or watergrass), Poa trivialis (rough-stalked meadowgrass) and Holcus lanatus (Yorkshire fog). There is little awareness among the majority of farmers of the proportion of unsown species, i.e. weeds, in leys only two or three years old. A frequent comment is "It was a bit thin to begin with but it filled in well"; filled in, of course, with the indigenous grasses I have just mentioned. The fact that it seems to make little difference in productivity is more a reflection on plant breeding than a justification of the farmer's attitude. Undoubtedly the difficulty of recognition is a major factor - "If only weed grasses were red instead of green" is a sigh that has often been heard in the past from grassland advisers. Yet farmers distinguish one breed of sheep from another without difficulty by characteristics that are far more subtle than those which distinguish Agrostis spp. from Lolium spp.

In unsown pastures there is much more difficulty in deciding which plants should be regarded as weeds. Most farmers would say "Any broad-leaved plants other than clovers". It is about weed grasses that controversy starts. I would like to suggest a definition of a weed in unsown pastures - "A weed in unsown grassland is any plant that is poisonous, unpalatable or appreciably below the average in productivity". It is not too hard to distinguish plants with the first two characteristics: ragwort for example, is poisonous and tussock grass is not only unpalatable but also practically uneatable. It is when we try to distinguish unproductive plants, especially grasses, that we are in difficulties.

Yet the productivity of grass species must be the main criterion by which to decide which of them, if any, should be regarded as weeds. The evidence we have had until recently is, in my view, not only insufficient but also possibly misleading. You have heard something of this from Dr. Spedding, who stressed the importance of looking at productivity as the amount actually useable by the animal, that is, the production of digestible nutrients. Until recently all data from grass productivity experiments was given only in terms of yield of dry matter; differences in digestibility between species were not taken into account. More serious is the fact that, until this year, seed from commercial sources was used to represent weed grasses in species productivity experiments. Agrostis tenuis was often chosen to represent weed grasses, and the only seed of this species readily available was New Zealand Browntop - lawn grass seed! The assumption was made that Agrostis from this source - from fields on the other side of the world harvested for seed for year after year - would have the same productivity as the Agrostis tenuis in our grazed pastures, which rarely seeds on well-grazed fields.

Subject to these qualifications, the few experiments carried out in recent years have shown that with high fertiliser applications the production from so-called weed grasses was not much lower than that of the best sown grasses. Evidence throwing light on this question indirectly has come from productivity experiments comparing leys with permanent pasture carried out at the N.A.A.S. Great House Experimental Husbandry Farm and by the N.A.A.S. West Midland Region. These have shown that permanent pasture, containing a high proportion of so-called "weed" grasses, has given production of the same order as sown leys, when compared over several years. A similar pattern is shown by the grassland recording data collected from five or six hundred fields over three years by N.A.A.S. Cheshire. At high nitrogen rates there was only a small difference in production between permanent pasture and leys.

The Grassland Research Institute have just started an experiment comparing the yield of actual indigenous grasses transplanted from fields in this country to experimental plots at Hurley, and compared with pedigree varieties established similarly. These are harvested at three-weekly intervals under irrigation and high nitrogen applications. Although yields of digestible nutrients are not yet available, dry matter yields in this first year show that most of the indigenous grasses, including Agrostis stolonifera and Holcus lanatus gave at least as high yields as S 24 perennial ryegrass and S 48 timothy.

To sum up, the evidence available, although not conclusive, suggests that in total productivity under high nitrogen applications, indigenous grass species differ little from our usual sown species. Although there are valuable agronomic characteristics other than total yields, this suggests that herbage plant breeders should look to their laurels. From the farmer's point of view, it throws doubt on the concept of "weed grasses" and suggests that intensive farmers should pay less attention to what grasses are in the field than to how they are treated. For less intensive farming, the possible superiority in yield of sown grasses seems to be still an open question.

"What is the benefit to the farmer of using present-day herbicides in grassland to control broad-leaved weeds?" Though there may be fringe benefits from removing weeds, the main economic justification must be the effect on productivity. Here the information is very scanty. Experiments by various workers at the Grassland Research Institute, the Weed Research Organisation, I.C.I. Ltd., and Plant Protection Ltd., reported in the Weed Control Conference Proceedings between 1958 and 1962, compared the effect of herbicides with and without fertilisers on sites with an infestation of broad-leaved weeds, principally Ranunculus repens (creeping buttercup). There were large increases in yield from the fertiliser treatments, but the effect of herbicide applied to the fertiliser treatments was not consistent. In general the total yield of herbage did not increase, and sometimes decreased, but at most sites there was an increase in the yield of weed-free herbage, the best result being an increase of the order of 30 per cent as the average of 17 sites reported by GUTSELL. The results from two sites reported by Baker and Evans were not so favourable to herbicides. All trials were carried out with MCPA and different results might be obtained with herbicides less damaging to clovers.

It is obvious that the greater the proportion of susceptible weeds on any site, the greater the yield increase to be expected. It seems probable to me that the sites for the experiments mentioned were chosen as likely to give a good response to the treatments - in other words, as being very weedy. So we may regard these results as representing the upper limit of yield increases that may be expected from using MCPA in addition to fertiliser on normal weedy fields. Though useful, these benefits are not very striking compared with those from higher nitrogen usage, which itself tends to reduce weeds of this kind. Nevertheless, it seems to me that spraying is worthwhile if a farmer is going to increase the intensity of stocking and fertiliser use on a field which has an appreciable proportion of susceptible broad-leaved weeds. Spraying to control weeds arising from poor grassland management, where this is not going to be improved, seems to be economically unjustifiable. I need hardly add that in extreme cases the presence of certain weeds, such as rushes, can reduce the production of land drastically. In such fields the argument for weed control is not in doubt.

In one aspect of grassland farming, the value of chemical weed control seems to have been under rated by farmer and research worker alike. Annual weeds in direct-sown leys can delay the establishment of the new ley and weaken its vigour, so that one would also expect them to reduce the yield, often appreciably. Yet to my knowledge, no research worker has attempted to measure the effect on yield of controlling weeds in the early stages of a grass/clover ley. The usual attitude of farmers is that most weeds can be controlled satisfactorily by cutting or grazing. By the time this is possible, however, the major competitive effect of weeds has probably already taken place. Commercial firms could help themselves and the farmer by providing evidence of the economic value of this weed control technique.

To sum up, in my view the benefit to the grassland farmer of present herbicides is in certain specific situations rather than in a general indiscriminate attack on eyesore-weeds in grass fields.

So far we have been discussing the present situation; are things likely to be different in the foreseeable future? The steady trend today is towards greater intensity of grassland production. Even now dairy farming is an intensive form of production compared with cereal farming. The more heavily stocked farms already have variable grassland costs of £10-£15 per acre, while the total variable plus basic costs can amount to £50 per acre. Gross margins for dairy farming can be as high as £80 per acre or more. Looked at in another way, 10% of the production of an acre of dairying land is associated with a gross margin of £8 or more. This way of looking at it helps to assess the potential value of any yield-increasing technique such as chemical weed control. It also helps to answer the frequent question "How much would the farmer be willing to pay for this new chemical?" This process of intensifying production per acre will undoubtedly go on, so that in the future the farmer will have even bigger margins per acre from which to pay for techniques of real economic value. It must be the job of the research service and of the chemical industry to provide convincing evidence of the economic value of herbicides in grassland if their use is to be extended.

One possibility in the future is that the plant breeders will be able to do for grasses what they have done for cereals in the last 20 years. The potential yield of cereals has been pushed up tremendously while that of grasses has stood still. If the yield of cultivated grasses could be increased the benefits of weed control in sown pastures would automatically rise. The control of indigenous grasses in leys could in future become both a technical possibility and a means of increasing yield.

There will surely also be a better scope for weed control in the future if grass production becomes simplified, as some people have predicted, to the growing of one variety of grass for one purpose. Any other plant, whatever its virtues, will undoubtedly be a weed. The problems of selectivity and time of application will also be simplified.

For these reasons, and because man has always needed to have more and more control over his environment, I am optimistic about the future possibilities for weed control in grassland.

A COMMERCIAL VIEWPOINT

R.L. Harpur

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As a generalisation it can be said at the outset that as a market for herbicides, established grassland in the U.K, has proved both disappointing and profitless.

There are, of course, circumstances in which weedkillers have been used with great success and if the definition of grassland is widened to include undersown cereals, direct reseeds, and fodder crops in general the picture is much brighter.

THE MARKET

The agricultural statistics for England and Wales show that in 1965 there were :-

10.2 million acres of 'permanent' pasture

3.9 million acres of 'temporary' pasture

3.3 million acres of 'rough grazing' (1)

There are no official statistics to show the area of cereals undersown with grass and clover seed mixtures or of direct reseeded pasture. Thus the area of 'grassland' in England and Wales in 1965 was 17.4 million acres, 9.8 million acres more than the area of cereals which in that year was 7.6 million acres.

Unpublished, and possibly unreliable, market statistics available within my own company indicate that in 1960 about three-quarters of a million acres of grassland were sprayed; representing 4.3% of the total area. In 1965 the figures were much the same. MCPA was applied to over half the treated area in both years, with 2,4D coming a good second. In other words over 5 years the market had remained static or possibly even declined slightly, and from the chemical manufacturers' point of view it is worth noting the dominance of MCPA and 2,4D both of which commodities are the subject of severe price competition. Hence the statement that established grassland as a market has proved to be disappointing and profitless.

By contrast the market for weedkillers for cereals during the period after 1960 had not only showed a steady increase in terms of acres sprayed, but was also characterised by a decline in the percentage use of MCPA and the substitution of commercially more attractive novel compounds, either alone or in mixtures. (2)

To any commercial organisation the possibility of an entry into the grassland market as a means of expanding sales must be attractive. A study of the papers presented during grassland sessions at previous British Weed Control Conferences will show that a considerable amount of work has been done with weedkillers in grassland. It is therefore worth enquiring why this effort has not been reflected in increased sales.

The basic reason appears to be the extreme difficulty of showing economic benefit. Among the factors involved are these :-

1. Grass is not a marketable commodity. Apart from trifling quantities of dried grass or hay very little of the product of grassland is sold off the farm and therefore it has no unit value as a trade commodity.

2. The value of grass is dependant on the skill of the individual farmer. In as much as the value of grass lies in the meat or milk into which it is converted by the animals consuming it, it follows that the skill of the farmer is of paramount importance. He has both to manage his pastures in a way which will ensure that fodder is available at the right time and place, and also choose and manage his stock in a way which will ensure the most efficient conversion.

3. There is no universally accepted experimental method for determining the output of grassland or the significance of this output in terms of milk or meat.

These complications alone make it extremely difficult for the advisor or manufacturers' sales man to put forward a convincing economic argument in favour of weedkillers for use in grassland.

The previous paper has dealt with weeds from the farmers' point of view: but how does the chemical manufacturer see the situation?

If grassland is viewed in the broadest sense the rather depressing picture outlined earlier does not hold for all sectionsof the market.

Grassland as a crop is so diverse that in order the discuss the part that chemicals are playing it is necessary to divide it up into a number of separate entities, which include the following :-

<u>Grass Seed Crops</u>

These are essentially cash and arable crops and are dealt with in much the same way as cereals (3) with the exception that blackgrass (<u>Aleopecurus myosuroides</u>) control calls for special measures (4). Although the area under grass seed crops is apt to fluctuate according to the state of the seed trade, these crops form a useful but limited market.

<u>Sown Grass Crops during the establishment period</u>

Undersown cereals, i.e. cereals undersown with grass alone or grass/legume mixtures fall into this category as do direct re-seeded pastures. When the crop is undersown in cereals the farmer will normally spray for the benefit of the cereal as well as the young grass seeds, using either the appropriate weedkiller for the cereal crop if grass alone is sown, or when legumes are present, most likely mixtures of MCPB or 2,4-DB with other herbicides. (5).

In these circumstances the farmer is inspired not only by the thought of the damage the weeds can do to the cereal crop, but also by the adverse effects they may have on the establishment of the grass seeds.

When direct sown grass seeds are infested weedkillers do not appear to be so commonly used, as it is held by many farmers and advisors that the weeds can be suppressed by grazing or cutting; nevertheless there is a growing use of weedkillers, probably because of the relatively high cost of seed. In connection with establishment, the use a paraquat and other chemicals for destruction of the old sward before sowing should be mentioned. These techniques have proved particularly useful in areas where for some reason ploughing is difficult.

The undersown cereals and to a lesser extent the direct re-seeded land constitute therefore an attractive market.

Lowland grass in arable areas

On the Eastern side of England there has been a trend away from grass to arable cash cropping. Farmers here are apt to spray against unsightly weeds, using MCPA or 2,4-D, often to dispose of chemical which is left over at the end of the cereal spraying season. Where intensive grassland husbandry is practised it seems that many of the broad leaved weeds disappear of their own accord. This is probably not currently an important market in terms of percentage area sprayed.

Lowland grass in 'grassland' areas.

This is the grass in the wetter part of the country, not usually suitable for conversion to arable land on account of the high rainfall, small fields and hilly terrain. It represents the hard core of grassland, and it is the area in which there would seem to be possibilities for the use of herbicides and yet in which so little progress has been made. In cases where there are a great number of weeds (e.g. Rumex spp.) the farmer may be induced to spray, but in the main very little spraying is done. Potentially there is a market in these areas for chemicals to destroy poisonous weeds such as ragwort (Senecio jacobea) or horsetail (Equisetum spp.) but so far little spraying has been done, due mainly to the unreliable results from existing chemicals.

Hill pastures and rough grazings

These areas present special problems as in many instances they are difficult or impossible to plough and natural drainage may be disturbed if the soil is cultivated, with no hope of remedy by artificial means. Rushes (Juncus spp.), Gorse (Ulex spp.), Bracken (Pteridium aquilinum) are amongst the weeds encountered. Experience has shown that herbicides can make a contribution here especially against the soft rush and gorse, where the use of weedkillers results in a suppression of the weeds without damage to the drainage, or the creation of conditions which allow weed seeds to germinate and establish themselves.

Although technically fascinating, as a market this sort of operation has not been particularly interesting commercially as in many cases the stock carrying capacity of a hill farm is limited more by the availability of winter pasture than summer grazing. Like all spraying of established pasture, if the results are satisfactory spraying is not likely to be repeated for a number of years.

THE FUTURE

If the present economic trends continue there must be a greater intensification of grassland use. The farmer is caught up in a market where the price of produce is tending to fall and the cost of land to rise: if he wishes to maintain his income by increasing output he cannot very well escape intensification by buying cheap land. So it seems that some change in practice is likely to come about.

If the chemical industry is to make a contribution, it will be essential for those who are skilled in the art of grassland husbandry and who are working on new or improved techniques, to set out the objectives at which the industry should aim. Lack of agreement amongst grassland and nutrition specialists, and lack of clear objectives has, in the past, tended to deter the chemical industry and to channel effort into the development of products for cash crops.

From an industrial point of view any proposal to embark on a major research and development programme must be supported by estimates of the likely return. With cash crops it is possible to identify weed problems with some precision, to make or obtain an estimate of the area infested and to determine the likely benefit to the farmer and finally deduce the size of the market and the price the farmer would be prepared to pay. In this the manufacturers are helped by official advisors, Research Institutions, and specialist commercial concerns such as the corn trade and processing companies.

With grassland the position is, as already indicated, very different. What is held by some to be a weed, eg. Agrostis or Poa spp. is said by others to be a valuable constituent of the sward: this confusion arises, no doubt, from lack of definition of the type of grass crop under discussion. Also there is the added complication that improved management will frequently lead to the suppression of the broad leaved weeds and possibly grass weeds too, but whether this suppression could be hastened by the use of herbicides is not clear.

A worthwhile contribution from the chemical industry in the future will depend primarily on the ability of grassland specialists to sort out problems like these and give a clear message to the chemical researchers. It cannot be reasonably expected that the chemical industry itself will undertake extensive research into grassland husbandry problems as this would merely duplicate work which is being done elsewhere, and add to the already very high costs of chemical research and development.

In terms of future developments in practice there are a number of suggestions which have been made whihh should have a bearing on thinking in the chemical industry :-

1. The concept that grass should as far as possible be a short-term sown crop, probably a ryegrass or ryegrass clover mixture (6). This seems an eminently sensible suggestion, particularly for areas where ploughing is easy and machinery and labour available, as on the larger mixed farm. There should be no great difficulty in finding suitable weedkillers for use during the establishment phase, infact as discussed earlier, weedkillers are already available. Annual grass weeds may present a problem, but as there is already a great deal of work going on to develop suitable chemicals for grass weed control in cereals, it would be easy to extend these programmes to cover specific herbage grasses and grass weeds so long as the grassland specialists can clearly state what species they have in mind.

Part of the thinking behind the concept of grass as sown or arable crop involves better methods of conservation. A snag with hay is the difficulty of making it in a wet climate, and with silage the amount of water which has to be carted about along with the herbage. If very cheap power became available in the future dried grass may be the answer, but if not is there an opportunity for the chemical industry to make a contribution by devising substances which will disrupt the cell wall and hasten drying without impairing the nutritive value?

2. Improvement of established pasture without re-sowing by altering the balance of grass species by the use of chemicals. Work in this field was reviewed at the last British Weed Control Conference by Elliott and Allen (7). Although to date a somewhat speculative technique, it has obvious attractions in areas where by reason of lack of labour and machinery, or of difficult terrain, the growing of sown grass crops may prove uneconomic. A snag here is that if the benefits of removing weed grasses are to be realised the farmer would have to exercise considerable skill in sward management to prevent re-infestation.

3. The abandonment of grass as we know it and the substitution of arable forage crops. This can only be done in areas suitable for arable cultivation and involves keeping the consuming animals in yards or under cover. Crops such as fodder maize, lucerne, sanfoin and rye may be suitable for the purpose and a range of weedkillers is available for at least some of the crops and could no doubt be extended. Convenient methods of conservation are necessary to make the system work.

CONCLUSION

This expression of a commercial viewpoint can be briefly summed up in two statements, namely that hitherto the contribution of chemical weedkillers to the improvement of grassland has been very small, mainly from lack of any widely demonstrable economic benefit, and, secondly, that if a greater contribution is to be made in the future the stimulus must come from the grassland specialists who alone can define the targets at which chemicals should be aimed.

REFERENCES

(1) Ministry of Agriculture, Fisheries & Food, June 1965 Census. England and Wales.

(2) WOODFORD, E.K. (1964). Proc. VII Brit. Weed Contr. Conf., 3, pp. 944 - 962.

(3) WOODFORD & EVANS (Editor) (1965). British Weed Control Handbook, pp. 234 - 235.

(4) Ibid. p. 234.

(5) Ibid. pp. 124 - 127.

(6) WOODFORD, E.K. (1965). Grass Tomorrow. Pub. Seale Hayne Agricultural College, Newton Abbott, Devon.

(7) ELLIOT J.G. & ALLEN, G.A. (1964). The Selective control of grasses in permanent pasture. Proc. VII Brit. Weed Cont. Conf., pp. 865 - 877.

Mr. J. G. Elliott asked if the mathematical formulae introduced by Dr. Spedding could be carried further to give an economic value to each unit of dry matter production or of digestible nutrients when used in a particular utilisation system? Dr. C. R. W. Spedding agreed that this would be possible. He had carried the calculations up to the point at which they had general validity. Beyond that point there would have to be a separate calculation for each system of utilisation.

Mr. M. Eddowes said that it was important to consider the production of grass species as a dynamic problem. Thus the organic matter digestibility of perennial ryegrass and Poa trivialis (Rough-stalked Meadow grass) may change relatively with grazing techniques. The proportion of leaf to stem in the species may change in a competitive situation. Dr. C. R. W. Spedding agreed that the problem was necessarily over-simplified in his example, which was the simplest possible approach to illustrate the type of calculation required.

Dr. H. P. Allen asked what was known about the differential productivity of "weed" grasses, i.e. the periods of the season over which these grasses produce food for the grazing animal? Should this information be available, would not this "period of maximum productivity" be a good diagnostic feature of a "weed" grass and a good means of identifying the major target for selective herbicides? Dr. C. R. W. Spedding said that such information was not available in detail, though there was a little known about some individual species. He would prefer a different approach - to define closely a few simple systems of animal/plant combination and then to overcome the weed problems within those systems.

Mr. C. L. Campbell said that creeping thistle did not seem to be controlled as well as it used to be ten or fifteen years ago using MCPA or 2,4-D - particularly shoot kill in the year of spraying and the long-term control. Mr. J. M. Ormrod said that there was considerable variation in the response of creeping thistle. The problem had been examined experimentally and the Weed Research Organisation had a lot of data on variations of response. It was sometimes satisfactorily controlled, i.e. suppressed for a year or two but sometimes not. We did not know why this should be so.

Mr. S. A. Evans commented that grassland productivity could be increased by many means other than by controlling weeds and it was likely that weed control was going to contribute significantly to better grassland yields only when grassland management had become more sophisticated. The weed problems might then be different from those we have today and this should be taken into account in research and planning by herbicide manufacturers.

SESSION X A - VEGETABLES

Discussion

Mr. D.J. Allott gave information, supplementary to his first paper, on the use of dalapon to control couch grass in carrots. He said that, following the recent use of dalapon as a post-emergence treatment for the control of *Agropyron repens* (couch grass) in carrots trials were conducted in Northern Ireland to examine the tolerance of carrots to this treatment. It was found that under Northern Ireland conditions dalapon can be applied at 3.5 lb/ac to carrots at the second true leaf stage. This treatment caused an appreciable suppression of the couch without crop damage. Subsequently, however, there was considerable regeneration of the couch. A later application, at the same dose, when the carrots had reached pencil thickness also gave a good couch suppression from which regeneration did not occur. From other treatments in an unreplicated trial it appeared that at the pencil thickness stage carrots will tolerate dalapon doses up to 10.0 lb/ac. Further trials will be conducted in 1967. From the trials so far it would seem that this is a very promising treatment.

Mr. D.H. Bartlett said that the better weed control obtained by Mr. J.C. Cassidy with trifluralin applied under cool, moist conditions in March than when it was applied under warmer conditions in July was contrary to results obtained in Murphy Chemical Company's trials, where application under warmer conditions gave better results. He suggested that incorporation into the soil by raking, as done in Mr. Cassidy's trials, was not sufficient. Mr. J.C. Cassidy agreed that incorporation by rotary cultivation would have been more efficient and that the poorer weed control from the July application might have been due to loss of the chemical due to increased volatilization at higher temperatures.

Mr. D. van Staalduine observed that, in Holland, applications of 4 oz/ac of simazine to cauliflower and cabbage transplants in a light sandy soil, were satisfactory. On heavier soils higher dosage rates are necessary for good weed control. Mr. D.J. Allott mentioned that 1 lb/ac of simazine on transplanted broccoli at Loughgall was used primarily to assess the upper limit of tolerance of the crop and it was surprising that no damage occurred. On some other soil types damage was more likely. Mr. J.C. Cassidy said that, in trials at Kinsealy in 1966 on transplanted cauliflowers on a medium clay loam with over 7% organic matter, no apparent damage had occurred at doses up to 1 lb/ac. Season-long weed control had been obtained with 8 oz/ac. Mr. D.H. Bartlett observed that 6 oz/ac of simazine caused either death or severe damage to cauliflowers in a Bedfordshire soil containing approximately 35% coarse sand and 45% fine sand. Mr. H.A. Roberts said that the use of low doses of simazine, about 6 oz/ac was attractive, as good weed control was often obtained and the treatment was cheap. In trials at Wellesbourne there had been a variable degree of initial injury, sometimes resulting in yield reduction, sometimes not. The safety margin was obviously not great and until more was known about the conditions which affect the degree of crop damage obtained, we would be unwise to recommend this treatment to growers. Mr. M.B. Wood said that at Stockbridge House also effects had been variable. Miss H.M. Hughes referred to the need to plant deeply to avoid simazine damage. She also asked whether the correlation between mechanical analysis of the soil and tolerance to simazine had been worked out. Mr. P. Bracey said that damage to newly-planted strawberries could be avoided by splitting the treatment into two half doses, one applied immediately after planting and one four weeks later.

Mr. D. van Staalduine said that, in one experiment in Holland, the use of charcoal as a root dip gave an improved stand to transplanted cauliflowers. With strawberries growth was stimulated after dipping the roots in charcoal and this had been observed both in the laboratory and in the field. Mr. R.F. Clements asked for information on the mechanism of charcoal protection. Dr. J. Reynaert replied that it was due to the adsorptive properties of charcoal. Mr. A.R. Carter pointed out that, in Dr. Kosovac's pot experiments, the herbicide had been mixed thoroughly into the soil, so that new roots outgrowing the charcoal protection would be entering soil containing the herbicide. Mr. D.J. Allott also drew attention to this aspect. Dr. G.S. Hartley said that while nutrients and water were taken up mainly by the newly extending roots, the uptake of simazine was a passive diffusion process and occurred just as much through the older root system. Protection could, therefore, be better than might, at first sight, be expected. Dr. Z. Kosovac said that pepper plants were most susceptible to simazine damage immediately after transplanting, when charcoal would protect them. Once established the plants were less damaged by the herbicide.

Mr. P. Bracey said that charcoal coating of the roots of strawberry plants caused starvation of the runners. Mr. A.R. Carter pointed out that Dr. Z. Kosovac used charcoal on peppers planted in soil not treated with herbicides and this had had no effect on plant growth. Dr. J. Reynaert said that nutrients could also be adsorbed by charcoal if enough were used. Dr. G.S. Hartley did not think that pure active charcoal would show any significant adsorption of simple mineral nutrients. When charcoal had shown adverse effects in the absence of herbicide, this was most likely to be due to the presence of toxic impurities in the charcoal - especially copper - which are deliberately added to many charcoals for industrial application. For agricultural use, one should make certain of using non-metal treated charcoal preferably of vegetable or peat, rather than coal origin.

Mr. J. Gostinchar referred to the good selectivity of DCPA (dimethyl 2,3,5,6,-tetrachloroterephthalate) in cruciferous crops and referred to good results in the U.S.A. and in Spain. He asked why DCPA had not been included in trials with brassicas in the United Kingdom and Eire. Mr. H.A. Roberts said that DCPA had been examined in a limited way in England, but, under our conditions, it had not given effective weed control. Mr. J.C. Cassidy said that experience in Eire was similar to that in England.

Mr. D.M. Evans referred to reports of damage to dwarf beans by CP31393 in the papers by Cassidy, Roberts and King. He said that his impression was that this check occurred when the chemical was applied after the beans had germinated. If applied before germination, e.g. within three days after drilling, the check was much less. Damage was less likely to occur under dry soil conditions than when soil was moist, probably due to increased solubility of the chemical in moist soil. Mr. H.A. Roberts replied that he would agree that perhaps the check to growth was more likely to be severe when there was ample soil moisture and when application was made just before crop emergence rather than immediately after drilling. However, in the 1966 experiments cited in the report, he applied CP31393 to dwarf beans one day after drilling, yet still observed a persistent check to growth.

Mr. A.G. Biggs referred to the use of CP31393 on cauliflowers raised in containers and planted out and asked whether the herbicide had been used on crops which had not been raised in containers. He also asked when the plants in the Wellesbourne trial had been planted out and if there was any interaction between climate and herbicidal activity. Mr. H.A. Roberts replied that, in the experiment with early summer cauliflowers referred to, the plants were raised under glass in peat pots and planted out in April. He had, however, applied CP31393 overall to Brussels sprouts and cabbage planted out from seedbeds and in no instance had any crop damage. He believed that there had been similar absence of injury in trials elsewhere, and this particular treatment seemed to be a safe one.

AGRONOMIC ASPECTS OF DIRECT DRILLING

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INTRODUCTION

Ploughing and cultivations are the traditional means of killing weeds and providing a suitable environment for the germination and development of crop plants. Russell (1945) came to the conclusion that "a clean seed bed appears to be more important than the exact state of tilth or to put it in other words farm crops when young appear to be sensitive to weed competition but tolerant of a wide range of soil tilths". At that time the plough (providing it was properly set) was probably the most efficient means of killing weeds before drilling.

Since this investigation the selective control of weeds in most crops by herbicides has expanded very rapidly until to day it is an accepted part of crop husbandry with a corresponding decline in cultivations. The ultimate extension of this concept of minimal cultivation is to use herbicides to kill weeds before direct drilling the crop without any previous cultivations. The discovery of the bipyridyl herbicides particularly paraquat (1,1'-dimethyl-4,4'-bipyridylium-2A) with the unique property of being rendered herbicidally inactive by clay minerals in the soil opened up the possibility of direct drilling arable crops. This was first investigated at Jealott's Hill in 1961, and was extended in 1963 to outside farms. A number of the agronomic factors which influence the success of direct drilling have been investigated for cereals and kale and the data obtained are reviewed below.

THE HERBICIDE

For direct drilling to be successful the herbicides must control the unwanted vegetation, either pasture or stubble weeds, effectively. Paraquat acts primarily by contact action on the green parts of plants, hence at the time of spraying there must be sufficient green vegetation exposed to the spray to take it up and allow it to act efficiently. Tall rank vegetation or dead litter must be removed as it can shield underlying vegetation that is to be controlled. Paraquat will normally control most British grass and broad leaved weeds at the rates tested, but plants with underground systems such as *Agropyron repens* and *Rumex* spp. can recover after spraying, hence areas dominated by these are not suitable for direct drilling after paraquat.

It is possible to have some degree of control over both the time and rate of application of the herbicide.

Winter Wheat Under British conditions, where winter wheat often follows either pasture or another cereal crop, the time available for applying the herbicide is limited, hence it is necessary to know how near to the date of drilling spraying can be carried out, taking advantage of the soil inactivation of bipyridyl herbicides. Trials in which spraying on the day of drilling was compared with spraying two weeks before drilling showed that slightly higher yields were obtained when spraying was carried out in advance of drilling. However it was possible to spray and drill on the same day and obtain satisfactory yields. (Jeater and McIlvenny 1965).

Rates of paraquat were compared in 1965 when the yields following paraquat at 2 lb/ac were higher than those after 1 lb/ac (Jeater and Laurie 1966).

The same general picture was repeated this year as is shown in Table 1.

Table 1

Winter Wheat Comparison of Rates of Paraquat

Yield in Cwt/ac (adjusted to 85% Dry Matter)

Units Nitrogen/ ac*	Rates of Paraquat lb/ac 1·0	1·5	2·0	Mean
50	21·0	23·6	24·9	23·2
75	23·0	26·4	27·9	25·8
100	25·9	28·0	29·9	27·9
Mean	23·3	26·0	27·6	

S E (Means) ± 0·63 (24 d.f.)

*1 unit = 1·12 lb

There was a general increase in yield as both the rate of paraquat and nitrogen were increased.

Spring Barley For spring barley the potential time of application is longer than that for winter wheat; for practical purposes it is probably from October until the day of drilling. As with winter wheat it has been found that spraying on the day of drilling gives only slightly lower yields than spraying some three weeks before drilling (Jeater 1965). However trials conducted in 1965 showed that where *Agrostis stolonifera* was the main weed, spraying in the winter led to yields that were comparable with normal cultivations, but where spraying was delayed until the spring normal cultivation outyielded direct drilling (Jeater 1966). This year further trials did not show the same advantage from winter spraying. At the first site *Poa annua*, *Poa pratensis*, and *Stellaria media* were the main weeds, and at the second *Tripleurospermum maritimum* ssp. *inodorum*, *Veronica* spp. and *Stellaria media* were the main weeds. In neither trial did time of application affect subsequent yields. Table 2.

Table 2

Spring Barley. Time of Application of Paraquat

Yield in Cwt/ac (Adjusted to 85% Dry Matter)

Trial No.	Rate of Paraquat lb/ac	Time of Application January	February	March
1	1	22·5	21·7	23·6
	1·5	22·2	22·3	23·3
2	1	30·2	30·9	29·8
	1·5	30·4	30·8	30·7

S E Trial 1 ± 1·32 (20 d.f.)
2 ± 0·97 (20 d.f.)

In 1964 in two trials higher yields were recorded following paraquat at 2 lb/ac compared with 1 lb/ac (Jeater 1965), but in 1965 there were no real yield differences following these two rates of application. Again this year the yields following 1 and $1\frac{1}{2}$ lb/ac were very similar. Table 2. These data suggest that 1 lb/ac paraquat is adequate and there is considerable flexibility in time of spraying unless Agrostis stolonifera is present, when application should be carried out in autumn.

THE DRILL

The standard drills now available on farms are not capable of drilling into uncultivated land except on the very lightest soils. It has been necessary therefore to develop special drills. Two approaches have been used

1) The draught direct drill where weight is used to obtain penetration.

2) The rotary drill where penetration is obtained by the digging action of rotating tines driven by the power take-off of the tractor.

The Draught Direct Drill

This type of drill has been developed from the conventional seed drill but many features have been specially adapted for direct drilling. The preferred coulter system employs 3 discs - a small diameter plain disc to cut a narrow slot in the soil, and a pair of inclined large diameter discs which expand this slot to receive the seed and fertilizer. This coulter overcomes the main disadvantages of the earlier disc and knife coulter which had a tendency to rake trash, and had a high rate of wear which accentuated the penetration problem. The drills now being developed are much heavier and stronger than normal drills, and have hydraulically activated coulter springs which are much longer than usual.

The Rotary Drill

In this type of drill the tractor p.t.o. drives blades which cut slots in the soil into which seed is deposited. Because the blades in current drills are mounted on rigid rotors these machines are not able to follow soil contours. Their width and working speed are less than the draught type and their power requirement is high. In the Rotaseeder the flanges are spaced at 5 in. intervals along the rotor which rotates in the direction of travel. The slightly hooked blades are mounted on each side of the flanges and cut a slot about 1 in. wide in the soil. Soil is thrown out of the slot into which the seed is deposited and the soil falls back to cover the seed.

The covering of the seed is important because where slots are left open bird and slug attack is liable to have a very adverse effect on plant establishment. With the draught type of machine the seed is not always covered and the slots have to be closed after drilling either by harrowing or rolling.

The type of slot made by the drills is important as this provides the environment in which the seed has to germinate and establish. Any further development of direct seeding drills will probably require a further study of the condition required in the slot to give the seed the greatest chance of establishing. The main problem arises on heavy soils with a high clay content in wet conditions where the draught type of machine can cause smearing of the walls, and the rotary type produces large clods.

SEED RATE

In general, plant extablishment counts have shown slightly lower figures on direct drilled areas compared with ploughed and cultivated ones at equivalent seed rates. This could be related to the efficiency of the drills currently available. An initial trial on seed rate was put down at Jealott's Hill with winter wheat in the autumn of 1965. The data obtained averaged over four rates of nitrogen (0, 40, 80, 120 units/ac) are given in Table 3.

Table 3

Direct Drilled Winter Wheat Comparison of Seed Rate

Seed Rate Cwt/ac	Mean Number of Plants Established per yd/row	Yield Cwt/Ac 85% Dry Matter
1·5	40	33·1
2·0	53	38·4
2·5	65	35·2
		S E ± 3·05(9 d.f)

Increased seed rate gave an increase in the number of plants established per yard of row but the highest yield was given by the middle rate 2 cwt/ac. This is slightly higher than the seed rate normally used for winter wheat.

RESPONSE TO NITROGEN

In Britain the use of varieties which respond to increased fertilizer levels, particularly nitrogen, has contributed to the higher yields that are now obtained. It is essential therefore that any new cultural technique such as direct drilling should allow crops to respond equally well to fertilizers.

Winter Wheat The response of winter wheat to autumn and spring nitrogen was studied both at Jealott's Hill and in an outside trial. In both cases there was little response to autumn nitrogen but a very marked response to spring nitrogen applied as one application in April (Hood, 1965). This response to spring nitrogen was confirmed in another trial at Jealott's Hill using two varieties Cappelle and Rothwell Perdix. Table 4.

Table 4

Direct Drilled Winter Wheat Response to Spring Nitrogen
Yield in Cwt/ac (Adjusted to 85% Dry Matter)

Units Spring Nitrogen/ac	Variety Cappelle	Rothwell Perdix
0	30·6	34·7
40	36·9	42·7
80	40·1	47·4
120	44·5	50·6

S E (Columns) ± 2·5 (84 d f)

Time of application of top dressing direct drilled winter wheat was studied for the first time this year both at Jealott's Hill and in outside trials. The data for the Jealott's Hill trial averaged over 80 and 120 units/ac are given in Table 5.

Table 5

Direct Drilled Winter Wheat Timing of Spring Nitrogen Top Dressing

Yield in Cwt/ac (Adjusted to 85% Dry Matter)

Control no nitrogen	Date of application Single Applications				
	28.10.65 -	7.3.66 -	28.3.66 -	21.4.66 -	12.5.66 -
	33·1	42·7	43·4	40·7	38·2
29·8	Split Applications				
	14. 2.66 21. 4.66	14.2.66 12.5.66	7.3.66 21.4.66	7.3.66 12.5.66	
	42·7	41·2	42·8	42·9	

S E $\pm$ 2·26 (73 d f)

From the single applications the highest yields were recorded from March application. February was too early and most of the nitrogen was lost, while May was too late. The split applications did not show any advantage over the single one in March.

The same pattern of highest yields from a March application and lower yields from one in May was also shown in two outside trials. The data averaged over 75 and 100 units/ac are given in Table 6.

Table 6

Direct Drilled Winter Wheat Time of Spring Nitrogen Top Dressing

Yield in Cwt/ac (Adjusted to 85% Dry Matter)

Trial No.	Date of Application March	April	May	
1	38·6	37·4	33·7	S E $\pm$ 0·9 (30 d f)
2	28·3	27·8	24·8	S E $\pm$ 0·87 (27 d f)

Spring Barley Direct drilled spring barley has also shown a good response to nitrogen. Table 7.

Table 7

Spring Barley Responses to Nitrogen

Yield in Cwt/Ac (Adjusted to 85% Dry Matter)

Units Nitrogen/ac	Cultural Treatments	
	Direct Drilled	Ploughed/Cultivated
0	27·5	43·4
50	44·7	54·5
75	55·3	55·8
100	57·0	55·3

S E (columns) ± 1·48 (27 d f)
(other comparisons) ± 2·04 (8 d f)

At the lower levels of nitrogen application normal cultivations usually outyield direct drilling, but direct drilled crops show a greater response to nitrogen and at adequate nitrogen levels yields are comparable.

For spring barley the fertilizer is often combine drilled with the seed, but on some farms there has been a move back to broadcasting the fertilizer to speed up the drilling. This comparison between combine drilled and broadcast fertilizer is germane to the study of direct drilling for at present it is not possible to combine drill the fertilizer with the seed when using the rotary types of direct drill. This was studied in two trials this year, both with moderate P and K status. Although in general slightly higher yields were recorded from combine drilling on both these trials, for direct drilling and normal cultivations these differences were not significant. Table 8. From these preliminary results it would appear that the differences between combine drilling and broadcasting fertilizer are similar under the two cultural regimes.

Table 8

Spring Barley Comparison of Combine Drilling and Broadcasting Fertilizer

Yield in Cwt/ac (Adjusted to 85% Dry Matter)

Trial No.	Rate I.C.I. No.2 (22:11:11) Cwt/ac	Direct Drilled		Ploughed	
		Combine Drilled	Broadcast	Combine Drilled	Broadcast
1	3·0	36·5	34·5	36·0	32·7
	4·5	37·9	37·1	37·2	36·8
2	3·0	38·3	41·2	38·3	35·0
	4·5	46·7	45·4	45·8	44·9

S E Trial No.1 ± 2·6 (21 d.f)
" No.2 ± 1·65 (21 d.f)

Kale

The response of kale to nitrogen is very marked and follows the general pattern in that at low levels of nitrogen normal cultivations outyield direct drilling but at adequate nitrogen levels the yields are similar or in favour of direct drilling. Table 9.

Table 9

Kale response to Nitrogen

Fresh Weight Yield in Tons/Ac

Units Nitrogen/ac	Direct Drilled	Ploughed/Cultivated
0	8•5	16•0
100	22•0	23•6
150	24•2	24•0
200	26•8	24•3

S E (columns) ± 0•45 (27 d.f)
(other comparisons) ± 0•61 (8 d.f)

Moisture Conservation and Drainage

One of the traditional means of conserving moisture is to cover the soil with a mulch, which also reduces the risk of erosion. By using the direct drilling technique the weeds are killed in situ and water loss is reduced. Normally in Britain there is an adequate supply of moisture available for plant growth, and water conservation is not a major problem. However in 1964 there was a very dry summer and autumn with only 6•5 inches of rain falling at Jealott's Hill between June and December. During this period a kale trial was put down comparing direct drilling with normal cultivations. At harvest the direct drilled kale outyielded the normally cultivated at all levels of nitrogen in contrast to the general picture and shows the advantage of direct drilling under dry conditions. Table 10.

Table 10

Kale response to Nitrogen under Dry Conditions

Fresh Weight Yield in Tons/Ac

Units Nitrogen/ac	Direct Drilled	Ploughed/Cultivated
0	7•3	4•9
100	15•3	10•6
175	19•1	15•1
250	22•3	16•8

S E (columns) ± 1•08 (27 d.f)
(other comparisons) ± 1•52 (8 d.f)

Normally in Britain direct drilling has been most successful on well drained soils. Where the drainage is impeded, water logging is more likely to occur on direct drilled areas and this can lead to reduced yields, as was shown at Jealott's Hill with winter wheat. Germination was good, but subsequently many plants on the direct drilled plots succumbed to water logging, whereas little of the crop on the plough was affected. There was also a marked recovery of weed grasses after spraying in this situation. At harvest the yield at all levels of nitrogen on the direct drilled plots was poor compared with normal cultivations. Table 11.

Table 11

Winter Wheat on Soils of Impeded Drainage

Yield in Cwt/ac (Adjusted to 85% Dry Matter)

Units N/ac	Direct Drilled	Ploughed/Cultivated
0	10•9	19•5
75	13•6	32•9
100	18•0	35•5

S E (columns) ± 5•04 (12 d.f)
(other comparisons) ± 5•04 (7 d.f)

Continuous Winter Wheat

For direct drilling to be a practical technique it must be possible to grow a number of successive crops using it. The first trial at Jealott's Hill was put down in the autumn of 1961 and has been continued with winter wheat ever since, the fifth crop being harvested this summer. The yield data for the five years at a nitrogen level of 70-80 units/ac (1962 - 70 units 1963 - 75 units 1964-66 inclusive - 80 units) are given in Table 12.

Table 12

Continuous Winter Wheat 1962-66

Yield in Cwt/ac (Adjusted to 85% Dry Matter)

Incidence of Take All 1964 - 66

Year	Yield		Percentage Tillers Infected with Ophiobolus graminis	
	Direct Drilled	Ploughed	Direct Drilled	Ploughed
1962	58•1	59•0	-	-
1963	52•5	53•1	-	-
1964	41•8	35•5	3	20
1965	37•1	26•4	14	64
1966	37•8	38•1	24	48
Mean	45•5	42•4		

From this it will be seen that in general there has been very little difference in yield between the two techniques except in the third and fourth years, when direct drilling outyielded normal cultivations. Averaged over the five years direct drilling has outyielded normal cultivation. These yield differences can be related to the much higher incidence of 'take-all' (<u>Ophiobolus graminis</u>) on the ploughed plots in these two years. In the fifth year there has been a reduction in the number of infected tillers on the ploughed plots compared with the previous year and this has been reflected in an increased yield. On the direct drilled plots the incidence of take-all has increased but is still only 50% of that on the ploughed.

CONCLUSIONS

Direct drilling offers a much simpler method of transferring from one crop to another than traditional methods and is less demanding in man hours. Only two operations are necessary, spraying and drilling, and the former is a much quicker operation than ploughing and cultivating, hence it gives more flexibility than normal cultivations. In some circumstances this can lead to increased yields as was shown at Jealott's Hill in 1964 when it was possible to direct drill spring barley two months before it was possible to drill after normal cultivation. Table 13.

Table 13

<u>Spring Barley Effect of Time of Drilling</u>

<u>Yield in Cwt/ac (Adjusted to 85% Dry Matter)</u>

Units Nitrogen/ac	Direct Drilled February	Direct Drilled April	Ploughed April
0	36·6	32·2	40·9
50	47·1	41·1	42·6
75	49·3	40·2	41·5
100	48·7	39·1	37·8

S E (columns) ± 0·95 (27 d f)
(other comparisons) ± 1·17 (9 d f)

With the drills currently available or likely to become available in the near future direct drilling can achieve satisfactory yields of cereals and kale providing certain agronomic conditions are fullfilled. At present the lighter well drained soils are most suitable. It is necessary to farm towards direct drilling so that any unwanted vegetation is exposed to the herbicide and not shielded by dead trash or other live vegetation. Areas dominated by plants with rhizomes or large tap roots are not at present suitable for this technique. The herbicide must be applied at a rate and time which will give the optimum control of vegetation, and even application is essential. The drill must be adjusted so that it produces a slit which is conducive to seed germination and seedling development, and this slit must be closed to guard against slug and bird attack. Adequate levels of fertilizer, particularly nitrogen, should be applied to the crop.

Over the past five years a considerable amount of data and expertise relating to direct drilling have been accumulated from over 60 fully replicated trials. However more data are required particularly with regard to the control of perennial weeds with large underground systems and to the use of this technique on the heavier soils.

References

1. Hood A.E.M. (1965) Ploughless Farming Using 'Gramoxone'
Outl Agric IV 286-294

2. Jeater R.S.L. and McIlvenny H.C. (1965) Direct Drilling of Cereals After
Use of Paraquat Weed Res 5 311-318

3. Jeater R.S.L. and Laurie D.R. (1966) Comparison of Rates of Paraquat
Prior to Direct Drilling Cereals Weed Res in press

4. Russell E.W. (1945) What are the Minimum Cultivations Necessary for High
Farming Proc Instn Br agric Engrs III 99-109

THE WEED PROBLEM

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A consideration of the weed problem in this new situation must start by defining the techniques by which land may be prepared for sowing a cereal crop and their influence on weed growth.

A. Ploughing and subsequent cultivations

These have three basic effects upon the soil and its weed flora:-

Burial of surface vegetation and weed seeds

Inversion of the soil so that weed seeds previously buried are brought to the surface

Disturbance of the soil by ploughing shatters rhizome and root systems and the shallower disturbance by subsequent cultivations provides conditions suitable for the germination of many weed species. Where cultivation is continued after germination, seedlings may be killed by mechanical damage and desiccation. Rhizomes and roots of perennials may be dragged to the surface.

B. Cultivation without ploughing

This must be regarded as extremely variable in effect depending on the implement used, the depth and speed of work, soil conditions and so on. However, we do know that the three basic effects described above will be reproduced to some extent. Burial of weed seeds and surface vegetation will take place but will be relatively inefficient. Holroyd (1964) has studied the distribution of a tracer applied to the soil surface and cultivated in. He found that the most efficient of the implements tested, a spring-tined harrow and a rotary cultivator working to a depth of 4in. succeeded in taking about 20% and 40% respectively of the tracer to 2-4in. below the soil surface. We would expect burial of weed seed to be of the same order. Conversely some buried matter will be brought towards the surface but the depth of the soil exploited will usually be less than ploughing depth.

With or without ploughing, cultivation may be equally efficient in producing a seedbed for both crop and weed seeds. Established plants may be uprooted and killed but this form of disturbance may not be so effective on large well established plants.

C. Direct-Drilling

This situation may be regarded, in theory, as one in which the soil is not disturbed although in practice it is doubtful whether this will over be absolutely true.

Burial and inversion will be reduced to a minimum but there will at least be some displacement of weed seeds by earthworm and mole activity etc. Darwin (1881) calculated that earthworms could raise to the surface about 18 tons of soil per acre per annum or two inches in 10 years. In addition some of the machines used the young shoots from the action of the herbicide, this being particularly important in the case of paraquat.

For the future it seems that, in this as in other fields, we need more reliable methods of control of rhizomatous and tap-rooted perennials. In the meantime by investigating the possibilities of split applications or rotational use of the herbicides now available we may be able to prevent the build up of species resistant to any one herbicide.

WEEDS DEVELOPING DURING THE LIFE OF THE CROP

a) Plants arising from seed

A number of factors are known to affect the germination of weed seeds and most of these are likely to interact with the intensity of cultivation. For example seed dormancy is very pronounced in many weed species and it has been pointed out that this is a valuable adaption on land which is ploughed annually (Harper, 1957). In this situation, some seed is ploughed up towards the surface every year and the soil "reservoir" of seeds is topped up sporadically whenever the weed is able to set seed. One value of burial is that, by this means, the seed is protected from some of the hazards which face it during the period of dormancy, e.g. attack by surface-feeding animals and birds. In the case of *Avena fatua* there is direct evidence that the population is placed at a severe disadvantage if seeds are allowed to remain on the soil surface (Whybrew, 1964) but this may possibly be an extreme example due to the pronounced dormancy of the seed and to the relatively large size of the seed which makes it an attractive target.

We may expect, therefore, that species with pronounced inherent dormancy will not be favoured by minimum cultivation. On the other hand light is necessary for the germination of some species e.g. *Matricaria recutita*: such species may germinate more freely at or near the surface of slightly compacted undisturbed soil, whilst they may be placed at a disadvantage by seed burial. This generalisation may well apply to other species characterised by germination at or near the surface.

Not all the reasons for differences in response to soil disturbance are perfectly understood but we are beginning to accumulate a certain amount of direct information on how, in fact, many species do respond. Chancellor (1964) studied the emergence of weed seedlings in an experiment, which compared plots dug by hand at varying frequencies or left undisturbed. He categorised the sixteen species present in the experiment in two ways; the time of year at which they germinated and their response to cultivation. He defined three categories of response to cultivation:

(i) "The Arable Weed Response" i.e. the more the soil was cultivated the more the seeds germinated. This group contained a number of common arable weeds such as *Raphanus raphanistrum* which responded to cultivation at suitable times of the year by producing a flush of seedling emergence.

(ii) "The Inverse Response." In this group there was a consistent decrease in germination with increased cultivation although there was still considerable emergence on the cultivated plots, controlled by the normal periodicity of germination.

(iii) "The Intermediate Response." This was a rather more complicated group and appeared to contain some species responsive to cultivation at specific times of the year.

It was possible to put Chancellor's classification to a wider test this year when weed assessments were made on experiments at four of the Experimental Husbandry Farms of the National Agricultural Advisory Service. These experiments compare plough-for direct-drilling of crop seeds have the effect of violently displacing soil from the slit in which the seed is sown.

Finally weathering of the undisturbed soil surface may, by itself, produce conditions suitable for the germination of many species.

It is apparent that very significant differences exist between these three techniques, although, as far as their effects on weed populations are concerned, it may be better to regard them as a graded sequence rather than three water-tight compartments. These differences could be summed up by saying that the traditional techniques of ploughing and cultivation have the combined aims of producing a seedbed and achieving weed control. In this new technique these aims have been separated.

In one vital respect, however, this generalisation is not true. All techniques aim at producing a vigorous growth of the crop plant and a factor most profoundly affecting the weed population in a cereal crop is competition from that crop. In preparing these notes it has been assumed that all techniques are alike in this respect.

Since this factor of competition is so important it is necessary to review the weed problem as it affects two phases: before seedbed preparation and sowing, and during the life of the crop.

WEEDS PRESENT BEFORE SOWING THE CROP

This is basically a simple situation - it is necessary to identify the species present and kill them, or so modify their growth that they do not effectively compete with the following crop.

The species present may cover the whole range of weeds of arable land, some weeds of grassland and relict pasture grasses and clover. This is formidable, but, at any one site, the range of species will be more restricted and to some extent predictable, being dependant on the previous environment, chiefly the cropping history together with soil and climatic factors.

The many species involved differ in their reaction to the three herbicides which have been most commonly used: paraquat, dalapon and activated amitrole. Generally speaking, the latter is more effective against broad-leaved species than paraquat or dalapon and both amitrole and dalapon are more effective against rhizomatous species than paraquat. In addition there is now considerable evidence of more specific differences between grass species in their reaction to all these herbicides (Jones, 1962; Allen, 1965; Allen, 1966). For example *Alopecurus pratensis* appears relatively resistant to paraquat and *Lolium perenne* appears relatively resistant to dalapon.

Other factors affect the choice of a herbicide notably cost, which is outside the scope of this review, and timing of application. In general these herbicides should be applied as near to the time of drilling as possible so as to delay regrowth for as long as possible. This is modified by the fact that sufficient time must elapse between spraying and sowing the crop to allow residues of herbicide to be dissipated to a level at which they will not interfere with crop growth. Soil residues are most significant in the case of dalapon and amitrole, but paraquat residues on plant remains have on occasions caused injury to emerging seedlings.

Since all these herbicides must be applied to green foliage it is important that there is sufficient green tissue at the time of spraying to allow the herbicide to act. On the other hand an excessive amount of plant material may shield some of ing with direct-drilling. The response of total seedling weed populations to direct-drilling as opposed to conventional techniques was not consistent but there was a consistent effect upon the relative importance of species within the total population. The species most favoured by minimal soil disturbance were Poa annua and other seedling grasses, Senecio vulgaris, Stellaria media, Capsella bursa-pastoris, Matricaria spp. and Trifolium repens. Taraxacum officinale occurred at one site on the direct drilled plots only.

Only four of these species were present in Chancellor's experiment and of these he listed one, Taraxacum as showing the "inverse response," and the remaining three Poa, Senecio and Trifolium as showing the "intermediate response." Of the remaining species I have already stated that the mayweeds need light in order to germinate and Stellaria media also tends to germinate shallowly (Chancellor, 1964).

So far then our theoretical model has been a reasonably good guide to performance in the field and we may expect to acquire a lot more information as these experiments proceed. From the practical point of view we are only interested in these changes in weed population as they affect and are affected by the herbicides currently available. We need to be able to classify a wider range of species before much comment can be made on this aspect but it may be a matter for some concern that the grasses seem to be encouraged by the minimum disturbance technique and these do present a difficult problem in cereal crops.

(b) Plants arising from vegetative remains

Although this is clearly a distinct aspect of the problem it cannot be considered completely in isolation from the subjects we have just dealt with.

For example vigour of regeneration of these plants will be affected by the pre-sowing herbicide treatments discussed in a previous section, whilst many of these perennial plants are spread by seed in the first instance. Since the cultivations we are considering take place at a time of year when seed-producing plants have completed their life cycles but at a critical stage for plants perennating vegetatively it is likely that these perennials will generally tend to be favoured by the absence of soil disturbance. However, it is possible to postulate a range of response by these plants.

(i) Some species, many of them characteristic of grassland communities are seriously affected by the conventional ploughing and cultivation techniques so that they may be expected to increase markedly in an undisturbed situation.
These plants are mostly tap-rooted, e.g. Taraxacum officinale, Rumex spp., or stoloniferous or tillering e.g. Trifolium repens, Agrostis stolonifera, Poa trivialis and many pasture grasses.

(ii) An intermediate group of species may increase slightly in an undisturbed situation but are likely to be limited by some factor other than soil disturbance such as the competition of a cereal crop. A possible candidate for this group would be Cirsium arvense.

(iii) A third group of rhizomatous plants such as Agrostis gigantea and Agropyron repens although not discouraged by an undisturbed situation are likely to be modified morphologically and possibly restricted in their rate of spread. Palmer (1963) found that the rhizomes of Agropyron are formed nearer to the surface and grow nearer to the surface in more compact soil. On uncultivated land with an extensive litter layer rhizomes may grow over the soil under the protection of the litter layer. It also appears that Agropyron is to some extent stimulated and certainly spread about the land by limited cultivation although intensive cultivation is harmful to it. In an undisturbed situation then, these species are likely to remain "spot bound" making slow annular growth. It is, however, doubtful whether direct-drilling is synonymous with non-disturbance in this context.

From the practical point of view none of these three categories are very encouraging and even in the last case, although new infestations of A. repens and A. gigantea may spread more slowly, established populations may prove more difficult to control due to the presence of a higher proportion of dormant buds on the rhizomes.

In some cases we can possibly use existing herbicides to greater effect but the practice of minimum cultivation is only one of the aspects of modern agriculture which emphasises our need for new herbicides to assist us in the control of perennial grass weeds.

CONCLUSION

Three central points emerge from this review:-

1. We know that weed populations will be markedly affected by the practice of minimum cultivation.
2. To a limited extent we can predict what the changes will be and this ability should be improved as more information becomes available.
3. We need to keep a very close watch on aspects of these changing populations which might prove or have proved a limiting factor to this technique.

REFERENCES

Allen, G.P. (1965) The ability of paraquat, dalapon and amitrole-T to kill an Agrostis/Lolium pasture in July, October and April. Weed Res., 5 (3), 237-251.

Arnott, R.A. and Clement C.R. (1966) The use of herbicides in alternate husbandry as a substitute for ploughing. Weed Res., 6 (2), 142-157.

Chancellor, R.J. (1964) Emergence of weed seedlings in the field and the effects of different frequencies of cultivation. Proc. 7th Br. Weed Control Conf., 599-606.

Charles, A.H. (1962) Pasture establishment by surface sowing methods. Herbage Abstracts 32 (3), 175-181.

Darwin, C. (1881) "The formation of vegetable mould through the action of worms, with observation of their habits."

Fryer, J.D. and Chancellor R.J. (1958) Toxicity of dalapon and amino-triazole to some common British grasses: A progress report. Proc. 4th Br. Weed Control Conf., 197-202.

Harper, J.L. (1957) The ecological significance of dormancy in weeds. Proc. 4th int. Congr. Prot., 60.

Holroyd, J. (1964) Field investigations concerning the selective phytotoxicity of di-allate to Avena spp. in wheat and barley. Weed Res., 4 (2), 142-166.

Hood, A.E.M., Sharp, D.G., Hall, D.W. and Cotterell, R. (1964) The use of paraquat as an alternative to ploughing. Proc. 7th Br. Weed Control Conf., 907-912.

Jeater, R.S.L. and McIlvenny, H.C. (1965) Direct-drilling of cereals after use of paraquat. Weed Res., 5 (4), 311-318.

Jones, L. (1962) Herbicides to aid pasture renovation. J. Brit. Grassl. Soc., 17 (1), 85-86.

Sprague, M.A. et al (n.d.) Pasture improvement and seedbed preparation with herbicides. Bulletin 803, New Jersey agric. Exp. Sta., pp.72.

Palmer, J.H. and Sagar, G.R. (1963) Biological flora of the British Isles. Agropyron repens (L) Beauv. (Triticium repens L) Elytrigia repens (L.) Nevski. J. Ecol., 5 (3), 783-794.

Palmer, J.H. (1962) Studies in the behaviour of the rhizomes of Agropyron repens (L.) Beauv. 2. Effect of soil factors on the orientation of the rhizome. Physiol. Plant., 15 (3), 445-451.

Roberts, H.A. (1963) The problem of weed seeds in the soil. Crop production in a weed-free environment. Symp. Brit. Weed Control Coun., 2, 73-82.

Whybrew, J.E. (1964) The survival of wild oats (Avena fatua) under the continuous spring barley growing. Proc. 7th Br. Weed Control Conf., 614-620.

Salisbury, E.J. (1961) Weeds and Aliens, London, Collins.

THE SOIL PROBLEMS OF MINIMUM TILLAGE

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The traditional methods of soil tillage in Great Britain were based on the kind of work a team of up to four horses could do using implements made from wood and cast or wrought iron. Very efficient systems of tillage were developed, adapted to most soils in this country, based on the use of ploughs, cultivators, harrows and rolls for preparing a seed bed, based on seed drills, and based on hoes for weed control between the rows of root or fodder crops. But the introduction of the tractor as the source of power, and of modern steels for construction of implements has given the agricultural engineer the opportunity to develop quite new methods of cultivation; and the chemist has revolutionised weed control through the development of efficient herbicides, with the consequence that the practical reasons for the traditional methods of soil tillage have been called into question.

Critical experimental work on the reasons why soil cultivations are necessary and the consequences of omitting certain operations traditionally regarded as essential has been going on, on a relatively small scale in this country for the last forty years; initially at Rothamsted under Sir Bernard Keen, and to a lesser extent at Cambridge under Sir Harold Saunders, and a number of the early results were very disturbing to the traditional farmer, for operations which had always been regarded as essential could often be omitted without any loss of yield. In fact about twenty years ago we at Rothamsted concluded that farmers had over-estimated the virtues of cultivation, in so far as they affected soil tilth, and that the principal criterion of good tillage was in its efficiency for weed control. Now that weed control can be carried out very effectively by chemical means, the principal objectives of soil tillage need re-examining.

The major power demand in traditional soil cultivation is the conversion of a stubble into a seedbed, so a fundamental question in any discussion on minimum tillage is what are the essential features of a seedbed for a high yielding crop.

A seedbed must have two obvious characters - it must provide suitable conditions for the seed to germinate, and it must provide suitable conditions for the young seedling during the first few weeks of its life. For germination, most seeds need to be in sufficiently good physical contact with a moist soil to allow the seed to absorb the water necessary for growth to begin; and the seed must also be in a sufficiently well aerated atmosphere to allow the oxygen for the vital processes which provide the energy for germination and early growth. The seedling also needs to be able to push its growing point through the soil to reach the light of day as soon as possible, so it can start forming green leaves and provide itself with the energy needed for growth as soon as possible. If the seed is buried too deep in the soil the seedling may have exhausted the energy supply in the seed before it has formed any leaves, or it may be so weakened by lack of food that it becomes very susceptible to attack by soil micro-organisms. If it is too shallow, the soil may dry out during dry periods too quickly to allow the seed to take up the water it needs for proper germination and early growth, and if the seed is attractive to birds or vermin, an unnecessarily large proportion may be consumed by them. Further, since the plant tends to be at its weakest when in the seedling stage, it typically needs freedom from competition both from plants which will grow more quickly than it will itself and so shade the young seedling so strongly that its growth is severely limited, and also from plants whose roots may grow more rapidly than those of the young crop and so seriously hinder their growth or functioning.

It was part of the traditional art of the good cultivator to be able to prepare, in as wide a range of weather conditions as possible, a seedbed that was free from weeds and that allowed him to drill his seed at the correct depth in the

.il and at the correct spacing. The smaller the seed, or the deeper the seed s to be sown to protect it from vermin, the more important it is that the young dling should receive no unnecessary check before it can start carrying a green f.

Cultivations are obviously not inherently necessary for the growth of dlings, because the original parents of the crop grew wild naturally, but in so as they are used they need to produce a fairly intimate system of pores of about same size as the rootlets of the young crop, into which the rootlets will grow down which water can percolate and drain away. But the root system of an n and vigorous crop will produce just such a system of pores. When the roots alive and taking up water, they will cause the soil to crack in their neighbour-d and form a good crumb structure; and when they die and decompose they will ve a suitable system of pores or channels stretching from near the soil surface o the subsoil. Further, if there is a fairly large return of dead crop resi-s on to the soil surface, they will form a mulch which will protect the structure the actual surface of the soil against destruction and will encourage a large rthworm population which will build up a very desirable soil structure in the urface soil, given time. Thus, if it were possible to sow and harvest a crop ithout ever going on the land, the crops themselves would maintain the sort of ilth and pore space distribution needed for a seedbed and for seedling growth.

In practice of course, one can only sow and harvest a crop by running achinery on the land, and this is bound to compact the soil and destroy many of the larger pores in the surface soil needed for the easy entry of water, air and the rootlets of seedlings. The more frequently implements must run over the land, the heavier the implements, and the wetter the soil, then the greater the loss of these very valuable coarser pores due to compaction or to the deformation and flow of the soil under the implement wheels, with the further complication that in wet weather the wheels will leave the soil surface uneven and water will pond up in the depressions.

The effect of cultivating land that has carried a really good crop is to disturb the crumb structure built up by the root system and break the root channels which the previous crop produced. This breaking of the channels can lead to a slowing down of the movement of water from the cultivated layer into the subsoil, particularly if the land was ploughed rather moist and the plough share and tractor wheel compact the surface of the furrow bottom. On the other hand if the surface of the soil after harvest is left too uneven, it is almost essential to level it off, with cultivation, before it is possible to sow the seed of the following crop at a uniform depth. I suspect methods of minimum tillage can only make a real impact on the economics of farming when the harvest can be removed from the fields without the soil surface being left rutted. This will require either light trailers that can be easily and rapidly emptied into large lorries or trailers on the headland or it will need trailers fitted with large wheels having a much greater area of contact with the soil than present-day trailer wheels. The cost of doing this is likely to be the most important factor controlling the economics of minimum tillage.

One can take a trivial case where it is known in practice that one can obtain an adequate seedbed for a crop with effectively no cultivation and that is after a root crop which has been cultivated between the rows and harvested when the soil was dry, for under these conditions it is only necessary to level off the land with a cultivator or harrow before the next crop is drilled. It is interesting to note that current developments in potato cultivation implements should encourage this practice, for one of the problems in the mechanical harvesting of potatoes is the separation of soil clods from the potatoes, and the National Institute for Agricultural Engineering are developing methods of cultivation which give the minimum number of clods at harvest time.

This work could obviously have very wide repercussions in the whole problem of soil cultivation, for one of the primary characteristics of the plough is that it makes clods, which have subsequently to be broken down to produce crumbs of a suitable size for a seedbed, so it is obviously desirable to devise systems of cultivation which do not have this undesirable consequence.

Minimum tillage discussions must involve a detailed consideration of the reasons for ploughing, because as long as the conventional plough is the basis of cultivations, the reduction in the amount of tillage that can be brought about is strictly limited. The plough loosens the soil to the depth of ploughing, and exposes a larger volume of soil to the drying action of the sun and wind. The improved aeration, and the additional volume of soil that gets alternatively wetted and dried by being exposed, encourages decomposition of the soil humus, so increasing the amount of nitrates present in the soil. This benefit of ploughing was appreciated by farmers in the days of the bare fallow, and it is the probable reason that crops growing on land receiving minimum tillage require about 40 more units of nitrogen than crops on land traditionally cultivated.

This loosening of the soil brought about by the plough breaks up any plough pan, subsoil pan or tractor wheel pan, if set deep enough, and I have seen examples of deep ploughing to depths in excess of 12 in. make a striking difference to the efficiency of tile drains on heavy land, and to the general rate of drying of the surface soil of autumn-ploughed land in the spring. Oddly enough, in my experience, subsoiling was not nearly as efficient as deep ploughing, for reasons I was never able to discover. This observation does not mean it is essential to plough to maintain the permeability of heavy land, it merely means that if one ploughs heavy land regularly at a constant depth a subsurface pan may be built up which restricts the downward seepage of rain water. There is no reason to suppose that this compacted layer will build up if one does not plough or run heavy tackle on the land.

The second use of the plough is to bury all the old stubble and crop residues, which is essential if the following crop is to be drilled into the soil with a conventional drill. It will incorporate lime into the body of the soil to the depth of ploughing, which is very desirable if one wants to grow an acid sensitive crop on an acid soil. One would expect it to be desirable to plough down phosphates and potash also, for they only wash down into the soil very slowly. Crops can only take their nutrients from a moist soil, and if these nutrients are applied to the soil surface they become unavailable whenever there is a dry spell. Yet ploughing down phosphate and potash does not usually increase their effectiveness, possibly because crops can take up much of their requirements in the early stages of growth, and this is probably also the reason for the effectiveness of placing these two fertilisers near the seed, since this ensures that they are readily available to the young plant. The burying of farmyard manure can best be done by ploughing, and as long as this is produced on farms and needed for arable crops, the plough will probably remain the preferred way of incorporating it in the soil. But if the practice is adopted of collecting the faeces and urine of stalled cattle in tanks, and spraying this slurry on the land, the need for the plough will have gone.

A third reason for using the plough is on land that has got badly rutted, which can happen if combines or heavily loaded trailers are run over cereal fields at harvest when the soil is wet. Ploughing to a suitable depth followed by appropriate cultivation is the easiest way of undoing this damage. The plough may also remain a preferred implement for preparing land for root crops, particularly for sugar beet where the shape of the root is important; but I am not aware of any evidence to show that the plough, as distinct from the deep cultivator, is necessary.

This brings me back to the problem of what are the minimum requirements of a seedbed. One can look at this from a new angle, thanks to the development of general herbicides which will allow the direct drilling of seed in the land without any previous cultivation. The essential implement that must be developed if this technique is to be adopted is a drill that will not get clogged with surface trash but will cut a narrow slit into the bottom of which seed can be dropped, and drills are already being developed which will do just this. But it is probably necessary to fill up the open slit with soil, to protect the seeds or seedlings from vermin, such as birds or slugs, and it may be necessary either to cultivate the soil to a shallow depth just before or just after the drill shoe. It is interesting also to note that in spite of the seed often being very inadequately covered with soil at the bottom of the slit, there is commonly a surprisingly high germination, showing that at least in the moist conditions of British autumns and early springs, the seed can obtain sufficient moisture either from the soil below or from rain temporatily ponding in the bottom of the slit, for germination to take place. It may be found that this technique is less successful in dry periods because of the difficulty of ensuring that the seed is really in contact with moist soil, though it is in dry periods that traditional soil cultivation operations can do so much harm by drying out the soil to the depth of working.

A final word on the need for ploughing cereal stubble for disease control. So far there is no evidence that the absence of the plough encourages the build up of any particular pests or diseases, and in fact on the evidence of the field experiments reported by Mr. R. S. Jeater, it appears to discourage the build up of take-all. But it is quite impossible to predict a-priori if this will be found generally true should the practice of minimum tillage become widespread and be used continuously on the same land for a number of years.

One other aspect of minimum tillage which probably needs little discussion now-a-days is whether inter-row cultivation is really necessary for root crops. Before the advent of herbicides, inter-row cultivation had to be carried out for weed control, and in those days many farmers considered it had value for other reasons as well. Experiments carried out at Rothamsted in the late thirties and early forties failed to demonstrate any effects other than weed control, and I believe subsequent work has confirmed that crop yields are not reduced if weeds are controlled by herbicides rather than by cultivation,provided the soil is not badly capped when the seed is germinating. The replacement of inter-row tillage by herbicides does open up the whole question of row spacings in root crops, for in the past spacing was controlled by the width needed for hoeing, but this restriction is removed if a spraying machine is used.

I would like to end this talk by making two points. The first is that the best method any farmer has for keeping his soil in first class condition is to grow high yielding crops. Any patches or gaps in a crop encourage the growth of those weeds not easily controlled by the herbicide regime in use. The second point is that there is not yet any official research centre in Great Britain where active and coordinated work is in progress on the whole range of problems that must be solved before minimum tillage techniques can be fully fitted into our farming systems, so that our farmers can reap the full benefits of the revolution being brought about by the introduction of herbicides.

Discussion

SESSION X B - PRACTICE OF MINIMUM CULTIVATION

Mr. N. J. Brown "It would appear that a profitable point at which to open this discussion would be to consider in greater detail the statement introduced by Professor Russell where he said that "if it were possible to sow and harvest a crop without going on the land, the crops themselves would probably maintain a soil environment which would satisfy their germination and growth requirements."

Today, the mechanisation of crop production in arable farming in all but one aspect, that of tillage, is committed to creating a situation in the soil that will become progressively more and more compact. Even under systems of minimum tillage, at the present time there is still a necessity for considerable movement of traffic, and in the long term this could lead to a situation where the soil might become so compact that it will be impossible to maintain the current level of yields. Generally speaking every new machine introduced today is "bigger and better" than the previous model and, what is more important in this particular context it is also heavier. Machinery manufacturers if they are to survive in a very competitive market must keep their costs to a minimum. This limits their choice of pneumatic tyres with which they can equip their products to a very narrow range. In the past the main concern has been that the tyres would support the weight of the machine while providing adequate traction and flotation. Little attention has been given as to how these wheel loadings might be affecting the root environment of the crop. There is no doubt that the advances made in chemical weed control have revolutionised our approach to cultivations. It would indeed be unforgivable if the new techniques that are now open to us were allowed to fall into ill-repute because of a failure to consider crop production as a complete system because of concentration of the development programme on the initial stages only. It is conceivable that in the future manufacturers might have to provide equipment with very low wheel loadings and the increased cost of this feature will have to be balanced in the overall economic assessment of the new techniques.

The special drills which are available for direct seeding, and some are described in Mr. Jeater's paper, are all adaptations of existing drills or tillage machines. Although they have already achieved a fair measure of success, the technique of direct drilling surely warrants a much more original approach. Chemical herbicides allow a new freedom of action which is no longer bound by traditional methods. Professor Russell touched on this subject when he discussed row spacings in root crops and the fact that in the past these had been controlled by the width necessary for inter-row cultivations. If full use is to be made of the flexibility now granted by chemical weed control, there is surely scope for a programme of work to establish some basic principles as to how seed should be placed to the best advantage in uncultivated land. Little change has occurred since Jethro Tull introduced his drill in the middle of the 18th century and once again his aim was to place the seed in rows with sufficient space between them to enable the passage of a horse hoe to control weeds. It is only comparatively recently that row spacings on cereal drills have become narrower. While keeping in mind current knowledge on the ideal spatial arrangement of plants in cereal crops it should be possible to arrive at some basic principles from which an engineer could reasonably be expected to develop a complete machine for putting seed in o uncultivated soil.

Considering once more the drills that are already available, it would be fair to say that those responsible for the development of these drills are confident that the seed can be conveyed in one form or another into the soil over an acceptable range of soil and surface conditions. They are not, however, at all happy about the environmental conditions which should surround the seed or young plant. The drill designer at present can only hope to make an enlightened guess as to what type of environment he should aim at creating in the soil to satisfy plant requirements. Now as never before has there been such a pressing demand to specify the required plant root environment in an absolute quantitative manner. Whatever ultimately proves to be the correct environment one factor is already obvious. A positive effort must be made on all the drills being developed for work on uncultivated soils to provide more soil cover for the seed. Some work which has been done at the N.I.A.E. this year to measure the performance of such drills showed that one drill provided no cover at all and the largest amount of soil replaced over the seed in the slit was 52% by weight of the soil removed.

Professor Russell's final sentence where he points out that there is no one specific organization responsible for tillage studies in the United Kingdom must not be forgotten. In his paper Mr. Jeater points out that more than 60 fully replicated trials have been carried out by his organization during the last five years. How much further ahead in our knowledge of this subject might we have been if it had been possible for a multi-discipline interest to have measured all the right things at every stage of these trials. Failures have occurred in direct drilled crops, and any number of reasons are offered as to why this was so. The cause of these failures can only be isolated with certainty if all the relevant factors are monitored from the start.

Dr. D.W. Robinson Mr. N. Brown said there might be a tendency for the soil to become more and more compact under minimum cultivation. In fruit growing where non-cultivation techniques are being used it has been found that on a number of soil types the soil has become less compact. It is assumed that this is due to plant roots being able to grow in the soil surface for the first time. Although soil structure appears to have deteriorated, micro-morphological studies have shown that the deterioration is confined to a very fine layer at the surface.

J.P. Shildrick Could Mr. R.S. Jeater clarify the effect of paraquat residues in trash on subsequent seed germination or seedling growth? Mr. R.S. Jeater replied that the uptake of paraquat by emerging seedlings was a factor in the early work on grassland renovation. However, in the direct drilling of cereals we have not had the same problem. In only one trial has paraquat transfer been observed, and in this stubble was sprayed with 2 lb/ac paraquat on the day of drilling.

Mr. P.H. Rosher Minimum cultivation is only one aspect of adapting our agricultural systems to technical developments. Higher yields of maize, rice and melangene were obtained in Trinidad by closer spacing which was only possible if weed control was achieved with herbicides.

Mr. G.A. Toulson The production of the seed bed by rotating discs has departed from the original concept of the term 'minimal cultivation.' The success of this practice must depend upon costs in comparison with those associated with cultivation which have tended to remain fairly static in recent years.

Mr. R.S. Jeater This subject should not be considered in terms of ploughing versus direct drilling. With the use of herbicides there is now more flexibility.

Mr. J.G. Elliott The point about compaction made by Professor E.W. Russell and echoed by Mr. Brown is an important one. It is a sobering thought that much of the present paraphenalia of soil cultivation may be doing little more than restore the damage caused by the last harvest.

1959; Shklyar et al 1959; Shklyar et al 1961; Voderberg 1961).

An interesting finding by Mitzkovski (1959) is that although 2,4-D and MCPA applied in the usual doses have no harmful effect on the soil microflora they do adversely affect the epiphytal microflora of sprayed plants (particularly dicotyledons).

There are a number of reports that MCPA + 2,4-D may stimulate the growth of micro-organisms. Durkhanin and Kolosova (1962) demonstrated that in laboratory experiments 2,4-D at 3 kg/ha applied broadcast to sandy dernopodzolic and chernozem soils doubled or trebled the nitrate content two and a half months after application and also increased the mobile phosphorus. Vorobew and Abueva (1960) showed that spraying 2,4-D amine increased the number of ammonifiers, nitrifiers and cellulose decomposing micro-organisms in the soil. The mechanism is not clear. Illyin (1961) considers that the inhibition of protozoa in the soil by 2,4-D appears to cause an increase in soil micro-organisms (because of the lack of predatory effects) but this cannot explain the findings by Shennan and Fletcher (1966) and by Smith and Shennan (1966) that some fungi were stimulated by the presence of low concentrations of MCPA in aseptic culture.

Regarding symbiotic associations Morgan and Fletcher (unpublished) using isolated root culture techniques have found that low concentrations (1 ppm) of 2,4-D applied to the cut end of the root causes a marked increase in nodule numbers and nodule volume in Phaseolus vulgaris although this concentration has no effect on the rhizobia themselves. Presumably it is acting as a hormone within the plant root.

Dean and Law (1964) carried out a series of investigations on the action of 2,4-D on Bacterium lactis aerogenes (Aerobacter aerogenes). They found that this organism does not use 2,4-D as a sole source of carbon to any appreciable extent. They looked into the effect of long continued sub-culture of the organism in the presence of 2,4-D. At concentrations of less than 1000 mg/litre 2,4-D had little effect on growth. As the concentration was increased the growth rate declined gradually. Serial sub-culturing in a concentration of 500 ppm resulted in a progressive reduction in the lag phase over a period of 25 sub-cultures from an initial level of about ten hours to a negligible value. The growth rate which had remained constant while the lag phase was falling then began to decrease over the succeeding 91 sub-cultures providing evidence of the limited extent to which adaption to 2,4-D occurred. The authors consider that the progressive diminution of growth may have been due to a slight degree of degradation of 2,4-D to 2,4-dichlorophenol (which is more toxic than 2,4-D to this bacterium).

Shennan and Fletcher (1966) have shown that, at concentrations approximating to field rates of application, the acetic and γ-butyric forms of the common growth-regulating substituted phenoxy acid herbicides are harmless. At higher concentrations (above 500 ppm) however the γ-butyric acids were found to be toxic to a wide range of micro-organisms including algae, whereas the acetic acids had little effect on growth.

The reason for the significant difference in fungitoxic activity between the acetic and and γ-butyric acid homologues is not immediately apparent. A linear correlation between increase in toxicity and increase in molecular weight does not exist as the intermediate α-propionic acid herbicides (mecoprop, 2,4-DP) are non-toxic acting as α-substituted acetic acids.

The theory of β-oxidation likewise cannot be used to explain the considerable toxidity of the γ-butyric acid molecule since this process infers the breakdown of the aliphatic side chain to the acetic acid. As the α-carbon acetic acid is non-toxic to micro-organisms, the activity of MCPB and 2,4-DB cannot depend directly upon their degradation to the acetic acid.

Part of the reason for the greater toxicity of the phenoxybutyric acids to micro-organisms may be due to the fact that they are much more readily taken up by the micro-organisms. Kirkwood, Robertson and Smith (1966) treated mycelial discs and extracted mitochondria of Aspergillus niger with 500 ppm solutions of C^{14} carboxy-labelled MCPA and MCPB and the degree of respiratory inhibition was measured over a half hour period. In both discs and mitochondria MCPB was absorbed more rapidly than MCPA and the radioactive content of the various fractions showed a relatively greater uptake of MCPB-C^{14} after a 20 hour period.

Smith and Shennan (1965) have followed this up by attempting to locate the site of action. They extracted mitochondria from A.niger and found that the oxidation of succinate and NADH were inhibited by both compounds though in each case the inhibition by MCPB was much greater than by MCPA. The inhibitory effect of low concentrations of MCPB (5×10^{-4}M = 100 ppm) could be enhanced by prolonged incubation with enzyme preparations. The results of experiments on the effect of the substituted phenoxy acids on the component enzymes of succinate oxidase and NADH oxidase indicate that there are possibly two sites of action of the compounds; one is before the site of action of phenazine methosulphate; the second between the site of action of phenazine methosulphate and methylene blue. They consider that the main site of inhibition is at that part of the respiratory chain which involves ubiquinone, perhaps the enzyme complex ubiquinone reductase, although there may be other minor sites of action before and beyond this point.

BENZOIC AND PHENYLACETIC ACIDS

(a) 2,3,6-TBA (2,3,6-trichlorobenzoic acid). Selective weedkiller at low doses.

(b) Fenac (2,3,6-trichlorophenylacetic acid). Applied to the soil, used extensively in sugar cane for annual weeds and seedling perennials at 2.5 lb per acre. In North America at doses up to 16 lb per acre for control of perennial weeds.

(c) Chloramben (3-amino-2,5-dichlorobenzoic acid). Selective pre-emergence. Dose 2-4 lb per acre.

2,3,6-TBA

Although TBA may initially reduce the microbial activity - in some cases up to 28 days after treatment - there is recovery. (Chandra 1964; Chandra et al 1960).

FENAC

Fenac has no adverse effects at field rates on nitrification and CO_2 production (Corke and Robinson 1960).

CHLORAMBEN

Corke and Robinson (1960) and Ascheman (1963) are in agreement that field rate applications of chlbramben have no effect on the soil microflora (as measured by CO_2 production).

HALOGENATED ALIPHATIC ACIDS

(a) Dalapon (2,2-dichloropropionic acid).
Translocated herbicide toxic to grasses and other monocotyledons. Dose 4-40 lb per acre.

DALAPON

Magee and Colmer (1960) have found that concentrations of 50-5000 ppm increases the total number of soil micro-organisms to 264% of control, of actinomycetes to 691%, of moulds to 230% and many of the organisms are capable of using dalapon as the sole carbon source. Four consecutive monthly treatments at the same rate however reduced the total micro-organism number to 63% and the actinomycete number to 53% of that of the controls but at the same time the moulds increased 20 fold and dalapon-users 4 fold.

CARBAMATES

(a) Chlorpropham (isopropyl N-(3-chlorophenyl) carbamate).
Normally applied to the soil to prevent establishment of weeds growing from seed. Dose 3-4 lb per acre (propham)
1-2 lb per acre (chlorpropham).

CHLORPROPHAM

At rates used in practice chlorpropham does not inhibit fungi, Azotobacter, butyrate bacteria or aerobic cellulose decomposing bacteria (Shklyar et al 1959).

THIOCARBAMATES

(a) EPTC (S-ethyl NN-dipropylthiolcarbamate).
Active against a wide range of annual and perennial weeds if applied to and incorporated in the soil. Dose 3 - 6 lb per acre.

(b) Di-allate (S-2,3-dichloroallyl NN-di-isopropylthiolcarbamate).
Soil applied for control of wild oats. Dose 1 - 5 lb per acre.

EPTC applied to widely differing soil types at concentrations giving 5 and 100 ppm (the former approximating to field rates), causes a reduced level of activity for at least 28 days but there is great variability according to the soil type and the environmental factors. Microbial activity was estimated by the amount of CO_2 given off. (Chandra et al 1960).

DI-ALLATE

Chandra (1964) looked at the effect of a series of herbicides on the soil microflora. His findings for di-allate are very similar to those for amino-triazole (q.v.) except that at 10 lb per acre the residual effect had gone after 28 weeks.

SUBSTITUTED UREAS

(a) Monuron (N-(4-chlorophenyl)-NN-dimethylurea).

(b) Diuron (N-(3,4-dichlorophenyl)-NN-dimethylurea).
Non-selective at 10-30 lb per acre. At low doses 0.25 - 3 lb per acre may be used selectively in certain horticultural crops.

MONURON

At field rates monuron has no adverse effect on the soil micro-flora. (Corke and Robinson 1960; Shklyar et al 1961). Voderberg (1961) found that 40-200 ppm had no effect on bacteria and fungi. Raud et al (1959) found that it was toxic to a soil alga *Stichococcus bacillaris* at 10^{-6} (0.1 ppm) in vitro. The addition of glucose or lactose reduced the toxicity.

DIURON

Corke and Robinson (1960) found that diuron had no effect on nitrification and CO_2 evolution at field rates. Chandra et al (1960) and Chandra (1964) report however that at normal rates nitrification was inhibited for 8 weeks but nitrification subsequently occurred. The residual effects in greenhouse conditions had gone by the end of 28 weeks. In the field it lasted longer although even here the effects had gone 52 weeks after treatment.

DIAZINES

Pyrazon (5-amino-4-chloro-2-phenyl-3-pyridazone).
Affects weeds by both foliage and leaf uptake. Most important selective use is in sugar beet. Dose 2-3 lb per acre.

PYRAZON

At 66 ppm (= 200 kg/ha) pyrazon causes a slight increase in soil respiration. Increasing the concentration ten times to 660 ppm slightly reduces respiration. Nitrification is unaffected in muck soils by rates of up to 1000 kg/ha and inhibited in loamy sand, sandy loam and loam soils only by 1000 kg/ha. The above work was done by Jung (1964) and he concludes that the soil micro-flora concerned with CO_2 production and nitrification would be unaffected by the use of pyrazon at normal rates. Pommer (1964) has found that pyrazon at 1000 ppm in culture has no significant effect on the growth of several species of fungi.

TRIAZINES

Affect photosynthesis following uptake by the root system.

(a) Simazine (2-chloro-4,6-bisethylamino-1,3,5-triazine).

(b) Atrazine (2-chloro-4-ethylamino-6-isopropylamino-1,3,5-triazine).

(c) Propazine (2-chloro-4,6-bisisopropylamino-1,3,5-triazine).

(d) Prometon (4,6-bisisopropylamino-2-methoxy-1,3,5-triazine).
For non-selective control at doses 5-20 lb per acre.

ATRAZINE & SIMAZINE

There is general agreement that at field rates of application atrazine and simazine have no adverse effect on the soil micro-flora nor on nitrification. (Burnside 1959; Corke & Robinson 1960; Ponchon et al 1960; Steinbrennel et al 1960; Guillemat et al 1960; Burnside et al 1961; Voderberg 1961; Eno 1962; Pantos et al 1962; Mashtakov et al 1962; Viragh 1962;)and Guillemat(1960) found that 6 and 300 mg/ha applied to different soil types has no effect on the biological balance of the soil microflora even when a residue of 0.4 mg/litre soil remained in the soil 6 months after application of 6 kg/ha. Klyuchnikov et al (1964) however are exceptional in that they found that 2 kg/ha (the optimal for eradicating annual weeds) atrazine and simazine decreased the numbers of bacteria, fungi and cellulose decomposing micro-organisms in a sandy soil and retarded decomposition of flax tissue added to soil. In light sandy soil 6 kg/ha (the rate required to destroy perennials) atrazine decreased the number of bacteria and inhibited pigmentation in the fungus Trichoderma. The inhibitory effect penetrated to 25-35 cm in sandy soil but the effect of a single treatment was not great and did not inhibit microbial activity significantly.

There are some reports of low concentrations proving to be stimulatory e.g. Gramlich et al (1964) found that 0.5 - 10 ppm atrazine in the presence of sucrose enhances the growth of certain fungi and bacteria.

Kaufman (1964) has shown that both atrazine and simazine (also linuron and diuron) exert significant quantitative and qualitative effects on soil fungus populations. Both chemicals stimulate one or more genera of fungi known to be antagonistic to fusaria. Since certain fusaria are root-rotting organisms, Kaufman considers that the use of these chemicals may prove beneficial not only in weed control but also through their effect on the soil microbial population.

PROPAZINE AND PROMETON

Mixed with various soils of pH 5 - 7.8 and humus contents of 0.03 - 0.175% at rates equivalent to 12 kg/ha and incubated at 28°C for 15 days, neither of the two herbicides has any effect on CO_2 output or total micro-flora population (including aerobic nitrogen fixing, ammonifying, nitrifying, denitrifying, aerobic, cellulytic and amylolytic bacteria. Even 250 kg/ha has no apparent effect (Pochen et al 1960).

MISCELLANEOUS

(a) **Amino-triazole** (3/amino-1,2,4-triazole).
Active on many plants at low doses entering through root and foliage and readily translocated. Interferes with chlorophyll production. Dose 4 - 8 lb per acre.

AMINO-TRIAZOLE

Chandra (1964) has found that 8 lb per acre added to samples of soil in the greenhouse inhibits nitrification for about 8 weeks but some nitrification occurs subsequently suggesting that the toxic effect is decreasing. At 80 lb per acre the effect was noticeable for about 24 weeks. There was still a decrease in the number of fungi and bacteria four weeks after treatment but there was no effect after 20 weeks. In the field residual effects were longer but had gone by 52 weeks. A repeat application 56 weeks after the initial treatment showed an increased tolerance as nitrification proceeded much more rapidly than after the first application and Chandra suggests that repeated annual applications of the herbicides would have less residual effect than the initial application.

Guerin-Dumartrait (1960) has looked at the effect of amino-triazole at low concentrations ($5 - 50 \times 10^{-6}$) on the growth and pigmentation of the unicellular organism Chlorella pyrenoidosa. He found that it inhibits cell division and causes cellular hypertrophy. There was a reduction in the chlorophyll and carotinoid content and respiration was increased.

(b) Endothal (disodium 7-oxabicyclo (2,2,1)heptane-2,3-dicarboxylate)
Soil applied pre-emergence herbicides. Applied as a mixture 4:3 ratio with propham, the dose depending on the soil type.

(c) Allyl alcohol.

ENDOTHAL

Jensen (1964a) has found that doses of endothal about two to five hundred times the amounts applied in practice did not appear to influence the gross respiration of the micro-flora of the soil.

ALLYL ALCOHOL

The addition of allyl alcohol to soil causes a temporary inhibition of CO_2 evolution which can be overcome by the addition of cell suspensions of Pseudomonas fluorescens or Nocardia corallina both of which are able to use allyl alcohol as a nutrient (Jensen 1961).

CONCLUSIONS

Possibly one of the most satisfactory results of the investigations so far is that no herbicide tested has more than a transitory effect on the total soil micro-flora.

In many cases this is probably because some micro-organisms are able to decompose the herbicide. Corynebacterium simplex, a common soil microbe can utilise DNOC as a sole source of carbon and nitrogen. Other species as well as some Arthrobacter, Achromobacter, Bacterium, Pseudomonas and representatives of the actinomycetes decompose 2,4-D and related compounds. Dalapon, monuron, DNOC and other related herbicides can be used as energy sources by many soil micro-organisms. Chlorine substituents favour attack by Corynebacterium and other gram-positive organisms. Carbamyl, cyano or nitro-groups favour attack by gram-negative bacteria, especially Pseudomonas. Of the moulds, some species of Acrostalagmus, Aspergillus, Trichoderma and others have been shown to attack 2,4-D and similar compounds (Bollen 1962). In some cases however even where the herbicide is relatively persistent (e.g. simazine) it is non-toxic to the micro-flora.

It should be noted however that only a fraction of the herbicides in common use have actually been tested against micro-organisms. It should not be assumed that because those that have been tested are harmless that it follows that all are harmless.

It appears that not much work has been done in combinations of herbicides for synergistic effects. Kaufman and Sheets (1965) have shown that dalapon is more persistent in soil when applied in combination with amitrole. CIPC is more resistent in soil treated with the insecticide carbaryl and whilst fenac at 300 ppm strongly inhibits Nitrobacter, in combination with dalapon at 100 ppm the toxicity is reduced (Bollen 1962). These are important findings and these investigations should be extended.

In some cases (e.g. dalapon and DNOC) addition of herbicide to the soil leads to a marked stimulation of growth of micro-organisms. In the case of dalapon this is probably because the organisms can utilise it as a carbon source. This does not appear to hold for DNOC since the amounts of carbon dioxide that would arise from such metabolised DNOC would be much less than the observed amount (Jensen 1964). A number of authors have noted that at low concentrations some herbicides stimulate the growth of micro-organisms and use could possibly be made of this fact in processes e.g. yeast production, where increase in growth is desirable.

It appears that some of the herbicides may be selective in their action, some micro-organisms being knocked out, other unaffected and still others stimulated. The paper by Kaufman (1964) is an interesting one in which he finds that both atrazine and simazine stimulate certain fungi that are antagonistic to pathogenic fusaria.

The findings by Mitzkovski (1959) that although 2,4-D had little effect on the soil micro-flora it did adversely affect the epiphytal micro-organisms is probably related to the well known protective power of the soil and also that the concentration of herbicide on the leaf is probably much higher than that in the soil. This finding could have important consequences in the field of plant pathology. A number of papers have been quoted (Fletcher 1960) showing that herbicides can affect the course of certain plant diseases and that the storage life of certain fruits can be prolonged by treating them or their wrapping papers with, for example, 2.4-D. Shennan (unpublished) has found that 500 ppm MCPB did show some evidence of chemotherapeutic activity against Clover Leaf Spot (Pseudopeziza trifolii). If it could be shown that selective herbicides, as well as killing weeds could also control leaf and stem diseases in the crop then their sphere of action could obviously be much extended.

Although a great many papers have been published on the effect of herbicides on micro-organisms, remarkably little has been done on the investigation of their modes of action at the biochemical level. This may well be because relatively high concentrations are required to produce an effect. It would seem however that such investigations can be rewarding not only in their own right but also as giving a lead into their effects on higher plants. The work done on MCPA and MCPB is an example of this approach.

It is often assumed that once an organism has become adapted to a particular herbicide then that organism will, in the presence of continuous additives of the herbicide, multiply more rapidly because of the lack of competition from its more susceptible fellows. This may not however be the case. Experiments carried out by Dean and Law (1964) showed that the growth rate of Aerobacter aerogenes which had remained constant over some 25 sub-cultures in the presence of 2,4-D began to decrease over the succeeding 91 sub-cultures providing evidence of the limited extent to which adaptation to 2,4-D occurred.

References

ASCHEMAN, R.E. (1963) The fate of Amiben (3-amino-2,5-dichlorobenzoic acid) in plants and soil. Diss. Abstr. 24, (1), 14-15.

BOLLEN, W.B. (1962) Herbicides and soil micro-organisms. Proc. 19th Western Weed Control Conf. 48-50.

BURNSIDE, O.C. (1959) The influence of environmental factors on the phytotoxicity and dissipation of simazine. Ph.D. Thesis Univ. Minnesota, pp. 114.

BURNSIDE, O.C., SCHMIDT, E.L., & BEHRENS, R. (1961) Dissipation of simazine from the soil. Weeds 9, (3), 477-84.

CHANDRA, P., FURTICK, W.R., & BOLLEN, W.B. (1960) The effect of four herbicides on micro-organisms in nine Oregon soils. Weeds 8, (4), 589-98.

CHANDRA, P. (1964) Herbicidal effects on certain soil microbial activities in some known soils of Saskatchewan. Weed Res. 4, (1), 54-63.

CORKE, C.T., & ROBINSON, J.B. (1960) Herbicides and the soil population. Proc. 7th ann. Meet. agric. Pest Tech. Soc. Canada, 69-72.

DEAN, A.C.R., & LAW, H.S. (1964) The action of 2,4-dichlorophenoxyacetic acid on Bacterium lactis aerogenes (Aerobacter aerogenes). Ann. Bot. 28, (112), 703-10.

DURKHANIN, A.A., & KOLOSOVA, A.A. (1962) (Effect of 2,4-D on the nitrate phosphate nutrient regime of sandy and chernozemic soils.) Trudy vsesoyuz nauch-issled Inst. Vdober Agropochvoved (39), 226-32.

ENO, C.F. (1962) The effect of simazine and atrazine on certain of the soil micro-flora and their metabolic processes. Proc. Soil Crop Sci. Soc. Fla., 22, 49-56.

FERNANDES, C.S. (1957) Action of 2,4-D and TCA on nitrification of ammonia. Univ. rural Pernambuco Oomm. tech., 4, pp. 14.

FLETCHER, W.W. (1960) The effect of herbicides on soil micro-organisms. Proc. Br. Weed Control Coun. Symp., Herbicides and the Soil. 20-62.

GRAMLICH, J.V., COUCH, R.W., SIKKA, H.C., DAVIS, D.E., & FUNDERBURK, H.H. (1964) Preliminary report on atrazine metabolism by micro-organisms. Proc. 17th Sthe Weed Conf., 356.

GUERIN-DUMARTRAIT, E. (1960) Action du 3-amino 1, 2, 4 triazol sur la croissance, la teneur en pigments et les intensities photosynthetique et respiratoire de Chlorella pyrenoidosa Chick. C.R. Acad. Sci., Paris, 250, (18), 3044-6.

GUILLEMAT, J. (1960) Interactions entre la simazine et la mycoflore du sol. C.R. Acad. Sci., Paris, 250, (7), 1343-4.

GUILLEMAT, J., CHARPENTIER, M., TARDIEUX, P., & POCHON, J. (1960) Interactions entre une chloro-amino traizine herbicide et la microflora fongigue et bacterienne du sol. Ann. Epiphyt., 11, (3), 26-95.

ILLYIN, A.M. (1961) (Effect of herbicide 2,4-D on soil micro-organisms) Mikrobiologiya, 30, 1050-1.

JENSEN, H.L. (1961) (Biological decomposition of herbicides in the soil. II Allyl alcohol) Tidsskift for Planteavl. v.65, 185-198.

JENSEN, H.L. (1964a) (Biological decomposition of herbicides in the soil. III Endothal) Tidsskrift for Planteavl. v.67, 553-571.

JENSEN, H.L. (1964b) (Influence of dinitro-ortho-cresol (DNOC) dinitrobutyl-phenol and 2,4-dinitrophenol (DNP) on soil respiration. Tidsskrift for Pleanteavl. v.67:863-874.

JUNG, J. (1964) (The effect of Pyramin on soil respiration and nitrification.) Wiss. Aussprache über chem Unkrautbekämpfung in Zuckerrüben mit Pyramin, Ludwigshafen am Rhein, 85-91.

KAUFMAN, D.D. (1964) Effect of s-Triazine and phenylurea herbicides on soil fungi in corn and soybean cropped soils. Phytopathology, 54, 897.

KAUFMAN, D.D., & SHEETS, T.J. (1965) Microbial decomposition of pesticide comb-inations. Agronomy Abstracts 57:85.

KLYUCHNIKOV, L. Yu., PETROVA, A.N., & POLESKI, Yu.A. (1964) (Effect of simazine and atrazine on micro-flora of sandy soil). Mikrobiologiya, 33, 992-6.

KIRKWOOD, R.C., ROBERTSON, M.M., & SMITH, J.E. (1966) Differential absorption as a factor influencing the selective toxicity of MCPA and MCPB. Proc. Symposium Use of Isotopes in Weed Res. Vienna, 1965, 47-56.

LENHARD, G. (1959) The effects of 2,4-D on certain physiological aspects of soil micro-organisms. S. Afric. J. agric. Sci., 2, (4), 487-97.

MAGEE, L.A., & COLMER, A.R. (1960) Effect of dalapon on the microflora of Mhoon soil. Sugar Bull., 38, 242-5.

MASKTAKOV, S.M., GURINOVICH, E.S., SIMENKO, T.G., & KABAILOVA, I.V. (1962) (Effect of herbicides on micro-flora soil). Mikrobiologiya, 31, 85-9.

MITZKOVSKI, M. (1959) (Contribution to the knowledge of the influence of the herbicides 2,4-D and MCPA on the soil and epiphytal micro-flora of sprayed pests and plants). Agrochemiga (8), 58-63.

PANTOS, G.Y., et al (1962) (The effect of field applications of herbicides on species and groups of the soil micro-flora and micro-fauna and on mycorrhizae with some questions on the biological inactivation of herbicides). Erdeszettud. Közl., Sopron., (2), 3-57.

POCHON, J., TARDIEUX, P., & CHARPENTIER, M. (1960) Recherches sur les interactions entre les aminotriazines herbicides et la micro-flora bacterienne tellurique. C.R. Acad. Sci., Paris, 250, (8), 1555-6.

POMMER, E.H. (1964) (The effect of Pyramin on soil fungi) Wiss. Aussprache über chem Unkrautbekämpfung in Zuckerrüben mit Pyramin, Ludwigshafen am Rhein, 92-4.

RAUD, G., TYSSET, C., & VACHER, B. (1959) Recherches sur les proprietes algostatiques de la 3-p-chlorophenyl 1-1 dimethyl uree (monuron, CMU) en microbiologie du sol. Ann. Inst. Pasteur, 96, (2), 242-4.

SHENNAN, J.L., & FLETCHER, W.W. (1965) The growth in vitro of micro-organisms in the presence of substituted phenoxyacetic and phenoxybutyric acids. Weed Res., 5, (3), 266-274.

SHKLYAR, M.S., VOEVODIN, A.V., & MARKOVA, V.G. (1959) (The effect of 2,4-D and chloropropham on the development of some soil micro-organisms.) Bull Nauchno-Tekh. Inf. Selsk. Mikrobiol (4), 14. (Russ.).

SHKLYAR, M.Z., VOEVODIN, A.V., & BESHANOV, A.V. (1961) (Effect on soil microflora of herbicides applied before the emergence of crop seedlings). Agrobiologiya (2), 222-5.

SMITH, J.E., & SHENNAN, J.L. (1966) The effect of substituted phenoxyacetic and phenoxybutyric acids on the growth and respiration of Aspergillus niger. J. gen. Microbiol., 42, 293.

SMITH, J.E., & FLETCHER, W.W. (1964) 3:5 dihalogeno-4-hydroxybenzonitriles and soil micro-organisms. Hort. Res. 4, (1), 60-62.

STEINBRENNEL, K., NAGLITSCH, F., & SCHLICHT, I. (1960) Der Ein fluss der Herbizide Simazin and W6658 auf die. Bodenmikroorganismen und die Bodenfauna. Albrecht-Thaer-Archiv., 8, 611-31.

VIRACH, A. (1962) Combaterea Burvienelor cu Ajutorul Erbicidelor: referate sustinue la Consfatuirea Internationata, Bucharest, 195-9.

VIRAG, A. (1959) (The effect of chemical weedkillers on some microscopic fungi). Agrartud. Egyet mez ögazd Kar. Közl, 343-56.

VODERBERG, K. (1961) Abhängigkeit der HerbizidWirkung auf Bodenmikroorganismen vom Nährsubstrat. NachrBl. dtsch. PflSchDienSt., Berl., 15, (2), 21-3.

VOROBEV, F.K., & ABUEVA, A.A., (1960) (Effect of the trimethanolamine salt of 2,4-D on nitrogen metabolism) Dokl. s-kh.Akad. Timiryazeva, 52, 347-53.

WOODFORD, E.K., & EVANS, S.A. (Eds.) (1965) Weed Control Handbook, Blackwell Scientific Publications.