WEED MANAGEMENT IN CROPPING SYSTEMS

G.W. Cussans
Long Ashton Research Station University of Bristol,
Long Ashton, Bristol, BS18 9AF, England

Summary. It is suggested that the objective of weed management should be cost-efficiency in the long-term. This implies containment of the total weed population and prevention of harmful evolution of new problems. To acheive this objective, realistic appraisal of the short term management considerations is needed. Long-term management approaches are even more important. It is known that changes in land management and herbicide use will result in changes in weed populations. The challenge is to predict these changes. It is suggested that more knowledge of weed behaviour should be acquired and incorporated into models.

INTRODUCTION

The term weed management is not just jargon; it is affirmation of an observable fact that our weed flora is a direct, if unintentional, result of past land management. In earlier times, the evolutionary pressures on the weed flora were entirely cultural; type of crop, time of planting, cultivation method, seed cleaning and other basic agricultural techniques all had a powerful influence and could even eliminate some weeds. More recently, herbicides have added to the selection pressure, both directly and, indirectly, by allowing the abandonment of cultural control methods. As a result of this we have observed evolution of the weed flora in three basic ways:

* by changing the balance between existing species.
* by introduction of new species
* by evolution within species (e.g. herbicide resistant biotypes)

The challenge therefore is whether this "passive" weed management, whereby we note the response of weeds to agricultural practices, can be replaced by a more active management, and whether we can predict these changes. Prediction would be the first step towards planned weed control systems.

I would like to propose some management objectives and discuss how knowledge of weed biology may help to meet those objectives. Finally, I propose to describe some of the changes in weed populations which have occurred in the UK, with particular reference to changes in tillage practices.

Short-term objectives

A rational definition would be "to achieve cost-effective weed control". However, many farmers who are highly rational and profit minded, are powerfully motivated by pride in a clean crop and by long-term considerations. Their objective might be defined as "to achieve a clean crop". The conclusion perhaps is that there can be no sustainable short-term objective. Weed control has to include the long-term considerations.

Long-term objectives

The choice of long-term aim has traditionally been expressed as the choice between weed eradication or containment. Containment can mean geographical restriction e.g. containment of a newly introduced weed to its original focus of infection. Alternatively, containment can mean the restriction of a widely distributed weed to population levels below those considered seriously damaging. The latter definition has been more commonly applied in Europe. In the UK eradication is rarely attempted and even more rarely attained in practice. It may be possible for a few species, notably wild oats which are conspicuous at low density and can be pulled or "rogued" by hand.

It seems logical to take eradication more seriously in the case of newly introduced species. It appears more likely that a species could be eradicated when populations are scattered and small, than when a seed bank is well established at a number of locations. This, however, is an approach for national authorities rather than individual farmers. Australia and Canada have traditionally been conscious of the risks of introduced weed species. It has been more difficult to get European governments to take the risks seriously for weeds even when there is a strong tradition of quarantine for other problems. In the UK, for example, we maintain a programme of exclusion of the Colorado potato beetle which involves destruction of contaminated produce, treatment of any colonies which are found and restrictions on the subsequent use of the land. This is in spite of the poor adaptation of the beetle to our cold and erratic spring weather and it contrasts with the official lack of interest in introduced weed species and in the development of herbicide resistance in established weeds. A survey of the incidence of *Phalaris paradoxa* and some subjective analysis of the causes of its recent increase in the UK was funded by the independant British Crop Protection Council but not by government. In contrast, the Netherlands government has imposed new legislation to eradicate, or at least to restrict the spread of *Cyperus esculentus*, which has been introduced relatively recently from North America.

To sum up, eradication may be a valid long-term objective of weed management. It could well be taken more seriously but it must remain a minority case and it should not be proposed as an objective unless there is at least some chance of success at realistic cost.

The alternative objective is long-term containment of weed populations and I would like to suggest that this is the most common approach. Let us take the definition a little further to say that the objective is "To contain weed populations at such a level that cost effectiveness of weed control is sustained over the long-term". This implies containment of the total weed population and prevention of harmful evolution of the weed flora.

Thus we can define our objectives in two broad ways. The economic objective is cost efficiency - attained in the short-term by control tactics and in the long-term by control strategy. The biological objective is economically important too, because any weed species becomes a major problem if its population builds up unchecked. However, we can define the objective in population biology terms as either eradication or containment of the whole weed biota and/or individual components of it.

To satisfy any of these objectives perfectly requires an ability to predict the future, which might seem daunting. Ideally we need to be able to predict:

* economic trends (changes in land values, interest charges, commodity prices)

* agricultural elements (crop yields, changes in cultivation technique, or cropping).

* biological elements (response of range of weed species to changes in agricultural practice).

It may well be that this perfection cannot be attained, but we ought to try, and we ought at least to attempt an answer to some basic "what if?" questions.

SHORT-TERM WEED MANAGEMENT

Cousens (3) has recently produced a severe *critique* of the current interest in "thresholds". My own views are similar but not quite so severe so I will not repeat the argument. It is sufficient to say that there is a continuing need to quantify (with a view to predicting) the relationships between weed density and crop yield. This information can lead to threshold guidelines for farmers. Much of the interest in thresholds has been naive and simplistic. It is vital that in proposing thresholds their derivation is made quite clear and it is recognised that they are only guides and do not represent a complete economic analysis.

A short-term economic analysis of weed control decisions should take into account the complete "decision tree" and thus involve economists and general crop production specialists as well as weed experts. As a weed specialist myself, I should perhaps go no further but I will attempt to give some simple examples.

An individual grower with a weed population which is known, or can be predicted, has a range of options. The field may be left untreated or sprayed with a number of possible rates of various herbicides, alone, or in mixtures. We could summarise the options as those involving choice of:

* time of treatment

* likely degree of success (not the same for all species in a mixed weed stand)

* probability of success risk of poor control

* risk of crop damage

* cost of the alternative options.

The grower must choose between these options, using a mixture of criteria concerned with economics and ease of management. Not all the information required is available from the state advisory or registration authorities, or from the chemical supply industry, so growers have to decide on the basis of their own previous experience and judgement.

<u>Economic judgements</u>. What loss of yield and produce quality is likely from untreated populations, or from the survivors after treatment? Is time of treatment an important decision? This may be especially significant in UK winter wheat crops which are sown in September/October for harvest the following August/September. Recommended herbicides are available for spraying almost every month from September to May. In some cases there may be a yield benefit from early removal but it must be remembered that a September treatment could incur six months additional interest charges on the cost of treatment compared to one made in March. There is also the chance of substantial weed germination in spring. These late emerging plants are much less competitive on a per plant basis and may often be ignored altogether, but some of our weeds have two distinct peaks of emergence and the spring peak may

be substantially greater.

Management/indirect economic considerations. Can the herbicide be tank mixed with a fungicide to save application costs? What pressure of other work might interfere with spraying? UK farmers, for example, mostly apply very high applications of nitrogen fertilizer in April at a time of year when soil conditions may be limiting access to the land. Thus, there is a great incentive to avoid extra work at that time and to prefer chemicals which can be tank mixed.

Risk. Many farmers are averse to risk. They would rather ensure that they make a profit each year than maximise profits over a run of years. We cannot calculate the risk element of most of these crop protection decisions and this remains an area which needs attention. However, we can see how a subjective analysis of risk may influence decisions. Reverting to the September versus March/April spray decision, we can see that an early (pre-emergence) spray may be costly (the decision must be made before the weeds are seen), and it clashes with a busy period. However, early treatment reduces any risk of early weed competition and it is a "low risk" decision in that the farmer does not gamble on the soil being dry enough to allow a later spray application. An early spray also leaves time for a second attempt (if soil conditions permit) should the first spray be inadequate.

This has been an over simplification of some of the major elements involved in making a weed control decision. If we are to progress the science of weed management these elements and others need to be developed into quantified alogorithms to introduce an element of objectivity into what is often a highly subjective decision making process. Above all we have to recognise that short term tactics, although important, cannot be divorced from long term considerations.

LONG-TERM MANAGEMENT

Let us establish straight away that this is not just an abstract concept. Recent work has shown that the long-term element in weed control is just as important economically as the short-term response of crop yield. A combination of short and long term modelling showed that a strategy of treating only when a short term economic threshold was exceeded would not be economically optimal for two grass weeds, *Alopecurus myosuroides* and *Avena fatua* in continuous cereal cropping. The long term economic optimum spray threshold was lower than the short term threshold by a ratio ranging from 1:3 to 1:7 depending on the cultural methods by which the continuous cereal crops were established (2, 6).

To exploit the possibilities of planned managment in the long term we need a great deal of biological knowledge on our weeds. We need to establish, ideally by both empirical observation and by modelling from component information, the following:

* the potential rate of population increase in the absence of control measures.

* the potential rate of population decrease in the complete absence of further seeding (or vegetative propagation).

* potential immigration and emigration of weed propagules.

* the influence on the above basic elements of herbicides of varying levels

of efficiency and of major variations in husbandry methods.

So far we only have this sort of information for a few very important species; in UK this would inclue *A. fatua*, *A. myosuroides*, *Bromus sterilis* and *Galium aparine*. However, we should be accumulating information on a wide range of species. It is easy to identify existing problem weeds but weed specialists should be developing an ability to predict future problems. We are anticipating an era when farmers may be more ready to leave a few weeds untreated, or treated with relatively inefficient materials in order to economise, or, in some cases, to prevent excessive diminution of the flora. This is to be encouraged but not at the expense of building up future problems which could vitiate any short term advantage.

It may be helpful to review some practical examples of these aspects. Specifically, let us examine the extent to which minimum tillage has influenced our weeds and the extent to which this could be predicted from biological knowledge.

<u>Potential population change</u>

Weeds survive by a variety of strategies. The typical successful weed in traditional cropping systems produces seed with marked dormancy and great longevity. In any one season plants can only be produced from the fraction of the seed bank which has been released from dormancy and is in a suitable position in the soil to germinate successfully. This protracted germination has a damping effect on population changes. The maximum potential rate of population increase is rather slow even in the absence of control measures and despite prolific seed production. Conversely, seed production could be prevented altogether for several years without a major effect on seedling numbers or serious depletion of the seed bank. Examples of weeds of this type would be *Veronica hederaefolia* and *Polygonum aviculare*. Fig. 1 derived from data by Brenchley and Warrington (1) shows the remarkable stability of seed populations of *V. hederaefolia* compared to *A. myosuroides* in a regime which alternated two years without seeding with three years of uncontrolled growth. Table 1 from Pollard and Cussans (12) shows similar stability in seedling numbers of *P. aviculare*. The large response to tillage method did not lead to any marked trends in populations. The ratio between treatments was similar each year as though inexhaustible reserves of seeds reacted in the same way each year. We could call these "long cycle" species.

Table 1. Density of *Polygonum aviculare* (plants/m^2)

	1969	1970	1971	1972	1973
Direct drill	0.46	3.62	4.94	0.61	0.72
Shallow tine cultivation	1.62	19.99	8.40	5.38	3.32
Deep tine cultivation	2.78	32.11	12.22	9.22	7.74
Plough	10.65	24.88	21.73	22.96	14.40

(Source: Pollard and Cussans (12))

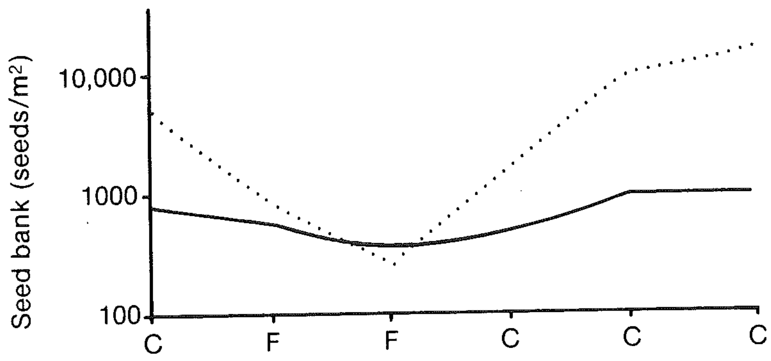

Figure 1. Effect of rotation (C = cereal cropping; F = fallow) on seed banks (seeds/m^2) of *Alopecurus myosuroides* and *Veronica hederaefolia* (Source: Brenchley and Warrington (1)).

At the other extreme of survival strategy there are "short cycle" species producing seeds with relatively weak dormancy and comparitively short life span. *Bromus sterilis* seeds persist for a maximum of one year whilst even *Avena fatua* and *Alopecurus myosuroides* seeds have a life span of six to ten years compared to 50 or 60 years for some of the broad-leaved species. Weeds of this type therefore exhibit rapid build up in the absence of control and rapid decline if seeding is presented. I have suggested (4) that, with any successful weed, there has to be an approximate balance between the two broad characteristics of potential population increase and potential decline; as was, indeed shown in Fig. 1. Species with a low rate of increase and a high rate of decline are presumably all extinct. Conversely, the factors leading to long term survival limit the potential for short term population increase so it is almost impossible to combine the two. The terms long and short cycle are, of course, convenient but over simplified. It is impossible to fit weeds into two simple categories and there are many intermediate patterns of behaviour.

It can be easily appreciated that long cycle weeds are well adapted to rotational farming, whereas short cycle species are much better adapted to continuous mono-cropping. It might also seem logical that long cycle plants are well adapted to mouldboard ploughing. Annual inversion of the surface soil buries newly shed seeds below the most biologically active surface layers of the soil and thus protects them at a time when they would be unlikely to germinate in any case. Later ploughing brings back seeds towards the surface, with a variety of effects. The physical abrasion, exposure to light and aeration help to release a proportion of the seeds from dormancy and their positioning in the upper soil layers makes successful seedling emergence more likely.

In contrast, burial of freshly shed seeds by mouldboard ploughing prevents short cycle plants from exploiting their seed producing capacity to the full because few seeds are able to establish successfully if they germinate at depth (11). Later on, when the land is reploughed, short cycle species cannot benefit if insufficient seeds remain viable when brought back towards the soil surface to increase the population. The data for *Poa annua* in Table 2, and those for *A.myosuroides* in Table 3, show rapid response to changed tillage regime.

Table 2. Density of *Poa annua* (plants/m²)

	1974	1975	1976
Direct drilled	21.8	90.3	106.2
Shallow tine cultivation	23.7	50.0	52.3
Deep tine cultivation	21.8	56.3	37.8
Plough	23.9	16.7	8.1

(Source: Cussans, *et al.* (5))

These basic factors controlling population response are, of course, conditioned by the use of herbicides. The final outcome is therefore determined by the combined effects of three factors; the biological characteristics of the weed, the cultural methods, and the herbicides used. In general, our observation of the effects of tillage on weeds fit well with the concept of long and short cycle species (12, 13, 15, 16).

Table 3. Density of *A.myosuroides* (plants/m²) in Novembern 1975

Site	Plough	Tine	Direct Drill
1	4	78	177
2	28	139	159
3	8	88	91

(Source: Moss (9))

<u>The use of population models in long-term management</u>

The many factors which control weed populations can only be combined in demographic models. It is not beyond the wit of man to devise multifactorial experiments of such a long-term nature that some of these effects and interactions could be determined experimentally. However, it is beyond the capability of most of us to carry them out. It seems logical therefore, to study elements of the population cycle separately and to combine them in models of behaviour. These need not be especially elaborate; most of our models involve calculations of the simple seed cycle shown in Fig. 2 using data from long and short term experiments, and even some observations form non-experimental fields.

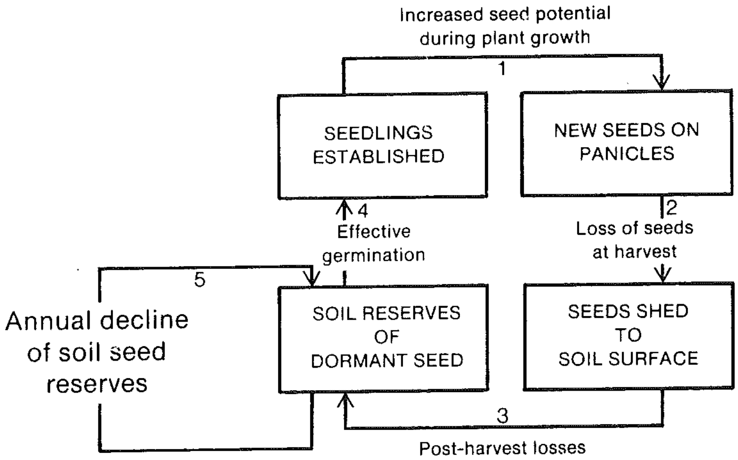

Figure 2. A model of a weed seed cycle

The first use of these models was also simple; we set out to calculate the annual percentage kill by herbicides needed to maintain a static population as shown in Table 4.

Table 4. The annual percentage kill by herbicides needed to maintain a static population of *A. myosuroides*[a]

	Straw burnt	Unburnt
Ploughed	50	65
Direct drilled	88	92

[a]From Cussans and Moss (6)

This simple calculation tells us a great deal because the herbicides available can be expected to give 85 to 95% kill in most seasons with occasionally much better or worse effects. This indicates that there is no possibility for economy in control in a direct drilled situation and, indeed, that average or above average standards of control must consistently be attained. We were fortunate in having some evidence that herbicides did not, in fact, work so well in minimum tillage regimes (9, 10) and we were able to do some "what if" modelling before this became a widespread problem (6). Fig. 3 assumes that herbicide performance starts at 95% mortality but declines by 5% for every year that direct drilling is practiced. We never pretended that this was precise forecast but, in fact, the 3 to 4 years of "honeymoon" followed by an exponential slide into disaster in 7 to 10 years was very much the pattern followed by many farmers in practice. The same model suggested that a complete return to mouldboard ploughing was not necessary; a rotation of one year ploughing in about five years of minimum tillage was likely to be adequate even under more extreme decline in herbicide performance than was likely to occur in practice (Fig. 4).

The model for *Avena fatua* (17) suggested that this species does not respond quite so strongly to changes in tillage, and in the worst case, a lower level

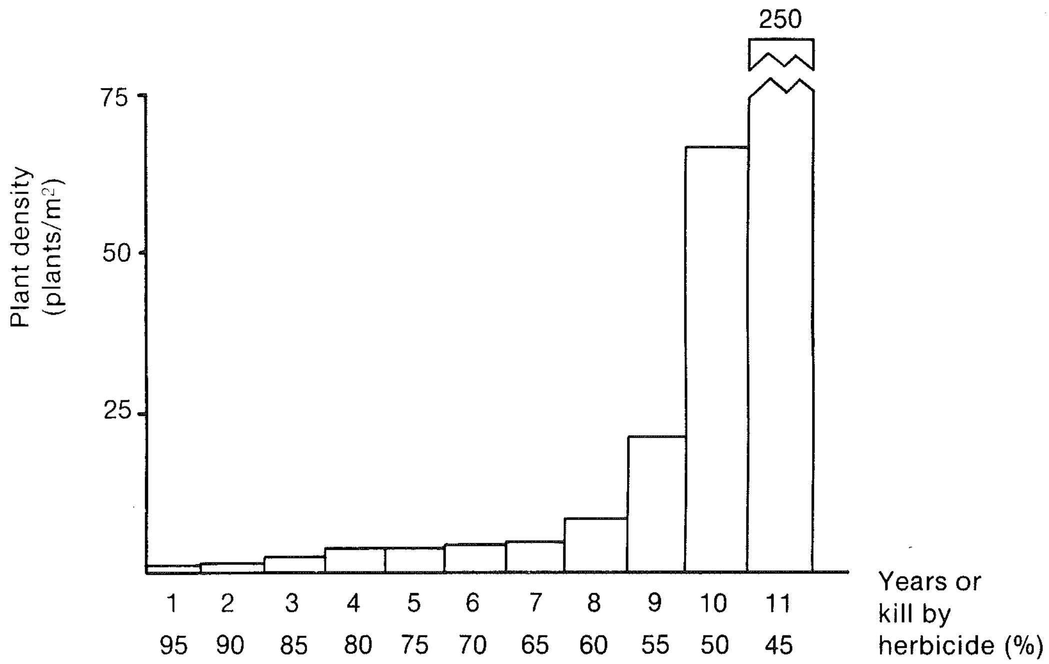

Figure 3. A model for *A. myosuroides* populations on direct drilled land which assumes an initial 95% kill by herbicides which declines by 5% for each year of direct drilling (Source: Cussans and Moss (6)).

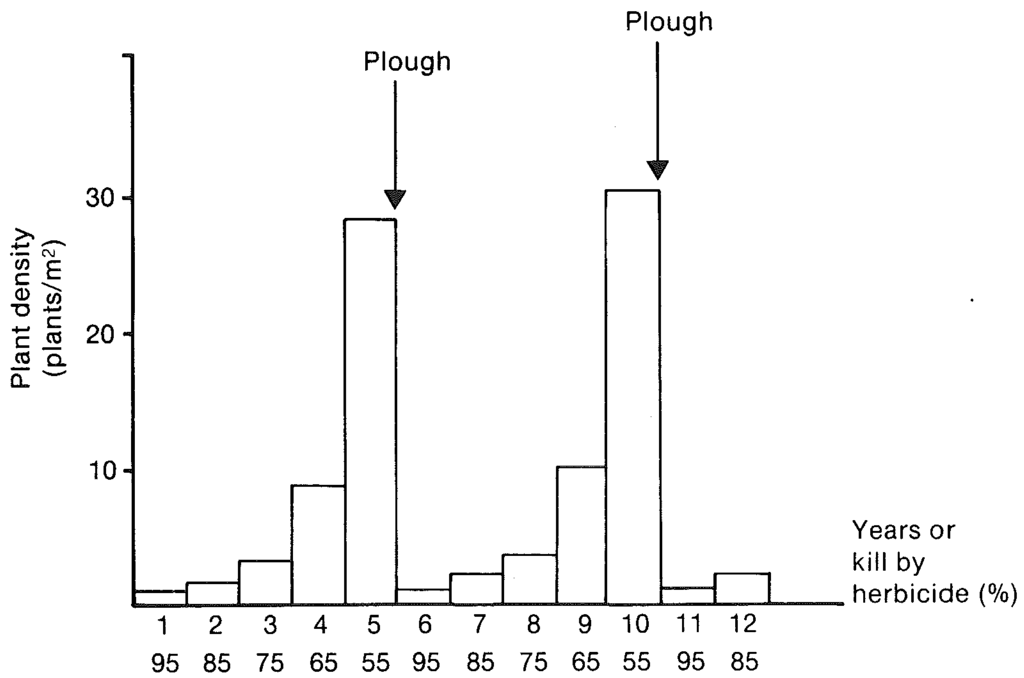

Figure 4. A model of *A. myosuroides* populations assuming kill by herbicide to decline by 10% for each year of direct drilling.

of control will contain the weed. The corresponding values to those in Table 4 are: for tine cultivation, 75% kill with straw burning and 85% without; and for mouldboard ploughing, 70% with and 80% without burning. These values are all within the range of performance which can be expected from the chemicals available and indeed wild oats have declined as a national problem while blackgrass has become our most serious weed in winter cereal crops throughout Europe.

The work on *Bromus sterilis* which also culminated in a model (14) showed that this species is almost entirely dependant on minimum tillage for survival as a field weed although it is common as a field margin species (8). In minimum tillage conditions a very high level of herbicide performance is required which is quite unobtainable in practice. This species and *Bromus commutatus* and, less frequently, *B.mollis* remain as serious and intractable problems of minimum tillage systems, although fortunately they have not spread far from field margins in the great majority of infested fields.

There are other uses for descriptive models. Cussans (4) showed that dose and timing of herbicide relative to a break crop could be considered as variables, while Wilson *et al.* (17) showed the importance of a break crop in a continuous winter cereal cropping regime. More recently Cousens *et al.* (2) and Doyle *et al.* (7) showed the importance of long term effects in setting weed threshold values. Models are also valuable for identifying the data which are needed but, all too often, not available.

Although a very good case can be made for population modelling, we have to confess that there are very few cases where knowledge of weed biology has predicted the rise in importance of a "new" weed. This is partly because of the historically low level of funding for weed research in general and weed biology research in particular, and partly because of the "quasi political" nature of research funding. Thus, only when a problem exists can money be obtained for the biological studies to explain why the problem occurred in the first place. The weed biologist who has a "hunch" that a very minor species might have the potential for increase and therefore be worthy of study has little chance of success. The academic ecologists might well have tackled this intriguing problem of why some species become major weeds whilst others remain as interesting rarities, but they have traditionally only studied species which occur above 1000 m in altitude, or below sea level, or on a site studied by their professor 30 years before.

CONCLUSIONS

Weed populations are influenced by many aspects of crop management, not only by deliberate herbicide use. We must expect that our weed flora will go on evolving as it has evolved so far with the development of agriculture. We need to develop our subject away from a concentration on yesterdays problems, sometimes amounting to overkill, and towards prediction of future problems. When we succeed we will be able to talk of weed management rather than weed control.

However, we must be careful that enthusiasm for a good idea does not lead to naivety as has been the case perhaps with some of the uncritical approaches to thresholds. Management must involve a degree of prediction and our knowledge of weed biology is too restricted to take use far. Let us make the case strongly for more work on weed biology and for more use to be made of the existing body of knowledge.

REFERENCES

1. Brenchley, W.E. and Warrington, K. 1936. J.Ecol., 24, 479-501.
2. Cousens, R., Doyle, C.J., Wilson, B.J. and Cussans, G.W. 1986. Pest. Sci. 17, 1-12.
3. Cousens, R. 1987. Plant Prot. Qrtly. 2, 13-20.
4. Cussans, G.W. 1980. Proc. Brit. Crop Prot. Conf. Weeds. 3, 823- 831.
5. Cussans, G.W., Moss, S.R., Pollard, F. and Wilson, B.J. 1979. Proc. EWRS Symp. on the Influence of Different Factors on the Development and Control of Weeds. pp. 115-122.
6. Cussans, G.W. and Moss, S.R. 1982. In: Brit. Crop Prot. Counc. Monograph. 25, 91-98.
7. Doyle, C.J., Cousens, R. and Moss, S.R. 1986. Crop Prot. 5, 143-150.
8. Froud-Williams, R.J. 1983. Ann. Appl. Biol. 103, 139-148.
9. Moss, S.R. 1978. Proc. Brit. Crop Prot. Conf. - Weeds 1, 107-112.
10. Moss, S.R. 1981. Ann. Appl. Biol. 91, 91-100.
11. Moss, S.R. 1985. Weed Res. 25, 201-211.
12. Pollard, F. and Cussans, G.W. 1976. Proc. Brit. Crop Prot. Conf. - Weeds 3, 1019-1028.
13. Pollard, F., Moss, S.R., Cussans, G.W., Froud-Williams, R.J. 1982. Weed Res. 22, 129-136.
14. Pollard, F. 1982. Proc. 1982 Brit. Crop Prot. Conf. - Weeds. 3, 973-979.
15. Wilson, B.J. 1981. Weed Res. 21, 23-28.
16. Wilson, B.J. 1985. Weed Res. 25, 213-221.
17. Wilson, B.J., Cousens, R. and Cussans, G.W. 1984. Proc. 7th Int. Symp. Weed Biol. Ecol. and Systematics (EWRS/COLUMA) pp 287-294.