Identifying ways of optimizing herbicide use in crops

G.W. Cussans

Rothamsted Experimental Station, Harpenden, Hertfordshire, AL5 2JQ, United Kingdom

Summary

Optimization is defined as a reduction of the level of active ingredient used to a minimum necessary to meet a defined need. Three approaches need to be integrated; reducing the need for herbicides by cultural means, used as part of a rotation to avoid development of a specialized weed flora; defining the need for herbicides in quantitative terms and, finally, matching herbicide use to the defined need. It is already possible to reduce herbicide use by known techniques and these are briefly reviewed. Considerable advances have been made but it is suggested that the subject is more notable for the research which remains to be done rather than for the information which exists.

Introduction

Our profession is under great pressure to reduce the use of herbicides. There are two imperatives; the wave of environmental consciousness, which has already led to constraints on the use of agrochemicals and can be expected to lead to more, and the need to economize on inputs if some of our farmer "clients" are to remain in business.

"Optimize" will, therefore, be taken to mean "reduction of the level of active ingredient to a minimum necessary to meet a defined need by means of integrated approaches". Many complexities are hidden behind this laudable aim. We can describe, sometimes even define the principles, although I will suggest much remains to be done. Even where we have the basic knowledge, the challenge remains for farmers and their advisors to interpret and to put into practice the body of principle developed by the research community. The possibilities will be discussed under the following set of headings; Reducing the Need for Herbicides, Defining Need and Matching Herbicide Use to Need

This review will concentrate largely on the situation in North West Europe, and the United Kingdom in particular, although some more general principles are involved.

Reducing the need

As a general rule, weeds are not "natural", although some species which are relics of the climax vegetation have become serious weeds. More commonly, however, weeds are introduced species or occupy only a minor niche in the indigenous biota. In short, the weed flora is an assemblage of species which, whatever their origins, have been selected by the activities of man. Weeds are as much a product of agriculture as our crops (16). Recognizing this link between agricultural techniques and the weed flora is the first vital step in minimizing herbicide use.

There are a number of mechanisms which can be employed to reduce or replace the use of herbicides but which cannot be reviewed in detail in a short paper. Traditionally seed cleaning, by reducing the introduction of fresh seeds to arable land, has reduced the need for weed control and possibly led to the extinction of some species (e.g., *Agrostemma githago* from U.K.) before the advent of herbicides. The competitive ability of crops can be increased by manipulation of density (10,5) or selection of more competitive varieties (12) although Cussans (4) showed that major differences in growth habit of cereals may not be reflected in suppression of weed growth. Enhanced crop competition clearly reduces herbicide need but, surprisingly, has not been shown to interact to give enhanced herbicide performance.

Cultivation plays a role in many ways. The importance of inversion or non-inversion primary tillage will be discussed later. "Stale seedbeds" can be prepared so that the initial flush of weed seedlings can be killed before sowing the crop. Cultivation in the dark has been proposed (11) as a method for reducing seedling emergence and hence the need for herbicides. Finally, harrowing or mechanical weeding post-crop emergence is being examined again as an alternative or supplement to herbicides.

All of these techniques have some potential but the extent to which they can reduce herbicide use will depend very much on individual crop/weed situations. They all have some demerits and may select for resistant weed types in some circumstances. Thus, "stale seedbeds" may reduce crop yield and select for weed species or biotypes which germinate later. Dark cultivation, if it were widely practiced, would be a potent method of selection for species or biotypes with a lower light requirement for germination.

I will suggest, therefore, that these individual mechanisms have to be subsumed into an overall principle of **rotation**; rotation that is of **crop species**, of **time of planting**, of **tillage method** and of **herbicide use.** In the past, rotation of crops was necessary for many reasons. A rotation of crops with grass or fallow allowed restoration of soil fertility. Rotation of different species spread the seasonal demand for labour and reduced the economic impact of failure of any single crop, in the days when some crops could be completely wiped out by weeds, pests or diseases. However, the development of pesticides and the industrialization of agriculture has led to increased specialization. Many arable farms have no livestock and the tendency is to grow crops best suited to the soil and to the structure of the farm business. This may lead to reduced diversity of cropping or even to monoculture or near monoculture.

Such departure from the principle of rotation favours short cycle weeds, that is those species with limited seed dormancy and persistence but great propensity for rapid population increase. It also favours the increase of a limited sector of the potential weed flora; those species with time of germination and seedbed requirements similar to the crop. Non-inversion tillage also favours short cycle weed species so the combination with monoculture creates a very powerful selection towards short cycle species. These trends may not present a problem unless the favoured species are also difficult to control with herbicides, when the result will be a weed explosion. The special case of herbicide resistance is particularly interesting. Short cycle weeds, particularly in a non-inversion tillage system appear to be especially prone to evolution of herbicide resistance. The relatively rapid "turn-over" of seeds minimizes the opportunity for surviving weed plants to back-cross with plants from earlier and therefore less heavily selected generations. This adds the final element to the principle of rotation: that of rotation of herbicide use.

To go from the general to a specific case, from my own country. For centuries the staple crop in England has been wheat, sown in autumn and maturing in about 300 days. Traditionally, it was never grown more frequently than one year in three or four, in rotation with grass or with crops for stock feed and, less frequently, with potatoes or sugar beet. In the last thirty years we have seen root crops and vegetables concentrated on the more easily worked soils (with consequent specialization of the weed flora) and livestock production increasingly concentrated into large units. On the difficult to work clay soils of Eastern England, none of the alternatives are very profitable but farmers have discovered they can grow winter wheat very well, with yields of 8 to 9 tonnes per hectare being commonplace. The tendency has been towards monoculture of wheat with occasional break crops which are mostly also sown in early autumn. This dominance of autumn cropping has led to the final break with tradition on many farms, dispensing with the mould-board plough in favour of non-inversion tillage systems. These are cheaper and, more importantly, quicker, thus easing the problem of an intense peak of autumn activity. By retaining weathered soil on the surface and not ploughing up raw clay, these systems tend to result in more consistent crop establishment.

The resulting system is efficient from both technical and business viewpoints. It is also known to be conservative of nitrogen. The maximum leakage of nitrogen from agricultural soils tends to be from ploughed soils where there is no plant cover in winter to take up the mineralized soil nitrogen. A crop of wheat established early by minimum tillage is therefore the best safeguard against such leakage. However, the system is so favourable to the autumn germinating grass weeds that it is "breaking down" on some farms because of high levels of *Alopecurus myosuroides*, black-grass, (with herbicide resistance evolving in some populations) and *Bromus* spp. Where it is continuing, this system is totally reliant on herbicides, notably materials which are appearing in the water supplies at levels exceeding the limits set by the European Community.

Here is an example then, where herbicide use has increased massively in recent years and we know the technical answers. The need for herbicides can be reduced by a return to rotation with spring sown crops or grass and by a return to mouldboard ploughing, also on a rotational basis. These changes are already being implemented by some farmers and others may be forced to change if restrictions on herbicide use are imposed to comply with the EC directive on water purity. However, the technical answers only go part of the way. Modern business management and the cost of borrowing makes farmers averse to the high risk involved in establishing spring crops and the inconsistent yields of grass on the clay soils in our dryer areas. Spring cropping and increased use of tillage for weed control would increase leaching of nitrates to groundwater so there is a "trade-off" between two classes of pollutants. Who is to make the judgement on their relative importance?

This example is very specific to one farming system on no more than 2 million hectares of clay soils in the U.K. It does, however, illustrate some general principles which may be applicable far more widely. First, the introduction of herbicides has permitted changes in crop management which have, in turn, created greater dependance on herbicides. Where this succeeds we hear no more, but it is extremely difficult to turn the clock back if it does not. Second, we must not consider the options as simple alternatives. The principle of rotation can and should be extended much more widely, to prevent the weed flora from evolving in too "specialist" a direction.

Defining "need" for herbicides

There are two basic and universal reasons for weed control in crops: **to reduce or prevent yield loss** from competition and **to contain the weed population** such that economic agriculture can continue in the longer term.

Eradication is sometimes stated as an objective although I have argued that it is rarely feasible (6). Economic factors other than yield are frequently considered but rarely in a quantitative way. Limited analysis in U.K. conditions suggests that yield penalties usually occur at lower populations than economically important effects on ease of harvesting and quality of produce but clearly this is not true in every case.

Before we can consider optimization of herbicide use we need to attempt to define the level of control needed to achieve these two basic aims of preventing yield loss and population increase. Yield effects will be considered in the next section and have been the subject of much research. There have been fewer attempts to quantify the herbicide performance needed to achieve the aim of population containment. However, UK studies of the population dynamics of *Alopecurus myosuroides* and *Avena fatua* (7,20,13) have led to population models for these species. These can be used to study long term economics of weed control (3), to study the interactions between crop management and weed control and, above all, to estimate the level of control needed from herbicides in a range of systems. Examples are given in tables 1 and 2.

Table 1 *% Kill of A. fatua needed to maintain a static population in continuous cereal growing (from Wilson, Cousens and Cussans 1984)*

	Straw burnt	Straw removed
Ploughed always	70%	80%
Tine (non-inversion) cultivation always	75%	85%

Table 2 *% Kill of A.myosuroides needed to maintain a static population in continuous winter cereals (from Moss 1990)*

	Straw burnt	Straw removed
Plough (20-25 cm)	63	78
Tine cult. (20 cm)	87	93
Tine cult. (10 cm)	92	95
Direct seed or Tine cults 5 cm.	94	97

The models described above use % reduction of seed return as the parameter to describe "kill". The population model for black-grass includes a term for density dependance. Moss(1990) reviewed 131 field experiments in U.K. and Germany and concluded that the response curve shown in Figure 1 gave the best fit. It is described by:

$$y = Bx / (1 + a x)$$

Where y = number of heads/m²
x = number of plants/m²
B = heads per plant at low weed density
a = a constant governing response to density

When fitted to pooled data from 131 experiments:
B = 3.88, a = 0.0018

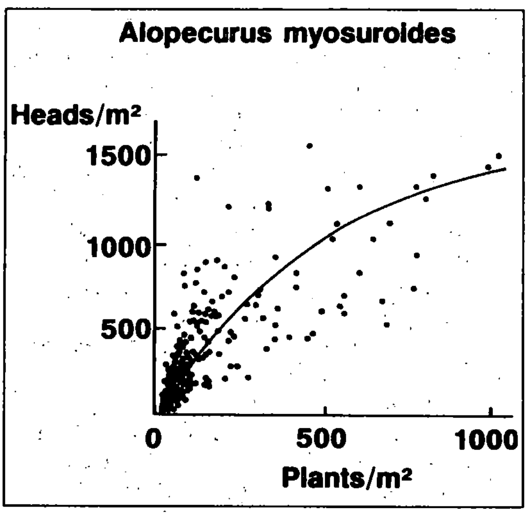

Figure 1 Relationship between A. myosuroides plant and head densities (from Moss, 1990)

It is not easy to discuss the effects of weed density on herbicide activity because so little work has been done. Can we assume that herbicides are equally effective at a range of densities? Some herbicides affect the vigour of survivors and intuitive reasoning suggests that the competitive ability of such survivors is reduced but how often has this been quantified? The density dependance equation from Figure 1 allows us to predict the interactions which will result can if the competitive ability of survivors is **not** affected. Table 3 shows values for *A. myosuroides* within a reasonable range of treated densities and herbicide efficacy.

Table 3 Relationships between kill of A. myosuroides plants and reduction in fertile tiller populations, assuming no effect on tillering ability of the survivors.

Sprayed population	% kill plants	% reduction of tillers	Surviving tillers/m²
100/m²	90%	88.4%	38.1
	95%	94.2%	19.2
	97.5%	97.1%	9.6
1000/m²	90%	76.3%	329
	95%	87.2%	178
	97.5%	93.3%	92.9

The three columns in Table 3 represent three measures of herbicide performance. The first shows the initial kill, as influenced by physiological conditions at or around the time of application. The second shows the result that would be observed in the final stages of a field trial. The third column indicates what the farmer perceives as the end result in absolute not relative terms. This is a gross over-simplification. So many factors are involved in the transition from the first to the third column that it is unreasonable to expect the relationship to be constant or predictable. However, for the farmer and the population biologist alike, it is the number of seeds returned to the soil which governs the ultimate success of control.

In attempting to be more precise in our herbicide use, I believe we need to be aware that we are entering an area more notable for the research that remains to be done than for that which has been done.

Matching herbicide use to need

1. Threshold management

Throughout the world there is a surge of interest in work on crop/weed competition much of which is being conducted with a view to developing thresholds below which weed control is not economically justified. This is being discussed elsewhere in this congress.

2. Patch spraying

Distribution of weeds is neither random nor regular. Weeds characteristically occur in patches but spray/no spray decisions are made on a whole field basis. Wilson and Brain (19) have shown that the distribution of *Alopecurus myosuroides* was remarkably stable over a ten year period and we (current author and B.J. Wilson) have observed similarly aggregated distribution of other species. Such aggregated distribution complicates threshold management (2). It does, however, open up the possibility of another method of matching use to need. With patchy weed populations, the greatest possibility for economy in herbicide use would come from an effective way of treating patches differentially. Moreover, in theory at least, this could be achieved with minimum risk because the sprayer could be triggered at low weed density. The potential is enormous and a number of research groups are working in this field. The challenge is to produce affordable technology with consistent performance and modest demands on manual and visual assessment.

3. Optimizing herbicide efficacy

In the context of the present paper we can define this as "reducing the dose of active material to the minimum needed". For many years we have been aware that commercial recommended doses tend to be cautious and can frequently be reduced with little or no penalty. Wilson, Cussans and Ayres (18) showed in a series of field experiments that halving the dose of barban and tri-allate rarely led to halving of effect and sometimes achieved optimum control. Streibig (14,15) developed the concept of parallel curve analysis to quantify phytotoxicity and this has been developed further to produce the concept of "factor adjusted doses" (9). Clearly, then, there is scope for manipulation of herbicide dose and many farmers regularly experiment. Before going further, however, we must ask;

1. are we expecting to reduce dose and maintain level of kill?
2. are we attempting to adjust dose to achieve a target level of control?
3. do we understand or can we influence the relationship between expected level of performance and risk

The concept of factor adjusted doses assumes that the effects of major sources of variation can be predicted and the dose adjusted accordingly. This is a logical approach and one which has met with considerable success but I suggest that many factors governing herbicide performance remain unpredictable and field performance is best described by a probabilistic curve (Figure 2.).

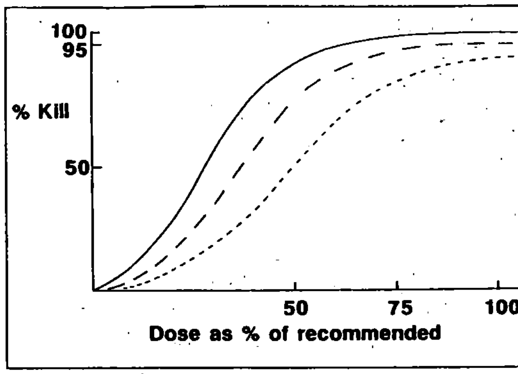

Figure 2 Expected performance of a "model" herbicide in a range of field conditions.

Figure 2 shows the expected dose response curves from a herbicide applied in a range of field conditions. The three lines show the average, best and worst performance. The recommended dose is chosen by the chemical company to minimize complaints of poor performance or crop damage and, thus, to provide the customer with the most reliable product possible. The curve shown in Figure 2 is hypothetical but it is supported by much field experience: for a recent example see Whiting *et al* (17). It provides a basis for discussion of the possibilities, almost the philosophies of optimizing dose.

Much of the farmer and researcher inspired dose cutting is based on the belief that an understanding of the factors controlling variation will allow doses to be reduced with zero or minimal risk of poor performance. Many have taken the concept further and attempt to adjust the dose to achieve a desired level of kill (1). This fits in with the concept of defining herbicide need set out earlier in this paper. Cussans, Cousens and Wilson (8) set out the economic effects of dose reduction on the threshold concept, using data on the control of *Avena fatua* by difenzoquat. The economic threshold is of course lower for reduced dose application but, because dose response is non-linear, the relationship between herbicide cost index (herbicide cost as a proportion of expected financial return from the crop) and the economic threshold was also shown to differ with dose. All of this assumes that we can predict herbicide performance and thereby eliminate the risk element shown in Figure 2. How realistic is this? Should we instead be encouraging rather more acceptance of risk of poor performance?

The two approaches of eliminating risk by predicting herbicide behaviour and accepting some increased risk are not mutually exclusive but both of them are a long way from the concept of buying a guaranteed performance at a nationally standardized dose. However, there is some conflict between two basic concepts. One suggests that we can best serve agriculture and the environment by regarding herbicides as commodities, with the farmer and his adviser being free to modify the prescription to suit local conditions. The other concept is that we must keep tighter control of pesticide application to ensure safety to consumer and environment and to achieve this by legally binding statements on labels. This dilemma must be resolved elsewhere but it does have a bearing on our discussions.

Towards an integrated approach

This has been an over-simplified review of the prospects. It is, however, vital that as an industry we move towards implementing these concepts. It is equally important that we realize how much further we have to go. Typically we do not possess the demographic data even on our most important species which will allow us to develop simple models as shown in Tables 1 and 2. For minor species we have almost no information but they may make just as much contribution to the overall herbicide use as some of the more obvious targets. Further, these models are simple and descriptive and we are a long way from truly predicting the behaviour of our weeds. Nonetheless, the challenge is there, we must meet it and we can only do so on the basis of further knowledge of our herbicides and our weeds. Knowledge which has to be employed against an understanding of the importance of husbandry techniques in the dynamics of weed populations and their control.

References

1. Baandrup, M. and Ballegaard, T. (1989). Three years field experience with an advisory computer system applying factor adjusted doses. Proceedings Brighton Crop Protection Conference - Weeds, 555-60.
2. Brain, P. and Cousens, R. (1990). The effect of weed distribution on predictions of yield loss. *Journal of Applied Ecology* 27, 735-42.
3. Cousens, R., Doyle, C.J., Wilson, B.J. and Cussans, G.W. (1986). Modelling t economics of controlling *Avena fatua* in winter wheat. *Pesticide Science* 17, 1-12
4. Cussans, G.W. (1970). A study of the competition between *Agropyron repens* (L.) Beauv. and spring sown barley, wheat and field beans. Proceedings British Weed Control Conference 331-6.
5. Cussans, G.W. and Wilson, B.J. (1975). Some effects of crop row width and seedrate on competition between spring barley and wild-oat (*Avena fatua* L.) or common couch (*Agropyron repens* (L.) Beauv.). Proceedings EWRS Symposium Status, Biology and control of grass weeds in Europe. 76-85.
6. Cussans, G.W. (1980). Strategic planning for weed control - A researcher's view. Proceedings 1980 British Crop Protection Conference - Weeds, pp 823-31.
7. Cussans, G.W. and Moss, S.R. (1982). The population dynamics of annual grass weeds. *In* 'Decision Making in the Practice of Crop Protection', British Crop Protection Council Monograph No.25 ed R.B.Austin.
8. Cussans, G.W., Cousens, R.D. and Wilson, B.J. (1987). Progress towards rational weed control strategies. *In* Rational Pesticide Use eds K.J. Brent and R.K. Atkin, Cambridge University Press.
9. Kudsk, P. (1989). Experiences with reduced doses in Denmark and the development of the concept of factor adjusted doses. Proceedings Brighton Crop Protection Conference - Weeds 545-54.
10. Pfeiffer, R.K. and Holmes, H.M. (1961). A study of the competition between Barley and Oats as influenced by Barley seedrate, Nitrogen level and Barban treatment. *Weed Research* 1, 5-18.
11. Hartmann, K.M. and Nezedal, W. (1990). Photocontrol of weeds without herbicides. *Naturwissenschaften* 77, 158-63.
12. Moss, S.R. (1985) The influence of crop variety and seed rate on *Alopecurus myosuroides* competition in winter cereals. Proceedings British Crop Protection Conference - weeds 701-8.
13. Moss, S.R. (1990). The seed cycle of *Alopecurus myosuroides* in cereals: a quantitative analysis. Proceedings EWRS Symposium 1990, Integrated Weed Management in Cereals.

14. Streibig, J.C. (1980). Models for curve fitting herbicide dose response curves. *Acta Agriculturae Scandinavica* 30, 59-64.
15. Streibig, J.C. (1984). Measurement of phytotoxicity of commercial and unformulated soil-applied herbicides. *Weed Research* 24, 327-31
16. Streibig, J.C. (1988). Weeds - the pioneer flora of arable land. *In* 'Ecological implications of contemporary agriculture'. Ecological Bulletins 39: 59-62. Copenhagen.
17. Whiting, A.J., Davies, D.H.K., Brown, H. and Whytock, G. (1991). The field use of reduced doses of broad-leaved weed herbicides in cereals. Proceedings Brighton Pest Control Conference - Weeds, 1209-16.
18. Wilson, B.J., Cussans, G.W. and Ayres, P. (1974). The effects of Tri-allate and Barban on the control of *Avena fatua* in spring barley, on the yield of barley and the presence of *A. fatua* seeds in the harvested grain. Proceedings British Weed Control Conference, 25-32.
19. Wilson, B.J. and Brain, P. (1991). Long-term stability of distribution of *Alopecurus myosuroides* Huds. within cereal fields. *Weed Research* 31, 367-74.
20. Wilson, B.J., Cousens, R.D. and Cussans, G.W. (1984). Exercises in modelling populations of *Avena fatua* to aid strategic planning for long term control of this weed in cereals. Proceedings 7th COLUMA-EWRS International Symposium on Weed Biology, Ecology and Systematics, 287-94.