

Non-chemical methods of weed control: benefits and limitations

Stephen R. Moss

Rothamsted Research, Harpenden, Herts AL5 2JQ, United Kingdom

Corresponding author: Stephen.Moss@bbsrc.ac.uk

Summary Non-chemical methods of weed control will become increasingly important in Europe due to a lack of herbicides, increasing resistance and a new European Union (EU) requirement for use of IPM. Compared with herbicides, non-chemical methods tend to be less effective, more variable, more expensive, may not reduce the requirement for herbicides, provide little visual evidence of success, may have adverse environmental implications and are often more complex to manage. Such control methods often have mean efficacy levels equivalent to a poor herbicide, but at a premium price. It is postulated that these reasons explain the limited uptake of IPM worldwide, not only for weeds, but for pests and disease control too. It is suggested that, if the primary objective of IPM within the EU is to reduce pesticide use, then it might be preferable to have this as a specific objective, rather than the more malleable concept of IPM.

Keywords IPM, IWM, weeds, *Alopecurus myosuroides*, cultural control, EU legislation.

WHY ARE WEEDS IMPORTANT?

In a review of crop losses due to pests, it was stated that: ‘overall, weeds produced the highest potential loss (34%) with animal pests and pathogens being less important (losses of 18% and 16%) (Oerke 2005). Herbicides accounted for 46% of global pesticide sales in 2005, with insecticides (26%) and fungicides (23%) accounting for smaller proportions of the \$33,600 million total spend (Agrow 2006).

THE INCREASING IMPORTANCE OF NON-CHEMICAL METHODS OF WEED CONTROL

While herbicides are considered the main means of weed control in many countries, there is increasing recognition that their use will have to be integrated with greater use of non-chemical methods. In Europe, the three reasons why farmers will have to adopt more non-chemical weed control methods are:

1. Fewer herbicides available due to past European Union (EU) regulatory actions, and lack of new modes of action.
2. Increasing resistance, especially in grass-weeds such as *Alopecurus myosuroides* Huds. (black-grass) and *Lolium* spp.
3. New EU regulatory actions requiring farmers to adopt Integrated Pest Management (IPM).

Availability of herbicides in Europe Past European Union (EU) legislation on pesticides (Directive 91/414/EEC) had a big impact on the number of pesticides available, from 945 active substances in 1999 to 336 (including new pesticides) in 2009, a 64% reduction. The majority were eliminated because dossiers were either not submitted, were withdrawn or the pesticide failed the review on issues relating to human health or the environment. Major herbicides no longer available in Europe include atrazine, paraquat, simazine and trifluralin.

Herbicide resistance In Europe, 62 weed species have evolved resistance to herbicides in a total of 21 countries. Of resistant species, 32% are grass-weeds, notably *Alopecurus myosuroides* Huds. (black-grass), *Lolium multiflorum* Lam. (Italian ryegrass), *L. rigidum* Gaudin. (annual ryegrass), *Avena* spp. (wild oats) and *Apera spica-venti* (L.) P.Beauv. (loose silky-bent). Resistant *A. myosuroides* is the major problem in many countries in western Europe, with resistance to ACCase inhibitors widespread in the UK and France, and increasing in several other countries.

The formulated mixture of the two sulfonylurea herbicides, mesosulfuron + iodosulfuron (‘Atlantis’), was introduced into France in 2002 and the UK in 2003, and is being used widely. In the UK, it was applied to 50% of winter wheat crops in 2008 (Garthwaite *et al.* 2008). Resistance to mesosulfuron + iodosulfuron had been identified in 293 populations of *A. myosuroides* in the UK by 2008 (Hull *et al.* 2008). ALS target site resistance (Pro197 and Trp574) has been confirmed in both the UK and France (Marshall and Moss 2008) and there is increasing evidence of enhanced metabolic resistance.

Increasing resistance, and the absence of any new modes of action, means that herbicide options for grass-weed control are being depleted rapidly. In the UK, the proposition that some degree of resistance occurs in all *A. myosuroides* populations regularly treated with herbicides, is not challenged by any of the major agrichemical companies.

New EU regulatory actions In 2009, a new Thematic Strategy for Pesticides was adopted by the EU and member states are currently in the process of determining how it will be implemented (CRD 2010).

The primary objective of the Thematic Strategy is to minimise the hazards and risks to human health and the wider environment from the use of pesticides. The Thematic Strategy consists of four pieces of legislation which, directly or indirectly, will affect pesticide use in all EU countries. These are:

1. Agrochemical Authorisation Regulation (EC 1107/2009). This concerns the placing of plant protection products on the market and introduces the concept of hazard assessment for the approval of active substances.
2. Sustainable use of Pesticides Directive (2009/128/EC). This promotes Integrated Pest Management and encourages non-chemical methods of plant protection in order to reduce dependency on pesticides.
3. Statistics Regulation (EC 1185/2009). This relates to pesticide sales and use statistics.
4. Machinery Directive Amendment (2009/127/EC). This sets standards for new pesticide application equipment.

INTEGRATED PEST MANAGEMENT (IPM)/ INTEGRATED WEED MANAGEMENT (IWM)

Despite there being over 65 existing definitions of IPM (Ehler 2006), the EU felt obliged to produce yet another: 'Integrated Pest Management means careful consideration of all available plant protection methods and subsequent integration of appropriate measures that discourage the development of populations of harmful organisms and keep the use of plant protection products and other forms of intervention to levels that are economically and ecologically justified and reduce or minimise risks to human health and the environment' (CRD 2010). Member states are required to produce National Action Plans setting quantitative targets and indicators aimed at reducing the impact of pesticides on human health and the environment. The implementation of Integrated Pest Management is obligatory, and low pesticide-input pest management must be promoted, with priority given to non-chemical methods of plant protection wherever possible. To encourage compliance, member states are required to determine appropriate penalties that are 'effective, proportionate and dissuasive' (CRD 2010).

Integrated Weed Management (IWM) can be considered one component of IPM, and has been described as the application of numerous alternative weed control measures, which include cultural, genetic, mechanical, biological and chemical means of weed control (Swanton and Weise 1991). However, Norris (2008) argues that, because IWM makes no attempt to integrate management of pests other than weeds, its use should be discontinued. He acknowledges that current IPM

programmes do not achieve this level of integration. This view is supported by perusing recent editions of IPMNet News, which has provided global Integrated Pest Management information since 1993. Very few articles feature more than a single pest category, and most deal with a single pest species.

THE POTENTIAL OF NON-CHEMICAL WEED CONTROL METHODS

Lutman and Moss recently completed a review of non-chemical methods for control of grass-weeds in the UK for Syngenta (unpublished). The weeds included were: *A. myosuroides* (black-grass), *Avena* spp. (wild oats), *Bromus* spp. (bromes) and *Poa annua* L. (annual meadow-grass). Most information was available for *A. myosuroides* in winter wheat and the results are summarised in Table 1.

Table 1. Non-chemical control of *A. myosuroides* in rotations based on winter wheat (number of comparisons in brackets).

Method (no. of comparisons)	% reduction achieved	
	Mean	Range
Ploughing (25)	67%	-20% to 96%
Delayed drilling (16)	37%	-64% to 82%
Higher seed rates (15)	30%	+8% to 53%
Competitive cultivars (4)	27%	+9% to 36%
Spring cropping (2)	80%	- ^A
Fallowing (1)	70%	-

^A – insufficient information.

Although this weed is mainly a problem in Europe, the levels of control achieved by the different non-chemical methods are likely to be broadly similar for other annual grass-weeds in many countries. Consequently the implications of these results are potentially of much wider relevance.

The results show that non-chemical control methods can give useful levels of weed control. They also highlight the great variability in efficacy between experiments, with negative control being possible. This can happen, for example, where mouldboard ploughing brings more seeds to the surface than it buries, with the consequence that the subsequent weed plant population is higher than where non-inversion tillage has been used.

THE LIMITATIONS OF NON-CHEMICAL WEED CONTROL METHODS

It is informative to present the mean efficacy results in a different way, pretending that they are actually herbicides, rather than non-chemical means of weed control.

On herbicide labels in the UK, weeds are given a rating of S (susceptible), MS (moderately susceptible), MR (moderately resistant) or R (resistant) depending on their response to that product. Note that ‘resistant’ in this case refers to the inherent insensitivity of the ‘wild type’ weed. The UK regulators data requirement handbook specifies the level of weed control expected for product label effectiveness claims (CRD 2010).

For a label claim of ‘susceptible’, consistent control of 85% and above is required generally, but for pernicious grass-weeds where seed return must be prevented, such as *A. myosuroides* and *Avena* spp., 95% is required. For label claims of ‘moderately susceptible’ and ‘moderately resistant’, the respective control levels are 75–85% and 60–75%. Less than 60% control means that the weed must be listed as ‘resistant’ on the label.

In Table 2, these criteria are applied to non-chemical control methods for *A. myosuroides*, and typical additional costs listed. The current costs per hectare of the two most widely used herbicides for grass-weed control in the UK are also included.

Table 2. Rating the effectiveness of non-chemical control methods for *A. myosuroides* on the same basis as herbicides.

Method	Label rating	Additional cost ha ⁻¹ £/€/NZ\$/Aus\$ [^]
Ploughing	MR	25/29/53/41
Delayed drilling	R	25/29/53/41
Higher seed rates	R	20/23/42/33
Competitive cultivars	R	potentially 0
Spring cropping	MS	high
Fallowing	MR	high – no crop
Meso.+ iodofluron (= ‘Atlantis’)	S	30/35/63/49
Pendimethalin (= ‘Stomp’)	S in mixtures	15/17/32/25

[^]Exchange rate used £1 = €1.15 = NZ\$2.10 = Aus\$1.64.

From this perspective, it is all too apparent that non-chemical control methods give, on average, levels of control that are very poor in comparison with herbicides. In addition, this poorer efficacy is not matched by correspondingly lower costs. It should come as no surprise that trying to ‘sell’ non-chemical control methods to farmers is such an uphill struggle.

WHY HAS IPM/IWM FAILED TO MAKE MORE IMPACT WORLDWIDE?

While there are undoubted cases of successful implementation of IPM and IWM, such as the ‘push-pull’

strategy for controlling pests and parasitic weeds of maize and sorghum in east Africa, there is a widespread view that neither has been adopted as widely as anticipated. For example, Ehler (2006) cites several references to support his view that there is little evidence that IPM, as originally envisaged, has been implemented to any significant extent in America, Western Europe or Asia. Sanyal (2008) states ‘IWM is still not widely adopted’. Bearing in mind that the integrated pest management concept was first promoted over 40 years ago, how can we explain this apparent failure in uptake?

We can consider why farmers are reluctant to adopt more non-chemical methods of weed control by using control of *A. myosuroides* in wheat crops in the UK as an example. I have summarised what I believe to be the key factors in Table 3. Some, but by no means all of these, have been mentioned by other authors trying to explain the lack of uptake of IPM (Ehler 2006, Wilson *et al.* 2009). I would contend that this list has much, much, wider relevance than control of a single weed in UK wheat crops. Indeed, I suggest that these factors provide a comprehensive explanation for the poor uptake of IPM worldwide, not only for weed control, but also for pest and disease control in many different crops. This may seem an ambitious claim, but it seems to me that, compared to non-chemical methods, pesticides are usually an easier, more reliable and cheaper option. Is it any wonder that farmers are reluctant to replace pesticides with non-chemical control methods which have mean efficacy levels equivalent to a very poor product, but often at a premium price?

A more detailed explanation of the factors listed in Table 3 is justified. Clearly, these are generalisations, and there will be exceptions to each of these factors.

Table 3. Reasons why farmers are reluctant to use non-chemical methods of weed control in place of herbicides.

1	More complex to manage – time constraints
2	Less effective than herbicides.
3	Control levels more variable.
4	More expensive than herbicides.
5	Control levels less predictable.
6	No compensation following control failure.
7	May not reduce the need for herbicides.
8	Little visible evidence of success.
9	More risky, to consultant as well as farmer.
10	Less return for supplier of herbicides.
11	May have adverse environmental effects.
12	Harder manual effort.

‘More complex to manage – time constraints’ If herbicides are replaced with several alternative methods, it is likely that the whole weed control programme will become more complex. The extra time needed to make management decisions may also be an important factor. The amount of time that can be spent, cost effectively, on weed related advice on any individual field is often very limited. In the UK, where most arable farmers use a crop consultant who advises on 4,000–6,000 ha of arable crops, it equates to, at most, 15 min ha⁻¹ year⁻¹ (Moss 2008). The situation will differ in other countries with different farm sizes and agronomic systems, but the general principle of limited time availability for weed control advice at an individual field level will often apply. The time and cost of travelling to each field, and cost of collating and analysing the data, needs to be considered. Such costs are nearly always ignored in research studies, but their omission raises serious questions about the economic validity of such studies.

‘Less effective, more variable, more expensive’ Tables 1 and 2 provide information supporting the view that non-chemical methods tend to be less effective, more variable and more expensive than pesticides for equivalent levels of efficacy. Although these relate specifically to *A. myosuroides*, I believe the principles are relevant to many other pest, disease and weed problems.

‘More unpredictable’ The control achieved by non-chemical methods can be very unpredictable. A technique that worked very well one year (e.g. delayed drilling to encourage weeds to germinate prior to sowing), may give very poor results in another year for reasons that are completely outside the farmer’s control (e.g. dry conditions may prevent any weed germination). Pesticides too can give variable and unpredictable control, but agrichemical companies commit substantial resources to maximising the consistency and performance of pesticides, which is usually superior to non-chemical methods.

‘No compensation following control failure’ If a pesticide fails to give adequate control, replacement or compensation from the supplier may be obtainable. This is common practice in the UK, provided that the pesticide has been applied correctly and in accordance with the recommendations. In contrast, compensation for failure of any non-chemical control method is highly unlikely, as it is much less obvious who is legally responsible.

‘May not reduce the need for herbicides’ None of the individual non-chemical control measures on their own can be expected to provide acceptable levels of weed control (Swanton and Weise 1991), so if herbicides still have to be used, a farmer may well question what has been achieved from the alternative methods. He, and his consultant, may have no clear idea whether any savings in herbicide use have been achieved.

‘Little visible evidence of success’ A farmer will usually have no idea how successful a non-chemical method has been at reducing weed populations. This applies to all the methods listed in Table 1. In field experiments, differences may be obvious because one can compare different treatments side by side. However, a farmer has, in effect, used a single treatment and cannot quantify its efficacy as he has nothing with which to compare it. With post-emergence herbicides (as with in-crop harrowing and hoeing), farmers can at least do some sort of ‘before’ and ‘after’ assessment. I believe this inability to quantify the efficacy of non-chemical control methods in commercial practice is a key, but largely unrecognised, factor responsible for the lack of adoption of IWM, and IPM more generally.

‘More risky to consultant as well as farmer’ For all the reasons given above, it seems obvious that use of non-chemical control methods can be considered ‘risky’. Farmers self-evidently need to minimise losses due to pests, diseases and weeds. Most farmers in the UK, as in many other countries, use a crop consultant or advisor for advice on crop protection. Some consultants are independent, purely supplying advice for a fee, while others are employed by agrichemical distributors who sell pesticides. Consequently, if use of non-chemical methods increase the risk of poor control, they are less likely to be promoted by independent consultants who need to maintain the confidence of their farmer clients.

‘Less return for supplier of herbicides’ If a farmer’s advisor is employed by an agrichemical supplier there will be an obvious, and even greater, conflict of interests than occurs with an independent crop consultant. The factors influencing decision making by farm consultants and advisors deserves greater recognition, as on many farms in the UK it is they, not the farmer, who makes many of the decisions relating to crop protection.

‘May have adverse environmental effects’ Few would deny that use of pesticides can harm the environment. However, some non-chemical methods can be in conflict with a requirement to protect the

environment. For example, mouldboard ploughing has advantages over reduced tillage systems for control of annual grass weeds. Conversely, reduced tillage systems are considered more sustainable in terms of soil and water conservation, carbon sequestration, mitigation of greenhouse gas emissions and maintenance of naturally occurring biocontrol agents (Holland 2004). Consequently, non-chemical control methods are not immune from causing adverse environmental effects.

‘Harder manual effort’ In highly mechanised farming systems, as in the UK, the relative manual effort of pesticide versus non-chemical approaches may be a relatively unimportant factor. However, it has some relevance in relation to hand roguing of weeds, such as *Avena* spp. In developing countries, the manual effort involved in hand weeding, as an alternative to using a knapsack sprayer to apply herbicides (e.g. glyphosate), may be all too apparent.

DOES IPM = REDUCED PESTICIDE USE?

One common aim of IPM and IWM is to reduce pesticide use. Sometimes this is stated explicitly, while in other cases the aims are vaguer, as in the recent definition of IPM by the EU (in full above), which aims to ‘keep the use of plant protection products and other forms of intervention to levels that are economically and ecologically justified’.

If the primary aim of IPM is to reduce pesticide use, then would it not be better to state this explicitly as the key objective? One could argue that other elements of IPM would then fall into place automatically. Whether this *should* be the primary aim, in a world with an increasing population and a finite land area subject to the negative consequences of global warming, must be questioned. It would certainly be easier to measure success or failure. For example, in the UK, pesticide usage surveys of arable crops show that the area sprayed with pesticides increased from 42.4 million spray ha in 1998 to 50.3 million spray ha in 2008, a 19% increase, whereas the weight of pesticides applied declined from 30,746 t to 18,758 t during the same period, a 39% decrease (Garthwaite *et al.* 2008). There are different views on whether such changes are ‘good’ or ‘bad’, but few would argue with the survey data. In contrast, assessing the success of IPM implementation is fraught with difficulty. Morse (2009) very appropriately, described the definition of IPM as ‘malleable’, with the consequence that different criteria can be used to serve different agendas, which can be used to ‘prove’ anything from 0% to 100% IPM compliance in the same farming system.

How successful member states of the European Union will be in assessing the success of IPM at

‘reducing the impact of pesticides on human health and the environment’, remains to be seen. Given that pesticides are subject to increasingly stringent approval procedures, it is highly unlikely that any benefits to human health will be proven. Success in achieving environmental benefits may be more likely, and will almost certainly be ‘claimed’, although linking these unambiguously with the new EU policy may prove rather more difficult.

TECHNOLOGY TRANSFER AND IPM/IWM

The successful implementation of an IWM system is highly dependent upon the efficient and thorough transfer of information and technology by education and extension. However, in the EU, most countries no longer have state extension services that could provide independent guidance and assistance to farmers and growers. Relying on commercial independent consultants and agrichemical distributors has its limitations, as detailed above.

In my opinion, there has been too much emphasis on research at the expense of extension. This is partly because extension is often seen as the ‘poor relation’ to research, attracting less funding and prestige. The pressure to publish, a result of misplaced academic elitism in many research institutions, means that the priority is the publication of results in ‘high impact’ journals, rather than ensuring any practical application.

It should never be forgotten that, however great the ‘impact’ of a publication, it achieves nothing in terms of improving our ability to manage pests, diseases and weeds until the information is actually used in practice (Moss 2008). ‘Knowledge without application is wasted’ is a succinct summary of this problem (Yeong 2009). Too much knowledge, not enough application is, perhaps, a concise explanation for the lack of uptake of IPM/IWM worldwide.

Morse (2009) stressed that, while research is an important part of the overall strategy, there must be greater recognition of what farmers are able and willing to ‘do’. This consideration needs to be central to the whole process, rather than added in, as so often happens, as an afterthought. A key aspect should be a greater recognition of the part played by farmers and their advisors in decision making.

Wilson (2009) found that farmers understand, but often do not practice IWM. However, he found that farmers do demonstrate the ability to effectively integrate education with experiential learning. Greater adoption of IWM may be achieved by greater attention to the farmer’s perspective, and by framing messages in a manner that coincides with the farmer’s experience and belief structure.

The practical issues were well described by Blackshaw *et al.* (2008) in a paper on the successful implementation of an IWM programme in Canada: 'Once viable IWM systems are developed, they must be demonstrated at the field level and a consistent message must be given by multiple people at multiple forums over multiple years. Patience is required by all involved, as meaningful change is usually a slow process.' Too often, it seems to me, insufficient time and resources are available to permit this 'slow process' of technology transfer. Indeed, the trend towards short-term projects, where the researcher's priority is often to identify sources of funding for follow-on projects, can only exacerbate this problem.

ACKNOWLEDGMENTS

Rothamsted Research receives grant-aided support from BBSRC, UK.

REFERENCES

- Agrow (2006). Global agrochemical market flat in 2005. *Agrow* No. 490, p. 15. (24 February 2006).
- Blackshaw, R.E., Harker, K.N., O'Donovan, J.T., Beckie, H.J. and Smith, E.G. (2008). Ongoing development of integrated weed management systems on the Canadian prairies. *Weed Science* 56, 146-50.
- CRD (2010). European Union issues and data requirements handbook. UK Chemicals Regulation Directorate (CRD) website: <http://www.pesticides.gov.uk/home.asp>.
- Ehler, L.E. (2006). Integrated pest management (IPM): definition, historical development and implementation, and the other IPM. *Pest Management Science* 62, 787-9.
- Garthwaite, D.G., Thomas, M.R., Parrish, G., Smith, L. and Barker, I. (2008). Pesticide Usage Survey Report 224: arable crops in Great Britain 2008. <http://www.fera.defra.gov.uk/plants/pesticideUsage/documents/arable2008.pdf> (accessed 16 August 2010).
- Holland, J.M. (2004). The environmental consequences of adopting conservation tillage in Europe: reviewing the evidence. *Agriculture, Ecosystems and Environment* 103, 1-25.
- Hull, R., Marshall, R., Tatnell, L. and Moss, S.R. (2008). Herbicide-resistance to mesosulfuron + iodosulfuron in *Alopecurus myosuroides* (black-grass). *Communications in Agricultural and Applied Biological Sciences (University of Gent, Belgium)* 73 (4), 903-12.
- Marshall, R. and Moss, S. (2008). Characterisation and molecular basis of ALS inhibitor resistance in the grass weed *Alopecurus myosuroides*. *Weed Research* 48, 439-47.
- Morse, S. (2009). IPM: ideals and realities in developing countries. In 'Integrated pest management', eds E.B. Radcliffe, W.D. Hutchinson and R.E. Cancelado, pp. 458-70. (Cambridge University Press, Cambridge, UK).
- Moss, S.R. (2008). Weed research: is it delivering what it should? *Weed Research* 48, 389-93.
- Norris, R.F. (2008). Integrated weed management, integrated pest management or integrated crop management? Proceedings of the 5th International Weed Science Congress, Vancouver, Canada. Abstract 543. (International Weed Science Society).
- Oerke, E-C. (2005). Crop losses to pests. *Journal of Agricultural Science* 144, 31-43.
- Sanyal, D. (2008). Revisiting the perspectives and progress of integrated weed management. *Weed Science* 56, 161-7.
- Swanton, C.J. and Weise, S.F. (1991). Integrated weed management: the rationale and approach. *Weed Technology*, 5, 657-63.
- Wilson, R.S., Hooker, N., Tucker, M., LeJeune, J. and Doohan, D. (2009). Targeting the farmer decision making process: a pathway to increased adoption of integrated weed management. *Crop Protection* 28, 756-64.
- Yeung, R. (2009). Personality: how to unleash your hidden strengths, p. 174. (Pearson Education Ltd. Harlow, UK).