ISSN 1392-3196
Zemdirbyste-Agriculture, vol. 95, No. 3 (2008), p. 103–109
UDK 632.51:632.954

RECENT ADVANCES IN WEED MANAGEMENT

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Abstract

In the future Integrated Weed Management (IWM) practices will have to be adopted by EU farmers not only as a result of the coming EU Thematic Strategy on Sustainable Pesticide Use but also to overcome the lack of effective herbicides and herbicide resistance. IWM implies, among other things, that other direct control methods than chemical control should be employed when feasible. In this review the recent advances in herbicide dose optimisation, non-chemical weed control, allelopathy and intelligent weed control technologies are presented.

Key words: herbicide dose optimisation, non-chemical weed control, allelopathy, intelligent weed control technologies.

Introduction

Weeds are a major constraint to the profitability of arable cropping causing the highest potential losses (34%) of all crop pests /Oerke, 2006/. Herbicides have been the mainstay of weed management for the last 50 years but stricter regulation on pesticides following an increasing public concern about side effects on human health and the environment, particularly in Europe, combined with the absence of herbicides with new modes of action will inevitable change this situation /Kudsk, Streibig, 2004/. The most evident consequence is the lack of effective pesticides in minor crops; however effects are also becoming apparent in major crops, particularly in relation to the control of resistant weed biotypes, e. g. *Alopecurus myosuroides* biotypes exhibiting metabolic resistance.

Until now, farmers in developed countries have relied more or less solely on chemical weed control and a lot of effort has been devoted to optimising herbicide use and developing more intelligent methods of herbicide application incorporating technologies for weed sensing and precision application of herbicides. In the future true Integrated Weed Management (IWM) practices will have to be adopted by farmers to overcome the lack of effective herbicides and herbicide resistance. IWM implies that other direct control methods than chemical control should be employed when feasible, that preventive and cultural methods should be part of the overall weed management strategy and that herbicides, if required, should be used judiciously.

In this short review it is not possible to cover all aspects of weed management and focus will be on new developments in optimisation of herbicide dose, non-chemical weed control and allelopathy and emerging intelligent weed control technologies.

Optimisation of herbicide dose

Herbicide labels contain the dose recommendations of the manufacturer and as agrochemical companies are liable if control is not satisfactory, label recommendations tend to reflect worst-case conditions. Hence, it is not surprising that herbicide doses can often be reduced below label recommendations under optimum conditions.

Herbicide performance is affected by many biotic and physicochemical factors and a basic understanding of the influence of the key factors is a prerequisite for optimising herbicide performance. Weed flora, growth stage of weeds, crop competitiveness, climatic conditions, application technique and performance in mixture with other pesticides are the most important parameters affecting herbicide performance /Kudsk, 2002/.

The response of weed species to herbicides varies from 0 to 100% effect, hence knowing the composition of the weed flora is crucial for optimising performance. Unfortunately identifying weeds particularly at the early growth stages is very difficult for most farmers and therefore a major obstacle for optimising herbicide dose. Furthermore, many farmers claim that weed mapping requires more time than is available in the spraying season. Hence, there is a need to develop alternative approaches for collecting information on the distribution of weeds and the composition of the weed flora in the field. One idea has been only to focus on selected key weeds but experiences from Denmark with such an incomplete weed mapping approach revealed that the potential for optimising herbicide dose was reduced significantly. The lack of an easy method for weed mapping is a major obstacle to the optimum use of herbicides and deserves more focus in the future.

It is well known that the performance of many herbicides is affected by climatic conditions before, during and after herbicide application. Climatic conditions affect the growth and physiological status of the weed and crop, the herbicide and the plant-herbicide interactions. Climatic conditions around the time of application are generally considered one of the key parameters affecting herbicide activity and the cause of much variation in herbicide performance.

Abundant information is available on the influence of climatic conditions; however most studies were done under controlled or semi-controlled conditions allowing for the manipulation of one climatic parameter while the others are kept constant. Such studies allow for a ranking of the climatic parameters but their relevance to practice is questionable as it is difficult to extrapolate the results to the more complex climatic situation in the field where climatic parameters fluctuate (e. g. temperature, humidity and light) and some climatic parameters interact (e. g. temperature and humidity). If results from studies under controlled conditions are to be implemented in practice to optimise herbicide dose it is important to be able to mimic natural conditions more precisely, e. g. using climatic simulators /Kudsk, 2002/. That climatic conditions can play a pivotal role is illustrated by the results from a joint experiment conducted by the EWRS Working Group on Optimisation of Herbicide Dose. The same cultivar of perennial ryegrass was grown at 18 locations within and outside Europe and treated with the herbicides iodosulfuron + mesosulfuron at growth stage 21–30. The estimated ED_{50} doses varied by a factor 8 and were primarily correlated to the temperature around the time of application.

In recent years, research on application technique has largely been devoted to reducing drift. Hydraulic nozzles minimising the risk of drift such as the air inclusion nozzles have replaced traditional flat fan nozzles and with the exception of small and erect targets, e.g. grass weeds at the 1- to 2-leaf stage these nozzles can replace the more drift-prone flat fan nozzles /Powell et al., 2002/. Recently it was reported that angling of the nozzles could increase the efficacy of foliar-active graminicides on weeds in the early growth stages /Jensen, 2007/. The improved performance could be explained by an increased deposition on the weed plants. Angling the nozzles could potentially increase the risk of drift as a result of the longer distance the droplet has to travel to reach the target, however due to the angling of the nozzles the boom height can be reduced from 50 to 25 cm which will reduce the risk of drift. Angling of the nozzles seems to provide a simple and inexpensive method to optimise the performance of foliar-active graminicides and hence to adjust the dose.

As mentioned previously, many factors may influence the performance of herbicides and for a farmer or advisor it is nearly impossible to determine the optimum dose. Due to the complexity, systems that can query large databases and perform calculations on the required dose are required. One example of such a decision support system is Crop Protection Online developed jointly by the Faculty of Agricultural Science at the University of Aarhus and the Danish Agricultural Advisory Service. More than 1600 validation trials have shown that Crop Protection Online can provide farmers with safe solutions with reduced herbicide doses. Nonetheless, herbicide use in cereals is almost twice the use compared to a situation where Crop Protection Online had been used by all farmers /Jørgensen, Kudsk, 2006/. In contrast, fungicide use in cereals is close to the level recommended by Crop Protection Online. The difference partly reflects the problems with mapping weeds etc. but it does also reflect that farmers tend to consider weeds as a long-term or chronic problem and a failure to control weeds effectively will cause problems in the subsequent crops, hence farmers tend to “go safe” to avoid future problems.

In the case that herbicides are required to provide effective weed control optimising herbicide dose is part of an integrated weed management strategy. It is, however, important to stress that reducing the dose reduces the herbicide use but not the dependence on herbicides although reducing doses and mixing herbicides may slow down the development of herbicide resistance

Non-chemical weed control

Increasing concerns about pesticide use and the need for weed control methods in organic farming have been major factors driving research on mechanical weed control methods /Melander et al., 2005/. In the future lack of herbicides in conventionally grown minor crops may become an even more important driver for the development of non-chemical methods.

The major challenge with mechanical weed control methods is the selective removal of weeds within the crop rows (intrarow weeding) whereas weeding between the crop rows (interrow weeding) can be done effectively with existing machinery. Effective weeding in the crop rows is important because weeds close to the crop cause the highest yield losses /Heisel et al., 2002/. Equipment for intrarow weeding includes torsion, finger and brush weeders as well as weeders using compressed air to blow away the weeds /Van der Weide et al., 2008/. Common for this equipment is that selectivity is poor and to operate safely crop plants should be larger and better rooted than the weed plants. In practice, this means that these non-chemical methods are most safe in transplanted crops.

A break-through for non-chemical methods for intra-row weeding requires that technology is developed that distinguishes between crop and weeds. The first example of such a machine has been commercialised in France for weeding in lettuce /Van der Weide et al., 2008/. A light beam is interrupted when it passes over the crop plants and based on these interruption a hoe is moved in and out of the crop row. The existing version requires that the crop plants are taller than the weed plants.

Non-chemical weed control (harrowing) has also been used in combination with herbicides with the objective to reduce the need for herbicides. The effect was comparable to herbicides alone but the reduction in herbicide costs did not justify the costs of an additional treatment.

Another non-chemical technology that could become of interest in particularly high-value crops is laser. Early research using laser to cut the stems of weed plants revealed that the energy input required was very high. Recent research targeting the apical growing point has shown that weeds can be effectively controlled with significantly less energy input /Mathiassen et al., 2006/ and in an ongoing research project the use of laser for weed control is further studied.

Allelopathy

Plant-plant allelopathic interactions have been studied for many years with the objective to improve weed management practices. The purpose of much of the research has been to identify phytotoxins that could serve as templates for new herbicides as phytotoxins often provide new modes of action and therefore could help to overcome the increasing problems with herbicide resistance. Besides isolating phytotoxins, allelopathy can be exploited by cultivating crops with allelopathic properties, intercropping allopathic plant species with crops or using allelopathic crops as green mulch /Fomsgaard, 2006/.

Much focus has been devoted to plants belonging to the *Cruciferae* family containing glucosinolates and cereals, particularly rye, containing benzoxazinone derivatives. Both groups of allelochemicals have been shown to have effects on weeds particularly on germination and root growth /Brown, Morra, 1995; Mathiassen et al., 2006/, however the inherent activity is low compared to synthetic pesticides. It has been stated that allelopathic activity is nearly always due to the effects and joint action studies with benzoxazinone derivatives and phenolic acids have shown that allelopathic compounds act additively or are antagonistic whereas synergistic interactions seems to be rare /Jia et al., 2006/. The modes of action of most allelochemicals are unknown although and it has been suggested that benzoxazinone derivatives act by multiple mechanisms /Reigosa et al., 2004/. Recent research on *Arabidopsis* has shown that the numerous genes are either down- or upregulated when exposed to the benzoxazinone derivatives BOA (Duke, pers. com.) supporting the assumption that the compound have multiple effects on plants.

Allelopathy has attracted more attention in recent years as it offers an intriguing alternative or supplement to the use of synthetic herbicides. In the coming years two developments can be anticipated. Firstly, allelopathic crops could be cultivated between crops and used as green mulch. Soil incorporation of allelopathic crops cannot replace herbicides but could reduce the need by inhibiting weed growth thereby increasing crop competitiveness. This would comply with the principles of IWM and additionally such an approach could reduce the loss of nutrients. Secondly, it can be anticipated that breeders will devote more attention to breeding allelopathic crops. Transgene technology could provide a powerful tool to reach that goal.

Intelligent weed control technologies

Weeds are not uniformly distributed in the field and the spatial heterogeneity of weeds has been studies by many researchers /Mortensen et al., 1998; Rew, Cousens, 2001/ and systems for spatial application have been developed /Giles et al., 2004; Gerhards, Obel, 2006/. Although most studies have revealed a significant potential for reducing herbicide and progress has been made in sensing, weeding and spraying technologies, there are few examples of commercial successes. In a review on real-time weed sensing, decision-making and patch spraying in maize, sugar beet, winter wheat and winter barley Gerhards & Christensen (2003) concluded that the main barrier was the balance between the potential savings and the cost of weed sensing. In an attempt to overcome this barrier focus has been shifted towards more generally applicable intelligent weed control technologies (IWCT) consisting of a weed sensing unit, a weed management model taking the decision to treat or not to treat and a precision weeding instrument.

Currently several IWCT are being developed and tested in Denmark representing different weed management scales. One system is the cell sprayer where the resolution is adapted to the spray nozzle (10 x 10 cm). The working principle is that only cells in which weeds are detected will be treated. Simulations have shown that the potential herbicide savings with a cell sprayer in maize sprayed 3 times with a selective foliar-active herbicides varied from 19 to 72% depending on the weed density (110 to 600 plants m^{-2}) with the lowest savings at high densities /Lund et al., in press/.

Another IWCT under development is a single droplet applicator working with a resolution or cell size of 1 x 1 cm /Mathiassen et al., 2008/. The system consist of a weed sensor and an application unit delivering in the range of 0.5 to 1.0 µL spray solution per plant. The single droplet applicator will only target weed plants, i. e. it will be possible to use a non-selective broad-spectrum herbicide like glyphosate. Experiments using pot-grown plants have shown that many weed species can be controlled by a glyphosate dose of just 1 ug $plant^{-1}$. Some weed plants will be present in more than one cell and will therefore be targeted more than one time. Assuming a density of 200 plants m^{-2} and that each weed plant is treated twice with a dose of 2 ug glyphosate the total dose required per hectare would be just 8 g ha^{-1}. Compared to a recommended dose of glyphosate of 360 to 540 g ha^{-1} for the control of annual weeds the potential savings are very significant.

Another advantage of the singlet droplet applicator is that herbicide deposition on the soil surface will be reduced to a minimum; hence the risk of leaching to the groundwater or surface runoff into streams and lakes is significantly reduced.

It should be stressed that the single droplet applicator could be equipped with other precision weeding instrument than a droplet generator, e. g. a laser unit or a mechanical device as on the French system developed for lettuce.

Conclusions

New solutions are required to manage weeds assuming a future scenario with fewer herbicides and, in particular, modes of action available to farmers. In a future scenario it can be expected that weed management will involve several technologies and not rely solely on the use of herbicides. If herbicides are required to manage a weed problem, they should be used more judiciously than today. Finally, although not included in this review, it must be stressed that preventive and cultural methods will continue to be important elements in any integrated strategy.

Acknowledgements

The author would like to thank the organizers of the international conference "Advances in new plant protection strategies" for the invitation to present this paper.

Received 2008-07-04
Accepted 2008-08-22

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