PHYSICAL AND CULTURAL WEED CONTROL – STATUS AND FUTURE DIRECTIONS

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ABSTRACT: Non-chemical methods for weed control play an important role for the management of weeds in organic cropping systems in Europe. With the expansion of the organic area in recent years, more research has been conducted to develop new methods and improve management strategies. Currently, weed harrows, rotary cultivators and inter-row cultivators are the principal methods used for full-width treatments in large agricultural crops, such as cereals, oil seed rape, maize and pulses. The mechanical methods are often combined with cultural measures, e.g. stale seedbeds, delayed sowing, placement of fertilizers etc., to benefit from the additive and sometimes even synergistic effects of combining direct and cultural methods. In row crops, such as sugar beets and horticultural crops, thermal and mechanical methods are mostly combined to remove as many weeds in the rows as possible in order to minimize the need for manual weeding. Weeds growing between the rows are easily controlled by inter-row cultivation. Robotic weeding for intra-row weed control is now possible for transplanted crops, and inter-row hoes have been equipped with GPS-systems and cameras for optimizing precision and steering. Works on new GPS technology is currently focusing on seeding systems with the ability to create parallel or diamond crop establishment patterns, which enable inter-row hoeing to be conducted in different directions. So far, non-chemical methods have had little uptake in conventional farming but national and EU-based legislative initiatives may change the situation radically in the near future. Several European countries have launched pesticide action plans and the EU a new directive for the implementation of integrated pest management (IPM); all aiming for minimizing the reliance on herbicides. This is expected to accentuate the need for non-chemical methods.

Keywords: mechanical methods, thermal methods, robotic weeding, camera steering

INTRODUCTION

Preventive, cultural and physical methods for weed control have gradually moved into the European agricultural sector in recent years and become management options that may expand further in the future. The change of focus from herbicides to more sustainable solutions has been driven by political awareness about side effects of herbicides and the need for regulations. Also an increasing conversion to organic farming, favourably subsidised by some European countries, has plaid a significant role. Research projects have been granted to develop non-chemical weed management in horticultural and agricultural crops. Considerable scientific publications have been produced and a European network (www.ewrs.org/pwc) discussing and disseminating information about non-chemical weed management was established in 1994 and is still operating. A wide range of direct physical methods (*i.e.* those used directly in the crop after the crop is either transplanted or sown) have been introduced and studied, some of which employ new principles (e.g. automated intra-row cultivation), while others employ old principles (e.g. weed harrowing) that have been subjected to new research. Physical weed control cannot act as a stand-alone treatment but has to be supplemented by preventive and cultural methods (MELANDER et al., 2005). Preventive and cultural methods have thus been important elements in research with a particular interest for their interactions with direct methods.

Still, non-chemical methods have had little uptake in conventional farming but national and EU-based legislative initiatives may change the situation radically in the future. Several pesticide action plans have been launched since the late 1980s in Denmark, all asking for a gradual reduction in herbicide use (JOERGENSEN & KUDSK, 2006). Similar action plans with analogous goals have recently been introduced in Germany, France and the Netherlands. On top of this, the EU has recently passed a directive that imposes on each member state the initiation of measures that will push crop protection towards integrated pest management (IPM) solutions (EU directive 2009/128/EC; HILLOCKS, 2012). In brief, this means that non-chemical methods should be used whenever feasible and necessary precautions should be taken to prevent excessive pesticide inputs. Cropping systems should be modified to minimize reliance on pesticides so that reduced treatment frequencies and herbicide dosages would suffice.

This paper reviews the status of non-chemical weed management in European arable cropping systems and comments on the future directions.

PREVENTIVE MEASURES

Crop rotation

Crop sequencing is a key-component in organic and low-input cropping systems for satisfactorily weed management. Crop choice and the sequence in which they are planned to follow one another have a great impact on the weed flora (BLACKSHAW et al., 2007). Crops have different growth cycles ranging from annual or biennial to perennial crops of different duration and with different seasons of establishment. The crop rotation strongly determines the growing conditions for weeds depending on the composition of crops; some weed species are favoured while others may be disfavoured. Weed control options are also linked to crop choice, and the spectrum of control tactics and active ingredients of herbicides usually expands with the diversification of the crop rotation (MELANDER et al., 2005).

Diversifying crop rotations usually leads to a diversified weed flora that prevents specific and noxious weed species from becoming severe weed problems. This has been verified in several studies but mostly where inverting tillage has been the primary method for crop establishment (e.g. ANDERSSON & MILBERG, 1996, 1998; MEISSLE et al., 2010). The inclusion of a fodder crop, repeatedly mown, may further reduce weed pressure as compared to rotations entirely composed of cash crops (SCHWARZ & MOLL, 2010). Whether tillage or crop rotation exhibits the strongest impact on the weed community depends on the diversification of the crop rotation. An unwanted weed flora developed under a specific tillage scheme can only be changed if the crop rotation is markedly diversified from the crop choices of previous years, unless tillage practices are changed (e.g. BARBERI & CASCIO, 2001; TEASDALE et al., 2004). The significance of modifying the crop sequence is particularly important in non-inversion tillage systems because these systems tend to select for weed species having short-persisting seed banks that are more likely to be affected by diversification of the crop growth cycles (CHAUVEL et al., 2011). The ultimate goal of crop sequencing from a weed management perspective would be to disrupt the weed seed bank community assuming to result in a more balanced and manageable weed flora. However, weed management purposes may easily clash with economic interests as very profitable crops sometimes have to be replaced by less profitable ones to achieve sufficient crop diversification.

Enhancement of crop growth

Crop growth can be manipulated in various ways to augment its suppressive ability against weeds. Organic growers take advantage of methods that can increase crop performance to improve the outcome of weed control interventions (MELANDER et al., 2005). A gradual change of herbicide based weed control towards IPM concepts will inevitably involve factors that can strengthen crop growth relative to weed growth. Especially fertilizer placement, crop variety choice, crop density and spatial arrangement and crop sowing time are relevant in this context.

Placement of mineral fertilizer and injection/placement of nutrients into the soil at the time of sowing of spring-sown cereals can improve crop competitiveness, effectiveness of mechanical and chemical weed control and crop yield (RASMUSSEN, 2002; RASMUSSEN et al., 1996). The crop gains an initial competitive advantage over weeds because nitrogen is taken up at higher rates than weeds due to nutrients being placed closer to the crop seeds.

Weed seeds capable of producing viable plants are more superficially placed in the soil and thus further away from the nutrients.

CHRISTENSEN (1994) found considerable difference in the herbicide dose needed to attain a certain weed control level among different winter cereal crops and among different varieties within crops. Barley varieties can be indexed for their suppressive ability against weeds based on just four varietal growth traits: reflectance, leaf area index, leaf angle and culm length (HANSEN et al., 2008). Indexation for competitiveness could be relevant as a standard practice in regular screening programmes of cereal varieties. The suppressive ability of a cereal variety can be further improved by increasing crop density and spatial uniformity (OLSEN et al., 2005).

Delaying sowing time of winter cereals may reduce weed pressure and improve crop growth relative to weed growth whereby weed fecundity and weed impact on crop growth are reduced (MELANDER, 1995; RASMUSSEN, 2004). Delaying the sowing date of winter cereals, however, is always a balance between risking a yield penalty and savings in weed control inputs.

DIRECT NON-CHEMICAL CONTROL METHODS

Direct control methods are regarded as those that can be used directly in a growing crop from the time of crop seed germination until crop harvest. Mechanical and thermal methods play a significant role in organic cropping systems but few methods have been taken up in conventional crop production owing to insufficient feasibility. Lower efficacy, higher costs and less ease of application as compared to herbicides are usually the major explanations brought forward (MELANDER et al., 2005).

Mechanical Control

The loosening, uprooting and burying mechanisms caused by cultivation can affect weed plants lethally depending on timing and intensity of application (KURSTJENS & KROPFF, 2001; TERPSTRA & KOUWENHOVEN, 1981). Weed harrowing with flex tine harrows in small grain cereals and pulse crops have been studied intensively for the past twenty years (MELANDER et al., 2005; RASMUSSEN et al., 2010). It is an important control tactic for broadcast-sown crops in organic farming. Its weeding effectiveness is inversely related to weed growth stage at the time of treatment and the avoidance of crop injuries relies on conditions for selective conduction and operators skills. Few attempts have been made to adopt the techniques to a non-inversion tillage systems, usually resulting in major drawbacks such as crop residues plugging the implement, soils difficult to till, high abundances of weed species being more tolerant to harrowing, notably grasses, and poor crop competition to suppress residual weeds after harrowing (BARBERI et al., 2000; JOHNSON et al., 2007).

Rotary hoes with two gangs of hoe wheels rolling on the ground are widely used in North America even by conventional growers (CLOUTIER et al., 2007). The implement is gentler to the crop as compared to flex tine harrows where settings can be more aggressive. However, rotary hoes are mainly effective against weeds at the white thread stage with effectiveness declining rapidly as weeds develop. The time span in which weed control can be made is narrower than with flex tine harrows. Rotary hoes have very little use in European agriculture, but they appear to have more relevance for non-inversion tillage systems than flex tine harrows. According to JOHNSON et al. (2007), rotary hoes can be modified to operate in the presence of crop residues and may become a useful tool to supplement reduced herbicide inputs in reduced tillage systems. Ground-driven and rotating weeding devices are also known to operate successfully in maize cropping. Especially gangs of wheels (e.g., ‘spiders’ (curved teeth)), finger weeders mounted on inter-row cultivators and disk hillers can be used for both inter-row and intra-row weed control: however, the results of the latter are strongly dependent on the conditions for selective application (CLOUTIER et al., 2007; VAN DER WEIDE et al., 2008).

Inter-row cultivation has common employment in row crops in both conventional and organic farming (MELANDER et al., 2005). Inter-row hoeing has even been studied for small grain cereals grown at an increased row spacing of typically 20 to 25 cm to allow the hoe blades to operate selectively between the cereal rows. However, row widths less than 20 cm would normally cause a yield penalty and intra-row weeds remain almost unaffected after treatment (MELANDER et al., 2003). Increasing the crop seed rate to increase plant density may provide more suppression of intra-row weeds. However, weed species having high growth rates and an erect growth habit usually overcome this and may shed seeds. Further narrowing row width would help improving crop competition against weeds but maintaining accurate steering then becomes critical (MELANDER et al., 2001). Nevertheless, BONIN et al. (2010) was able to conduct inter-row hoeing at 15 cm row spacing in winter wheat at a forward speed of 10 km h^{-1} using a camera-based guidance system for steering.

Inter-row cultivation in winter oil seed rape is currently far more promising than in cereals. Row spacing can be increased from the normal width of 12.5 cm to 50 cm without compromising yield, and modern inter-row hoes can be automatically steered by cameras (PEDERSEN & PETERSEN, 2011). The cultivators are mounted with goosefoot shares that effectively control inter-row weeds with one or two passes in the autumn and sometimes another pass in early spring depending on the weed pressure (KRISTENSEN, 1997). Intra-row weeds are less problematic than in cereals because the suppression inflicted by the crop is larger.

A new technology capable of precise placement of crop seeds is underway that has evolved from previous works on electronic crop seed mapping (e.g. GRIEPENTROG et al., 2005). The technology uses GPS technology to create parallel or diamond crop establishment patterns, which enable inter-row hoeing to be conducted in different directions, for example 90^{o} offset to the seeding direction. This might become a significant progress for mechanical control of intra-row weeds in row crops.

Thermal Control

Temperatures in the range of 55 to 95^{o}C are lethal for leaves and stems as the heat causes denaturation and aggregation of cellular proteins and protoplast expansion and rupture (ASCARD et al., 2007). Aboveground plant growth is easily terminated by heat, the exact effect mainly depending on temperature and exposure time. However, belowground propagules and to some extent protected growing points remain unaffected, usually resulting in renewed weed growth with the need for subsequent treatments. Only soil steaming can provide longer lasting control (ASCARD et al., 2007). Flaming, hot water and steam are the primary heat sources for weed control purposes and are used in horticultural crops, greenhouses and on hard surfaces in amenity areas. Flaming is the most commonly used thermal method in organic field horticultural crops, predominantly applied as a pre-emergence treatment in slow germination vegetable crops (MELANDER et al., 2005).

Thermal methods are generally energy demanding, have low work rates and relatively high purchase costs and may require multiple treatments for satisfactory control, and flaming may cause fires under certain circumstances (ASCARD et al., 2007). So far, no thermal methods have demonstrated any potential for use in larger agricultural crops such as cereals, pulses and oil seed rape. ULLOA et al. (2010) found that post-emergence broadcast flaming in winter wheat was too detrimental to the crop and only propane gas consumptions known to be ineffective against weeds could be tolerated. In maize, however, weed effective propane gas dosages can be used for broadcast flaming at the five-leaf growth stage with an acceptable impact on the crop (ULLOA et al., 2011). Post-emergence broadcast-flaming at early growth stages (1 to 5-leaf stage) supplemented by inter-row cultivation is currently applied on more than half the area grown with organic fodder maize in Denmark (The Danish Knowledge Centre 2011).

Future directions

A major problem with many physical methods is that they do not distinguish between weed and crop plants and need to be steered accurately or used in particular robust crops to avoid severe crop injuries. New and advanced technologies are regarded highly important for solving problems with poor selectivity. The GPS technology for the creation of specific seeding patterns mentioned above would mean a major step forward, not only for the typical row crops but also for full-width sown arable crops. Other advanced technologies with the ability to automatically detect and classify crop and weeds for guiding a weeding devise, operating in the intra-row area of row crops, could also improve problems with limited selectivity. Thereby unwanted crop injuries from weeding tools can be avoided, meaning that intra-row weed control can be conducted with high selectivity (VAN DER WEIDE, et al., 2008). Three new robotic weeders have been introduced on the European market, namely *Robocrop* from England (http://www.garford.com/inrow.html), *Steketee IC* from the Netherlands (http://www.steketee.com/product/Steketee-IC) and *Robovator* from Denmark (www.visionweeding.com). These systems are vision-based where cameras mounted on the implement are capable of analysing images of the crop immediately in front of the weeder. Thereby the weeding tool can be guided to work a certain area around each crop plant without impacting the crop. The first experiences look promising when operating in transplants with abundant space between crop plants. Still, more data on work rate and operational reliability when operating in the close proximity to the crops plants are needed before making more solid evaluations of their potential for row crops.

Band-steaming is regarded as the most promising method for row crops having dense crop stands in the rows with little spacing between individual crop plants (MELANDER & KRISTENSEN, 2011). Current weeding robots are not likely to become operational in such situations unless new technologies turn up. However, any modifications of the band-steaming technology that could reduce the energy input, including changing the energy source from fossil energy to biofuels, should have high priority in future research. Although band-steaming is currently accepted in Danish organic farming, the technology is still controversial in view of potential climate change and the desirability of reducing greenhouse gas emissions.

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