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Precise tillage systems for enhanced non-chemical weed management

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Abstract

Soil and residue manipulation can assist weed management by killing weeds mechanically, interfering in weed lifecycles, facilitating operations and enhancing crop establishment and growth. Current tillage systems often compromise these functions, resulting in heavy reliance on herbicides, particularly in no-till systems. Herbicides are an exhaustible resource, so new approaches to merge soil conservation and non-chemical weed management are needed. This paper broadly reviews various preventive and curative non-chemical weed management tactics. It also demonstrates how innovations can be derived from functional requirements of weed management operations, and from biological processes and weaknesses in weed's lifecycles. Mechanical weeding and enhancement of weed seed mortality are highlighted as examples. Major limitations with mechanical weeding include limited weed control in crop rows at early vulnerable crop stages, weather-dependent effectiveness, and difficulties in handling crop residues. Precise steering and depth control, improved seedbed friability and lighter tractors or controlled traffic could bring considerable improvements. To expose weed seeds to predators, position them for fatal germination, viability loss or low emergence may require completely different soil displacement patterns than those of current implements and systems. Controlled traffic and precise strip tillage offer good opportunities for implementing these weed management strategies in minimum-tillage systems.

Keywords: Mechanical weeding; Cultural control; Controlled traffic; Strip-tillage; Integrated weed management

1. Introduction

The available wide range of effective herbicides has been a key to the successful development and wide adoption of simplified, cost-saving and soil-conserving tillage systems (Lyon et al., 1996; Denton and Tyler, 2002). Herbicide reliance and non-chemical weed management have remained inferior issues in tillage research, as new herbicide development, improved application technology and herbicide-tolerant crops have strengthened the belief that new technologies will solve future weed problems (Bradley, 2002; Llewellyn et al., 2002; Tranel and Wright, 2002).

However, several developments challenge this assumption. In several countries, consumer aversion towards pesticides and their negative environmental impacts have resulted in serious governmental restrictions on herbicide availability and use in the European Union (EU) (e.g., EU Agricultural Pesticides Directive 91/414/EEC; Watts and Macfarlane, 1997). In the EU, the reduced number of registered formulations is already problematic in several minor crops (Gillott, 2001; Buffin et al., 2003). The costs to discover, develop and register a new agrochemical have increased dramatically, from 25 M€ in 1975–1980 to 200 M€ in 2000 (McDougall and Phillips, 2003). This and heavy competition in a

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saturated, shrinking herbicide market will probably sustain the declined herbicide innovation rate observed over the past decade (Kalaitzandonakes and Bjornson, 1997; Shaner, 2000). As the rapid adoption of herbicide-tolerant crops indicates great market opportunities, agrochemical companies will probably focus on developing transgenic crops that exploit current herbicides (Cobb and Kirkwood, 2000).

Despite the availability of many different products, present herbicides exploit only 15–20 different modes of action (Cobb and Kirkwood, 2000), whereas only one new target site has been commercialised in the last 20 years (Llewellyn et al., 2001; Gressel, 2003). Herbicide resistance has occurred in all known target sites, presently involving 310 weed biotypes, including 10 glyphosate-resistant weeds (Heap, 2006). The increased incidence of resistance (over 100 new resistant biotypes in the last decade; Heap, 2006) is largely attributable to the use of monocultures, reduced cultivation and persistent chemicals (Cobb and Kirkwood, 2000). Repeated use of few modes of action fosters weed resistance development and shifts in weed species composition (Shaner, 1995; Powles et al., 1997), which in turn narrows the effective range of chemical weed control options, thus increasing selection pressure further. Weed communities have shifted within 5–8 years of spraying glyphosate (Shaner, 2000; Hartzler and Owen, 2003), so that increased rates and other herbicides are required to control tolerant weeds. It is questionable whether new alternatives will become available, as compounds competitive to glyphosate are very rarely discovered (Baylis, 2000; Shaner, 2000). As the time between synthesis and sale of a new agrochemical is on average 9 years (McDougall and Phillips, 2003) or more (Fernandez-Cornejo et al., 1998), it is crucial to slow down weed species shifts and resistance development by, e.g. weed seed collection (Matthews et al., 2004), delayed sowing, increased seed rates and tillage (Cavan et al., 2000; Neve et al., 2003).

Although many scientists consider herbicide efficacy an extremely valuable (Gianessi and Sankula, 2003) and exhaustible resource that should be sustained proactively (e.g., Lyon et al., 1996; Cobb and Kirkwood, 2000; Llewellyn et al., 2001), farmers generally prefer simplified herbicide-based cropping systems and insufficiently anticipate resistance (Lemerle and Sutherland, 2000; Hartzler and Owen, 2003). The complexity and skill involved in the integration and appropriate use of multiple tactics contrast strongly with the flexibility and convenience of chemical weed control.

Most studies aiming at reducing herbicide reliance have focussed on combining herbicides with cultivation (Van der Weide et al., 1993; Mulder and Doll, 1994; Burnside et al., 1994) and weed-suppressive cover crops, residues or living mulches (Teasdale, 1996; Yenish et al., 1996; Brandsaeter and Netland, 1999) in existing tillage systems. Modifying tillage systems to facilitate adoption of a more diverse range of tactics has received little attention, but could be pivotal to the sustainability of conservation tillage.

This paper reviews the applicability of non-chemical weed management tactics in different tillage systems, clarifying the general needs for tillage system adaptation. It outlines the prospects of tillage innovations that facilitate weed management tactics, exploit weaknesses in weed life cycles and integrate non-chemical weed management with soil conservation through precise guidance and spatial diversification.

2. Applicability of non-chemical weed management tactics

2.1. Applicability as related to management systems

In tillage system design, the key issue is to maximise the number of methods (i.e., weed management tactics) that could be effectively and flexibly applied, to fit a wide range of conditions and allow for easy adaptation of weed management over time. Methods could include opportunities to (1) manage living or dead mulches, (2) carry out shallow cultivations, (3) disrupt rhizomes of perennial weeds, (4) bury weed seeds at depths from which they cannot emerge and (5) enhance crop competitiveness. Their applicability and effectiveness depend on climate, farm size, weeds, crops and management system.

A management system involves tactics that manipulate soil and residues in defined spatial management units (i.e., field, strip/zone or patch) over time. In Table 1, a method's applicability for management systems is determined by the properties of a management unit (i.e., surface flatness, soil structure, residue quality, residue amount, soil structure, crop presence) at the time of application. Management units might be generally categorised as: bare (eliminating all residue interference), mulch (allowing some soil disturbance) and no-till (no soil disturbance). A field may have multiple management units types present either spatially (e.g., strip tillage), or temporarily (e.g., no-till fallow/planting, followed by inter-row cultivation). Ridge till systems allow crop residues and seeds shattered on the soil surface to be moved to the inter-row zones, thus creating a bare ridge unit and a mulch furrow unit (Forcella and Lindstrom, 1988).