Enhancing Non-Chemical Weed Management – How Soil Tillage Research Can Contribute

Dirk Kurstjens, Wageningen University, Soil Technology Group,
P.O. Box 43, 6700 AA Wageningen, the Netherlands, dirk.kurstjens@wur.nl

Abstract: Tillage can help maintain weed populations at a low and stable level directly by killing or damaging weeds, or indirectly by improving the achievable performance and timeliness of operations, enhancing the establishment and growth of a competitive crop, and by interfering at other points in weed lifecycles. Two areas where soil tillage research can help reduce herbicide reliance of weed management are highlighted: mechanical weeding and enhancing weed seed mortality. This paper considers the following questions: 1) Can required tactics be accomplished in current tillage systems? 2) What tillage system improvements would provide better opportunities for mechanical weeding and reduced weed emergence? and 3) how can non-chemical weed management be merged with soil conservation?

Major limitations with mechanical weeding include limited weed control in crop rows at early vulnerable crop stages, the weather-dependent effectiveness and workability, and difficulties in handling crop residues. It is expected that precise steering and depth control of intra-row tools, improved seedbed friability and using light tractors and controlled traffic would bring considerable improvements.

To exploit the potential of exposing weed seeds to predators at the soil surface and disposing the remaining seeds in a position with high fatal germination, high seed viability decline and low emergence probability, completely different soil displacement patterns may be required than those created by current implements and tillage systems. High-precision strip-tillage could extend the period of weed seed decay and reduce weed emergence by burying weed seeds in narrow vertical slots.

Managing residues and living mulches is an important topic in weed management. As mouldboard plough systems generally facilitate a wider variety of non-chemical tactics than conservation and no-till systems, non-chemical weed management and soil conservation appear contradictory. However, controlled traffic and precise strip tillage might offer opportunities to merge mechanical and thermal control, enhanced weed seed mortality and maintaining residues.

INTRODUCTION

The availability of effective herbicides has allowed tillage systems development to focus on other issues than weed management. For example, conservation tillage and no-till systems have reduced erosion risks, soil structure degradation, moisture and carbon losses and energy consumption as compared to mouldboard plough based systems. In many cases however, conservation tillage and no-till systems have consolidated or aggravated the reliance on herbicides, as several weed-preventive and non-chemical tactics became more difficult to apply or became less effective.

The increased herbicide reliance is increasingly problematic because the declining development rate of new herbicides and the repeated use of few modes of action (e.g. in herbicide-tolerant crops [Darmency 1996]) increases risks of herbicide tolerance [Powles et al. 1997, Kudsk and Streibig 2003]. In many countries, consumer aversion towards pesticides and negative environmental impacts has resulted in serious governmental restrictions on herbicide availability and use. These developments are a threat to soil-conserving tillage practices as long as they remain heavily herbicide reliant. Enhancing non-chemical weed management options is needed to sustain the effectiveness and availability of key herbicides in the long term, so they could still be used as a emergency backup when other weed management tactics fail.

This paper uses two perspectives to examine how soil tillage can reduce herbicide reliance. The first considers the compatibility of various non-chemical weed management options with current tillage practices. The second identifies tillage requirements of two important non-chemical tactics: mechanical weeding and enhancing weed seed mortality. It examines the functions of soil tillage from a weed management perspective. This approach may bring up new ideas for developing tillage systems that combine non-chemical tactics with soil conservation and other functions.

LIMITATIONS AND POSSIBILITIES OF CURRENT TILLAGE SYSTEMS

There are many non-chemical ways to control weeds directly or reduce the need for control by preventive methods (Table 1). As each method influences specific groups of weeds in certain periods and conditions, the set of methods applied should be diverse enough to keep a wide variety of species in control. A method's applicability and effectiveness depends on crops grown, climate, soil, farm size and other factors that are hard to influence. It also depends on the type of tillage system, as related to possibilities for 1) managing living or dead mulches, 2) shallow tillage, 3) disrupting rhizomes of perennial weeds, and 4) burying seeds in deeper layers. Although qualifications in Table 1 are approximate and not situation-specific, it clearly shows that conservation tillage and no-till systems offer limited possibilities for direct thermal and mechanical weed control.

Table 1. General suitability of mainstream tillage systems to non-chemical weed management tactics.

Weed management tactic		Tillage system		
		mouldboard plough	conservation tillage	no till
cropping system	crop rotation	+	+	+
	fallow crops	+	+	+/-
	intercrops (parallel to cash crops)	+	+	+/-
	permanent predator habitats	-	+/-	+
	stubble cultivation	+	+	-
	false or stale seedbeds	+	+/-	-
crop management	decrease crop row spacing	+	+	+
	increase crop planting density	+	+	+
	competitive crop cultivars	+	+	+
	adapt planting time to weed emergence	+	+	+
	fertiliser placement	+	+	+
thermal weeding	flaming	+	+/-	+/-
	hot water	+	+	+
	band steaming	+	+/-	-
mechanical weeding	interrow cultivation	+	+	-
	rotary hoeing	+	+	-
	hoeing close to the crop row	+	-	-
	weed harrowing	+	-	-
	intra-row weeders	+	+/-	-
	mowing /mulching	+	+/-	+
	weed seed collection / predation	+/-	+/-	+

Principally, no-till systems seem well suited to expose weed seeds at the soil surface, sustain predator populations and prevent seeds from entering into the soil (e.g. through tillage, cracks, a rough cloddy surface). Mice, beetles and birds may consume a large proportion of the exposed weed seeds, but the amounts vary spatially [Lutman et al. 2002] and depend on the time of seed shedding [Westerman et al.

2003]. No-till systems provide virtually no non-chemical alternatives for killing weeds after crop planting except smothering weed growth by more competitive crops, cover crops and intercrops. Mowing and mulching may control inter-row weeds and manage cover crops and intercrops. Thermal weeders that apply hot water [Hansson and Ascard 2002] or hot air [Bertram 1996] could be applied in high-value crops with residues, but are relatively costly and energy demanding. Nevertheless, grasses and perennial weeds will remain very difficult to control without herbicides in no-till systems.

Conservation tillage offers additional options such as using false or stale seedbeds, post-planting rotary hoeing and inter-row cultivation and post-harvest cultivations to manage intercrops and dilute weed seeds. Ridge and strip till systems allow seeds shattered on the soil surface to be moved to the inter-row spaces and might allow for flaming and mechanical weeding on cropped strips. Living or dead mulches can be maintained between crop rows, but need to be mowed or cultivated to restrict competition and weed seed shedding. As frequent cultivation would compromise the basic aims of conservation tillage, weed control methods causing little soil disturbance and residue fragmentation should be further developed, with emphasis on perennial weeds and those with prostrate growth habits and short lifecycles.

Mouldboard ploughing buries weed seeds and residues and contributes to perennial weed control. Subsequent pre-sowing tillage can reduce the number and size of weeds and can create favourable soil conditions for flaming, band steaming and mechanical weeding with a great variety of intra- and inter-row implements. Although mouldboard plough systems presently facilitate the widest range of non-chemical tactics, the absence of residues and intensive tillage might adversely affect weed management, e.g. by destroying seed predator habitats and by decreasing topsoil workability and stability.

Matching the level of soil protection (residues, tillage intensity) to a set of non-chemical tactics that would sufficiently reduce herbicide reliance in specific situations is a key issue in tillage system selection and improvement. These are difficult and challenging tasks. As tillage both controls weeds and determines how well other weed management tactics can be carried out, the relationship between tillage (operations and systems) and weed control is quite complex. For example, effective broad-spectrum spectrum herbicides may wipe out lacks in controllability of some species, which would become more apparent with a different set of control tactics or in different crops or weather conditions. Classic empirical approaches have serious limitations in dealing with these complexities. Therefore, complementary approaches are needed to design and evaluate sets of weed management tactics integrated in cropping and tillage systems.

The following sections demonstrate two complementary approaches. The first analyses the functions of soil tillage required by specific weed management tactics, *in casu* mechanical weeding. The second uses biological knowledge on weed lifecycles to identify how tillage could enhance natural processes that suppress weeds, *in casu* to enhance weed seed mortality.

MECHANICAL WEEDING

In mouldboard plough systems, rotary hoeing [Forcella 2000] or weed harrowing combined with hoeing [van der Weide et al. 1993] can cut down herbicide use by 50-70%. As the shallow cutting action of hoe knives kills nearly all weeds between crop rows [Pullen and Cowell 1997], minimising knife spacing by innovative designs, automatic guidance, careful seedbed preparation and accurate sowing is an important aim. The intra-row strips between hoe knives can simultaneously be cultivated by torsion weeders, finger weeders, brush weeders [Ascard and Bellinder 1996, Bowman 1997, Fogelberg 1998], pressurised air [Lütkemeyer 2000] or other tools. As these tools utilise a difference in damaging susceptibility between weeds and the crop, weeds can only be controlled in an early growth stage once crops are robust enough to withstand the uprooting and soil covering action. In slowly growing, shallowly planted susceptible crops such as sugar beet, onions and carrots, the limited selectivity in early stages causes major weed management problems in organic agriculture, expressed by high labour requirements for manual weeding (70-250 hours/ha) [Ascard 1990]. Further shortcomings of mechanical weeding include the risk of weed regrowth under wet conditions, limited workability (timeliness), and difficulties in handling crop residues.

Successful mechanical weeding requires 1) accurate depth control and steering of tools working in or near to crop rows, 2) flat, fine seedbeds that remain friable under a wide range of conditions until canopy closure, 3) improved trafficability under wet conditions, allowing for frequent and timely cultivation (when weeds are still small), and 4) low levels of surface residue.

These requirements can largely be met by improving mouldboard plough, ridge and strip till systems. Controlled traffic with precise automatic guidance would improve implement stability, trafficability and topsoil workability and may allow for more precise tool control. In laboratory trials with a very precisely guided harrow, sugar beets could be harrowed at emergence and at the 2-leaf stage without significant plants losses (Kurstjens, unpublished results), whereas harrowing in the field is actually possible from the 4-6 leaf stage onwards (Wevers 1995). Earlier cultivation would prevent weeds from escaping control.

In addition, light tractors (e.g. 1500 kg, 20 kW) could be used to pull wide, self-carrying cultivators that only till narrow (e.g. 8 cm wide) strips near crop rows. The low axle load and small net cultivated width minimise soil disturbance and fuel consumption and would extend the workable period considerably. If weeds, residues and intercrops on inter-row strips could be managed by mowing or extensive cultivation, such a system could merge accurate mechanical weeding with non-inversion tillage.

Field experiments revealed considerable differences in weed uprooting due to varying topsoil properties (Kurstjens, unpublished results). Improved seedbeds might enhance differences in susceptibility to mechanical weeding between crop and weeds. Improved knowledge of how topsoil properties affect weeding selectivity and effectiveness could help adapt cultivation timing to the topsoil moisture status.

Furthermore, strategies to reduce the risk of establishment of large uncontrollable weeds during spells of wet weather should be developed, together with weeders that can work underneath the residue layer.

ENHANCING WEED SEED MORTALITY

Reducing the number of emerging weeds lowers the need for direct control measures. Principally, this can be accomplished by: 1) improving weed seed exposure to mice, birds and invertebrates, 2) sustaining seed predator populations, 3) collecting and removing weed seeds mechanically, 4) extending the period of seed burial at unfavourable depths, 5) creating soil conditions that enhance seed decay, 6) enhancing fatal germination, 7) preventing or delaying weed emergence, and 8) suppress weed growth and viable seed production. Although various tillage practices employ these principles, their effectiveness is often compromised by natural processes, counteracting influences induced by the same operation, or by other operations. For example, a biennal cultivation system designed to enhance fatal weed seed germination by frequent shallow cultivation between rows of a competitive crop, should exhaust the weed seedbank before planting a less competitive crop [Melander and Rasmussen 2000]. However, seed shedding after cultivation, the invasion of mobile seeds and weed emergence periodicity blurred the effects of intensive shallow cultivation. With post-harvest stubble cultivation, the effect of making seeds inaccessible to predators and inducing dormancy counterbalances the effects of killing remaining weeds and inducing germination of newly shattered seeds. Therefore, ecological and biological knowledge of weeds is needed to improve tillage practices.

Much knowledge still has to be developed, e.g. tillage effects on weed seed predation, soil condition effects on weed seed decay rate and knowledge on the release and fate of allelochemicals from crop residues that suppress weed emergence. Nevertheless, some of the above principles are useful to define functional soil manipulations from a weed management perspective. For example, a multi-year high-precision strip tillage system could dispose surface soil, residue and seeds in narrow vertical slots and put "clean" excavated soil back onto the cropped strip, while maintaining surface residues between crop rows (Figure 1). By shifting the slot position laterally each year, the "clean" soil would only contain weed seeds that survive for many years. The number of years available for weed seed decay depends on the profile depth, the soil volume displaced and achievable precision. Theoretically, with 8-cm wide and 5-cm deep strips at 75 cm row spacing and a profile depth of 20 cm, 3-cm slots spaced at 6 cm would allow seeds to decay for 15 years before the same slot is reexcavated.

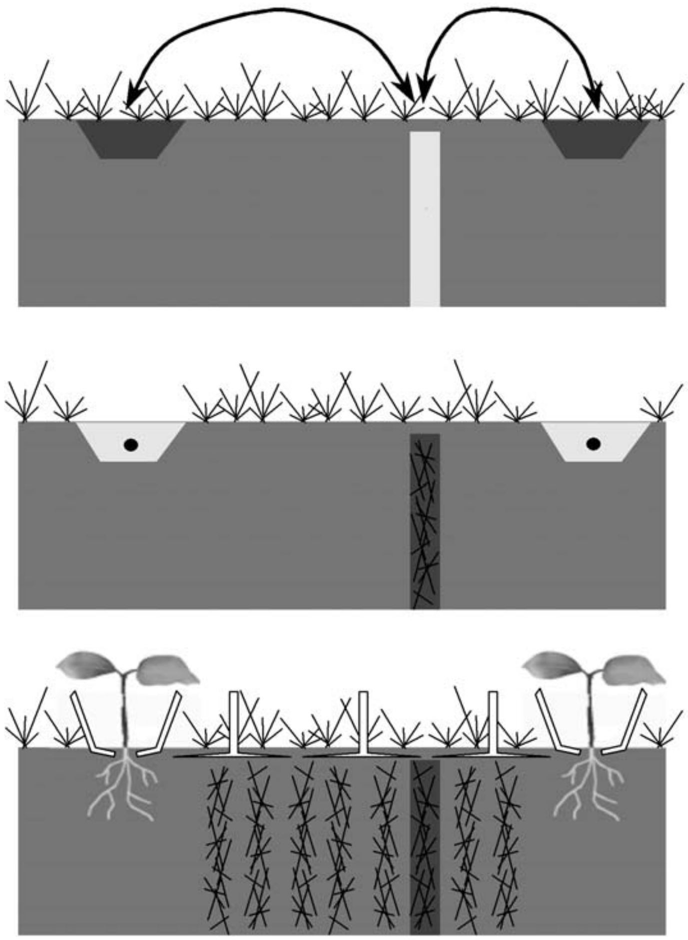

Figure 1. Schematic cross section of the arable layer in a precise strip tillage system, with narrow vertical slots to bury weed seeds and provide "clean" soil for the crop row zone. Surface residues between crop rows are maintained, whereas the residue-free crop row zones can be weeded mechanically. The thin surface layer may be cultivated and prevents new weed seeds from entering into the slots.

Although this specific idea may not be applicable with root crops or on heavy, stony or self-mulching soils, there may be other ways to implement the philosophy of preventing seeds mixing with soil. On its turn, this philosophy is but one of the many avenues to implement principle number 4. Using a systematic approach, other new avenues could be found to employ as many as possible of the eight principles for reducing weed emergence in a tillage system. Although this might seem yet far from practical reality, difficulties in combining soil conservation and non-chemical weed management in current systems may make drastic changes in tillage practices inevitable once herbicide reliance becomes really problematic.

CONCLUSION

The flexibility to apply a wide variety of weed management tactics is an important trait of tillage systems. In current tillage systems, soil conservation and reducing herbicide reliance are often controversial. Controlled traffic combined with high-precision strip tillage may offer good opportunities to merge mechanical and thermal weeding, enhanced weed seed mortality and maintaining surface residues. Analysing the requirements of specific non-chemical weed management tactics and a functional design of the soil environment based on biological and ecological knowledge could be a valuable approach to enhance weed management by tillage.

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References

Ascard, J. Weed control in ecological vegetable farming, Proceedings of the Ecological Agriculture, NJF-seminar 166, Alternative agriculture - No. 5 (ed A. Granstedt), Swedish University of Agricultural Sciences, Uppsala, Sweden, 178-184, 1990.

Ascard J. and R.R.B. Bellinder, Mechanical in-row cultivation in row crops, Second International Weed Control Congress, Copenhagen, Denmark, 1121-1126, 1996.

Bertram, A., *Geräte- und Verfahrenstechnische Optimierung der thermische Unkrautbekämpfung*, Ph.D. Thesis, Institut für Landtechnik der Technische Universität München, Weihenstephan, 1996.

Bowman, G. (ed.), *Steel in the field. A farmer's guide to weed management tools*, Sustainable Agriculture Network handbook series 2, National Agricultural Library, Beltsville, MD, USA, 1997.

Darmency, H., Potential disadvantages of herbicide-resistant crops in weed resistance management, Second International Weed Control Congress, Copenhagen, Denmark, 427-433, 1996.

Fogelberg, F., Physical weed control – Intra-row brush weeding and photocontrol in carrots (*Daucus carota* L.), PhD Thesis, Swedish University of Agricultural Sciences, Alnarp, Sweden, 1998.

Forcella F, Rotary hoeing substitutes for two-thirds rate of soil-applied herbicide, *Weed Technology 14*, 298-303, 2000.

Hansson, D. and J. Ascard, Influence of developmental stage and time of assessment on hot water weed control, *Weed Research 42*, 307-316, 2002.

Kudsk, P. and J.C. Streibig, Herbicides – a two-edged sword. *Weed Research 43*, 90-102, 2003.

Lütkemeyer, L., Hydropneumatische Unkrautbekämpfung in Reihenkulturen, *Zeitschrift für Pflanzenkrankheiten und Pflanzenschutz, Sonderheft XVII*, 661-666, 2000.

Lutman, P.J.W, N.C.B. Peters and S.E. Freeman, Post-harvest weed seed predation: an *Avena Fatua* case study, 12th EWRS Symposium, Wageningen, The Netherlands, June 24-27, 270-271, 2002.

Powles, S.B., C. Preston, I.B. Bryan and A.R. Jutsum, Herbicide resistance: impact and management, *Advances in Agronomy 58*, 57-93, 1997.

Pullen, D.W.M. and P.A. Cowell, An evaluation of the performance of mechanical weeding mechanisms for use in high speed inter-row weeding of arable crops, *Journal of Agricultural Engineering Research 67*, 27-34, 1997.

Weide, R.Y. van der, Spoorenberg, P.M. and H.K.J. Bosch (eds), *Themadag duurzame onkruidbestrijding*, Themaboekje nr. 15, Proefstation voor de Akkerbouw en Groenteteelt inde Vollegrond (PAGV), Lelystad, The Netherlands, 1993.

Westerman, P.R., A. Hofman, L.E.M. Vet and W. van der Werf, Relative importance of vertebrates and invertebrates in epigaeic weed seed predation in organic cereal fields, *Agriculture, Ecosystems and Environment 95*, 417-425, 2003.

Wevers, J.D.A., The integration of mechanical weed control into a low-dose herbicide system in sugar beet, Brighton Crop Protection Conference – Weeds, Brighton, UK, Vol. 3, 859-863, 1995.