

The intersection of integrated pest management and soil quality in the resistant weed era

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Highlights

- Conservation tillage hectareage is at constant risk of being converted to higher-intensity tillage systems due to lack of weed control.
- Most tillage operations promote soil loss, adversely affect surface water quality, and negatively impact soil productivity.
- Creative research programs have been developed that meet conservation compliance requirements and, at the same time, judiciously use tillage as an element for the management of resistant or troublesome species.
- Further research is critically needed when few or no other options are available to ensure the economic viability of farming operations while addressing long-term soil quality concerns.

Abstract

Agricultural producers and scientists have long recognized both beneficial and detrimental aspects of soil tillage. With the development and adoption of herbicide-resistant crops, particularly glyphosate-resistant crops, herbicides such as glyphosate replaced the need for tillage either before or after crop planting. Thus, tillage has become less important for weed management and has been a primary enabler for the success of the majority of conservation production systems. Currently, herbicide-resistant and troublesome weeds are continually challenging agricultural decisions throughout the world. Conservation tillage hectareage is at constant risk of being converted to higher-intensity tillage systems due to lack of weed control. The shift to higher-intensity tillage facilitates the burial of weed seed through the use of inversion tillage and/or of surface tillage to facilitate pre-plant incorporated and pre-emergence herbicides for control of herbicide-resistant or troublesome weeds, especially in non-irrigated production. For example, Palmer amaranth (*Amaranthus palmeri*) has become the

dominant weed problem in United States row crop production because of evolved resistance to glyphosate. Inversion tillage was clearly demonstrated to be an effective tool in helping the management of this weed. However, there is no question that most tillage operations promote soil loss, adversely affect (lower) surface water quality, and negatively impact soil productivity. Depending on the severity of the herbicide-resistant or troublesome weed infestation, multiple strategies involving the integration of cultural and chemical weed control will be needed to overcome the need for tillage. Utilizing high biomass conservation tillage systems, such as those used extensively in South America and introduced to the United States, can help reduce the emergence of weeds by suppressing weed germination and growth. A dense mat is formed on the soil surface when the winter cover crop is planted early and managed for maximum growth. Because weed emergence and growth are suppressed by the physical barrier and shading provided by the residue, more residue increases weed control. Conservation tillage systems that minimize soil disturbance (direct seeding or minimum tillage) can further reduce weed seed germination. In addition, allelopathy plays a role in weed suppression, but quantifying allelopathic effects in applied research is rarely accomplished. Creative research programs have been developed that meet conservation compliance requirements and, at the same time, judiciously use tillage as an element for the management of resistant or troublesome species. Similar programs are needed to help manage herbicide-resistant or troublesome weed species in other regions and cropping systems. Further research is critically needed when few or no other options are available to ensure the economic viability of farming operations while addressing long-term soil quality concerns.

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Key words: Conservation agriculture; herbicide resistance; herbicide trait stewardship.

Received for publication: 16 March 2021.

Revision received: 3 June 2021.

Accepted for publication: 25 June 2021.

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Italian Journal of Agronomy 2021; 16:1875

doi:10.4081/ija.2021.1875

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Introduction

In the United States (U.S.), conservation agriculture (CA) is defined as a production system that results in at least 30% of the soil being covered with crop residues after planting. Many systems such as no-till and various reduced tillage practices, including strip-till, mulch-till, and ridge-till, are all considered CA. While early forms of CA (e.g., stubble mulching) were utilized in the U.S. in the 1930s, research on reduced tillage to improve soil quality began in the early 1950s. Early research was focused on

identifying CA benefits, including reduced soil loss from runoff, reduced labour, and fuel usage, increased soil moisture and organic matter, and improved soil and water quality. As research progressed, the need for practical methods to implement conservation tillage, such as evaluating new equipment, was realized (Gebhardt *et al.*, 1985; Koskinen and McWhorter, 1986; Triplett and Dick, 2008). The introduction of herbicides in the 1960s helped facilitate the producer adoption of CA methods. However, by the early 1980s, producers identified inadequate weed control as the foremost reason for not adopting CA (Koskinen and McWhorter, 1986).

Marketing of herbicide-resistant crops in some regions in the mid-1990s facilitated the adoption of CA practices with less risk (Green, 2012; Duke, 2015). Over the past 20 years, the adoption of herbicide-resistant crops has been almost universal in some regions. For example, 94% of all soybeans (*Glycine max*) planted in the U.S. are herbicide-resistant varieties (USDA, 2015). Corn (*Zea mays*) and cotton (*Gossypium hirsutum*) have less area planted solely to herbicide-resistant varieties (12% and 10%, respectively) due to the use of stacked gene varieties (77% and 79%, respectively). While the adoption of herbicide-resistant crops facilitated an increased adoption of CA, herbicide-resistant weeds pose a growing threat to CA (Price *et al.*, 2011). As a result, producers increasingly face difficult management decisions regarding herbicide-resistant and troublesome weeds.

Conservation agriculture and weed management

In many regions, typical row crop integrated pest management (IPM) recommendations include tillage practices to disrupt weed life cycles and bury seed at depth beyond germination. Tillage for weed seed bank and emerged weed management are widely used practices and continue to be recommended by cooperative extension and crop consultants as part of IPM strategies throughout the world (Legere *et al.*, 2011; Norsworthy *et al.*, 2012; Shaw *et al.*, 2012; Lyon and Young, 2015). Until the development of highly efficacious herbicides, tillage was required for weed control. With the rapid adoption of herbicide use beginning in the 1960s, tillage combined with herbicide applications provided efficacious control of many troublesome weed species (Timmons, 2005). Combining tillage with herbicides provided control of weeds that were not easily controlled by tillage alone. Historically, herbicide systems have included pre-plant-incorporated (PPI) or pre-emergence (PRE) herbicide applications (or both) to prevent weed germination, followed by post-emergence (POST) or post-directed (PDS) applications to control weeds emerging after the crop throughout the growing season. The herbicide or herbicide program selection is based on several field attributes, including the weed species and their density, an herbicide's efficacy to weed species present, and soil-applied herbicides, soil characteristics, and soil moisture conditions. Weed control practices in cropping systems not utilizing herbicide-tolerant traits require considerable knowledge about herbicide efficacy and weed identification. In addition, substantial labour for scouting and decision-making is required to achieve high efficacy weed control. With the adoption of herbicide-resistant crops (*i.e.*, predominantly glyphosate-resistant crops since most corn, cotton, and soybean marketed in North and South America contain this trait), herbicides have replaced the need for tillage either before and/or after crop planting. Tillage has become less important for weed management; thus herbicide-resistant crop adoption has been a primary reason for the increase in CA hec-

tare (Shaw *et al.*, 2012). However, because of extraordinary herbicide selection pressure, resistant weeds are now present throughout the U.S. Currently, there are 153 herbicide-resistant weeds in the U.S. (Heap, 2015). Despite many hectares with herbicide-resistant weeds currently being CA systems, the difficulty of controlling these herbicide-resistant weeds places many of them at risk of being converted to higher-intensity tillage systems (Price *et al.*, 2011). The shift to higher-intensity tillage facilitates the burial of small weed seed and/or increased pre-plant incorporated herbicide activity to control problematic weeds, especially in dry-land crop production, such as cotton.

Soil tillage and soil quality

Soils hold approximately 1500 Pg C, making them the largest component of the global terrestrial C stock (Scharlemann *et al.*, 2014). Globally, agricultural soils have lost 36 to 78% of their initial soil organic carbon (SOC) in the top 30 cm of soil, largely due to frequent and disruptive tillage (Trimble, 1974; Sanderman *et al.*, 2018). Disturbance of soil aggregates and aeration of soil are maximized with conventional tillage, increasing microbial activity and subsequent release of CO₂ to the atmosphere (Sainju *et al.*, 2010). The use of CA practices, including reduced tillage, has been used to rebuild SOC, and it has been estimated that shifting from conventional tillage to conservation tillage can result in C sequestration rates of 0.45 to 1 Mg C ha⁻¹ yr⁻¹ dependent on soil type and climate (Franzluebbers, 2010; Zomer *et al.* 2017). Thus, conservation agriculture practices are critical to meet global initiatives to mitigate climate change like the *4 per mille Soils for Food Security and Climate program* (Budiman *et al.*, 2017). In addition to C sequestration, the benefits of CA practices to build SOC are widespread. Soil organic C is a universally accepted indicator of soil health because of its role in increasing soil nutrient-holding capacities, supporting microbial communities, improving soil aggregation and structure, and enhancing water infiltration and storage (Touchton *et al.*, 1984; Franzluebbers and Stuedmann, 2008; Watts *et al.*, 2010; Hawkins *et al.*, 2016; Nunes *et al.*, 2020).

As herbicide-resistant weeds become an increasingly prevalent issue globally, it is imperative to identify control methods that do not damage the advancements which have been made in protecting soil health. Reversion to conventional tillage systems threatens carbon sequestration made in recent decades. Increased C losses of 0.5 to 1.8 Mg C ha⁻¹ yr⁻¹ measured as CO₂ emissions have been reported for conventional tillage methods (*e.g.*, mouldboard plow, chisel plow) compared to no-tillage (Omonode *et al.*, 2007; Ussiri and Lal, 2009; Heller *et al.*, 2010). Losses of approximately 770 kg C ha⁻¹ yr⁻¹ were reported in sandy loam soils under conventional tillage in Italy using simulation models (Cillis *et al.*, 2018). Losses of SOC also threaten to reverse associated improvements in soil fertility, soil structure, and soil biology. High-residue cover crops will be an integral part of herbicide-resistant weed management to shade the soil surface to prevent weed germination and compete with weed species for water and nutrient resources. Approximately 64% of farmers (n=869) reported that herbicide-resistant weeds are an issue on their farms in a recent survey of U.S. farmers (CTIC, 2020). In the same survey, 91.2% of farmers (n=317) reported an improvement in weed control with a high-residue rye cover crop. A large barrier to the production of high residue (>4000 kg biomass ha⁻¹) cover crop is timely planting since ideal planting windows for many wintry annual cover crops often occur before the harvest of cash crops. Innovative planting methods (*e.g.*, inter-

seeding, aerial broadcasting) and variety selection for earlier-maturing winter annual cover crops may create conditions in which high biomass production is more feasible. In the case of interseeding cover crops, additional research is needed to identify

species that provide adequate ground coverage without competing with the cash crop. Planting summer annual cover crops may also be useful for crop rotations in which early harvest leaves soil exposed prior to winter cover crop planting.



Figure 1. Cover crop roller/crimper terminating a cereal rye cover crop.



Figure 2. Cotton grown in rolled high-biomass cereal rye cover crop residue.

Integrated pest management weed management practices to maintain conservation agriculture

The renewed interest in both high biomass winter and summer annual cover crops and their management for both soil quality and weed control attributes (Balkcom *et al.*, 2013). In the late-1990s, scientists at Auburn University and USDA - ARS National Soil Dynamics Laboratory, both in Auburn, Alabama, initiated research using a cover crop roller-crimper, a Brazilian style CA cover crop management practice used in combination with herbicides to terminate mature cover crops (Derpsch *et al.*, 1991; Ashford and Reeves, 2003; Price *et al.*, 2009; Balkcom *et al.*, 2015) (Figure 1). This practice was initially evaluated in CA cereal cover crops preceding cotton (Figure 2), soybean, and peanut. In the U.S., roller-crimpers have since been successfully used in CA systems to terminate a broad range of cover crops practices, including traditional and alternative species, grasses and broadleaves, summer and winter, and monocultures and mixtures (Price *et al.*, 2006; Kornecki and Arriaga, 2011; Reberg-Horton *et al.*, 2011; Price *et al.*, 2012). High-biomass cover crops contribute advantages of CA systems by promoting moisture conservation after cover crop termination, as well as weed suppression (Teasdale, 1996; Arriaga and Balkcom, 2006). In addition, high-residue cover crops are increasingly being recommended as an IPM practice to help alleviate herbicide resistance selection pressure through their suppressive weed characteristics (Norsworthy *et al.*, 2012). Another renewed cover crop management interest is mixing different cover crop species to increase the biological diversity of CA systems. Little research has been published in this area; however seed companies and technology transfer specialists in extension and farming associations tout advantages provided by cover crop mixtures, including soil health benefits (USDA, 2012; Solberg, 2013; White *et al.*, 2015).

Conclusions

Creative research programs have been developed that meet conservation compliance requirements and, at the same time, judiciously use tillage as an element for the management of resistant or troublesome species. Similar programs are needed to help manage other herbicide-resistant or troublesome weed species in other regions and cropping systems. Impacts on soil health should be considered when developing programs for managing the resistant weeds, and further research is critically needed when few or no other options are available to ensure the economic viability of farming operations while addressing long-term soil quality concerns.

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