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Review

Sustainable weed management in conservation agriculture

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ABSTRACT

Sustainable crop production is necessary to ensure global food security and environmental safety. Conservation agriculture (CA) is gaining popularity around the globe due to its sustainable approaches such as permanent soil cover, minimal soil disturbance, planned crop rotations and integrated weed management. Weed control is the biggest challenge to CA adoption. Weed ecology and management is different in CA than in conventional agriculture. In CA, weeds expression, seed bank status, distribution, dispersal mechanisms, diversification, growing patterns and competition trends are complex and differ from conventional systems. It is due to reduced tillage of the soil and the flora that thrives in CA. Reduced tillage systems affect the efficacy of herbicides and mechanical weed control measures. So, it is an important task to find out the differences and to fabricate new management options. In this review, changing weed dynamics have been framed. A novel aspect of this review is the comprehensive account of sustainable weed management strategies in relation to CA. Modified tillage operations, improved cultural practices, bioherbicides, chemical herbicides, allelopathy, and crop nutrition have been identified as suitable weed management tools. None of these offers complete control but the integration of these tools in suitable combinations works efficiently. Weeds dominating CA and their responses to CA components are highlighted. For example, small seeded and perennial weeds are more abundant in CA. The role of herbicide resistance in weeds and herbicide tolerant (HT) crops in CA is also highlighted. Allelopathy and crop nutrition are discussed as modern weed management tools for CA. A detailed account of weed responses to fertilizer management options is also given. Integrated weed management compatible to cropping patterns and climatic conditions offers the best results in CA. Future efforts must be directed towards the optimization and integration of these weed management practices.

1. Introduction

Crop production is important component of agriculture which is responsible for global food security. Effective crop production begins with successful soil management which is first and foremost principle of agronomy. Modern day agriculture is strongly associated with conventional tillage which is defined as a system having deep primary tillage followed by secondary cultivation operations (Holland, 2004). The practice of tillage in agriculture began thousands of years ago at the time when humans being shifted from hunting and gathering towards the raring of animals and settled down in productive areas near rivers like the Nile, Euphrates, Yangste and Indus (Hillel, 1991). The concept of tillage was prevalent in Mesopotamia in 3000 B.C. (Hillel, 1998; Lal, 2001). Tillage is the manipulation of soil for the betterment of aggregates for the development of a well pulverized and suitable seed bed prior to sowing. It is a multipurpose practice that aids in proper emergence of seeds due to optimum placement providing sufficient amounts of water, light and nutrients. It ensures the availability of nutrients and provides aeration of the soil layer (Reicosky and Allmaras, 2003). Different soil amendments are also added to the soil through tillage. It also helps in control of soil-borne diseases and pests (Owens, 2001). Tillage is an essential part of conventional agriculture for soil preparation, residue incorporation, planting and herbicides incorporation (Sherestha et al., 2006).

Besides all the plus points, conventional tillage is playing havoc to natural landscape and soil fertility. Heavy tillage implements are extensively used in conventional tillage system without considering the soil capability and fertility status. Increasing costs of energy sources, labor and other inputs are making this system unsuitable and unfeasible due to high cost of production (Edwards and Smith, 2005). Moreover, this system is problematic for environmental safety and global protection but conservation agriculture (CA) is a viable alternate which is suitable for today's limited

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natural resources and changing climate (Montgomery, 2007). That's why it is becoming a common approach in rainfed areas for water and soil conservation. About 45 million hectares have been reported under CA (FAO, 2001). CA is a broad spectrum and multidimensional term. CA defined by FAO (2001) as minimal soil disturbance (no-till, NT) and permanent soil cover (mulch) combined with rotations, is a recent agricultural management system that is gaining popularity in many parts of the world (Hobbs et al., 2008). The trend is spreading quickly in North and South America, semi-arid and tropical regions of the world (Lal, 2000). CA is designed to be an effective solution to agricultural problems in small land holding farming communities especially in tropical regions (Fowler and Rockstrom, 2001; Derpsch, 2003; Hobbs, 2007; Hobbs et al., 2008; Giller et al., 2009). Most important principles of CA (Minimal soil disturbance and permanent soil cover) are achieved by no tillage, zero tillage, minimum tillage/ridge tillage, reduced tillage, direct seeding and mulch tillage (Reicosky and Allmaras, 2003). All these practices are collectively called conservation tillage. These are used according to farming system, cropping pattern and climatic conditions (Reicosky and Allmaras, 2003; Giller et al., 2009). Zero tillage is a practice of least soil disturbance during single tillage operation to avoid soil degradation. It is mainly planting operation but also involve slight manipulation of soil. It has also been widely accepted by farmers in developed countries (Bolliger et al., 2006; Triplett and Warren, 2008). The precise and accurate definition of CA is very difficult to quote due to diverse climatic conditions and variable management practices around the globe. It varies according to the area and geographical as well as climatic conditions (Carter, 1994; Lyon et al., 2004).

Weed management has been recognized as essential component of CA and, thus, requires special attention. Weeds act differently in different habitats. Weeds also provide habitat for insects and disease-causing pests which can reduce the quality of the crop and increase the risk of crop failure. Tillage provides different types of natural and manipulated habitats to the weeds. Tillage plays an important role in weed control and has been used as an effective tool since ancient times. Tillage practices are still very effective; different types of modern cultivators and weeders are facilitating mechanical weed management (Wallace and Bellinder, 1992). CA also provides a specific set of environmental factors that affect weed populations. Weed infestations in CA is a major concern and a key reason for reluctant approach of farmers towards its adoption (Buhler et al., 1994). CA is mainly focused on minimal tillage with specific herbicide applications for better weed control (Lafond et al., 2009). Weed management in CA is a relatively complex approach involving different tillage practices, agronomic practices, engineering approaches and modern technologies of crop establishment (Lafond et al., 2009).

CA requires dedicated efforts to control weeds initially; however, after maintaining a certain threshold level, it is easier to manage weed infestations in these systems. Integrated approaches must be considered and optimized to have proper weed control in CA. It is necessary to study the ecological, biological and social issues related to weeds in CA. Moreover, a systematic approach is needed to optimize different sets of management options based on ecological and geographic features of a particular agro-ecosystem. It will help to determine new lines of action regarding site-specific weed management and sustainable control. Future endeavors in this regard must be oriented in such a direction to offer comprehensive solutions keeping a focus on the differences.

2. Weed dynamics in CA

Weeds are plants with specific characteristics that help them infest and invade crops and succeed under a wide range of environmental and climatic conditions (Labrada and Parker, 1994). CA promotes certain types of weeds including annuals, biennials and perennials. Certain weeds decrease after consistent practices of CA but some others may increase (Chauhan et al., 2006a). CA systems with low soil disturbance tend to leave more weed seeds on the surface, whereas high disturbance systems bury weeds (Chauhan et al., 2006b). Usually, small-seeded weed species are favored more in CA (Sosnoskie et al., 2006). Typically, small-seeded weed species thrive in CA compared to conventional tillage because the seed is not buried. The small-seeded species cannot germinate as readily from buried depths as they can from the soil surface. Weed emergence is less because of reduced soil manipulation in CA (Chauhan et al., 2007). There are many annual weeds that germinate well under no till system as they can germinate with less or no soil cover. Biennials also thrive well under CA (Curran et al., 1996). Perennial species can easily produce large populations under CA if a few plants get a good vegetative stand. They have gradual growth in the first year and proliferate in the second year. Reduced tillage cause changes in weed species, their distribution, densities and composition. So, different weeds have different response in CA. It requires special approaches for better weed management which is surely a point of interest for adopters of CA (Buhler et al., 1994). CA can produce more if row crops are introduced in rotation along with proper herbicide application (Phillips and Young, 1973).

3. Weed control measures under CA

3.1. Modified tillage

CA has a significant impact over weed populations and, thus, on weed management. Tillage affects weeds through disturbances like cutting, burial, uprooting and dislodgement of weeds; moreover, it changes the soil climate and influences weed germination, emergence and establishment by promoting or inhibiting their movement (Clements et al., 1996). Weed flora composition differs according to tillage system and, thus, we have to manage them by different approaches. For instance, small-seeded weeds proliferate well under CA and have to be controlled by special measures (Chauhan et al., 2006a; Sosnoskie et al., 2006). Reduction in tillage may cause serious problem regarding weed infestations (Buhler et al., 1994). The shift in weed species distribution and weed densities poses a great problem for weed management and can cause a reduction in crop yield under CA (Blackshaw et al., 2001). Tillage systems clearly affect weed density, weed distribution and weed seed bank reserves (Table 1).

CA may promote the germination and emergence of newly produced weed seeds that stay on or near the soil surface. Moreover, the extra residues managed on the surface in CA may cause a hindrance to herbicide efficacy. Perennial, erect or creeping weeds produce vegetative reproductive parts like rhizomes and tubers which are difficult to manage under CA (Shrestha et al., 2003). There is a problem of shift in timing of weed seeds germination and emergence during the course of crop growth which may cause a problem in the selection of time for herbicide application or other management practices (Bullied et al., 2003).

The shift in weed species has been reported previously but is inconsistent. Cussans (1976) reported the increase in dicot species under no till but Wrucke and Arnold (1985) opposed this pattern by attributing the distribution of broadleaved weeds showing similar trend under both conservation tillage and traditional tillage system. Pollard et al. (1982) studied different weeds and concluded that there was no proper and consistent trend of different weeds under reduced tillage. Tillage systems influence the emergence of annual and perennial weeds differentially and the vigor of different weed plants also varies significantly (Table 2).