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Long-term weed dynamics and crop yields under diverse crop rotations in organic and conventional cropping systems in the Canadian prairies

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ABSTRACT

Alternative cropping systems are gaining attention throughout the world in order to increase the sustainability of agro-ecosystems. On the Canadian prairies, the tillage-based crop-fallow system has been replaced by no-till reduced input systems or tillage-based organic systems with more diversity in crop rotations but with no external inputs. However, the long-term effects of these alternative systems on weed and yield parameters have not been assessed. A study to examine weed and crop yield dynamics under diverse cropping systems was conducted within a 18-year cropping systems study near Scott, Saskatchewan. The trial was laid out in a split-split-plot design with four replicates. The main plots were three levels of inputs; a high input system (HIGH) that used tillage and inputs to maximize yield, a reduced system (RED) that used no-till practices and minimal inputs, and a tillage-based organic system (ORG) with no external inputs. The subplots were cropping diversity (rotations); fallow-annual grains (LOW), diversified annual grains (DAG), and diversified annuals and perennial forage (DAP). The sub-sub plots were the six phases of each rotation. There was an input by rotation interaction for weed biomass but not for weed density and crop yields. ORG systems had 7× and 4× greater weed density (107 plants m^{-2}), 4× higher weed biomass (154 kg ha^{-1}), and 32% and 35% lower yields (1052 kg ha^{-1}) than RED and HIGH systems respectively. RED and HIGH input systems had similar crop yields and lower weed density than ORG. The LOW rotation had the lowest weed density. LOW and DAG rotations had similar yields, which were higher than in DAP. All systems showed an increase in weed density and biomass over time but did not impact on crop yields which was increasing over time likely influenced by a concurrent increase in rainfall. This study concludes that eliminating tillage and reducing agrochemicals is possible but eliminating agrochemicals requires better crop rotations for weed management as well as for nutrient management.

1. Introduction

Until relatively recently, many farmers have responded to the challenge of feeding an ever-increasing world population by relying on practices that maximize crop production (e.g., intensive tillage, the use of monoculture, and application of fertilizers and pesticides). Although these systems produce high yields (Tilman et al., 2001), they cause considerable environmental harm, including soil degradation (Bowman et al., 1999; Campbell et al., 2000), reduction in soil organic matter (Janzen, 2001), emission of greenhouse gases (Dusenbury et al., 2008; Guo et al., 2010) and negative effects on natural ecosystems due to pesticides and fertilizers (Carpenter et al., 1998; Tilman et al., 2001).

As information on the negative consequences of conventional practices have become available, farmers around the world have adopted no-tillage (no-till) systems, often in combination with greater crop diversity in crop rotations to achieve greater sus-

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tainability in crop production. Furthermore, organic farming is also gaining popularity as an alternative to conventional cropping systems. Therefore, reducing or eliminating external inputs (i.e., fertilizers and pesticides) and or tillage while increasing crop diversity and intensity have become key strategies for the sustainability in crop production.

In the last 30 years, the conventional tillage-based wheat-fallow monoculture system in the Canadian prairies has been replaced by reduced-input, no-till systems or tillage-based organic systems, with diverse crop rotations (Dhuyvetter et al., 1996; Lafond et al., 1992, 1993; Zentner et al., 2002). Until the 1980s, annual cropping followed a crop-fallow or crop-crop-fallow rotation, with spring wheat (*Triticum aestivum* L.) as the main crop (Campbell et al., 2002). Despite increased productivity and economic gains, use of intensive tillage, frequent fallow, and low-diversity crop rotations resulted in substantial loss of topsoil due to wind and water erosion, deterioration of the quantity and quality of organic matter, increased soil salinization, and greenhouse gas emissions (Campbell and Souster, 1982; Janzen, 2001). In contrast, conservation tillage (no-till or minimum tillage) which has become widespread in the prairies (Zentner et al., 2002), conserves soil moisture. These approaches allowed for more intensification and also encouraged diversification of crop rotations with pulses, oilseed crops, legume green manure crops and perennial forages (Peterson et al., 1993; Zentner et al., 2001, 2002; Entz et al., 2002; Entz et al., 2014). Organic farming is also gaining popularity in Canada, in response to concerns regarding the environmental impact of agro-chemicals, the costs of inputs in conventional farming, and the growing demand for organic products (Ngouajio and McGiffen, 2000; Entz et al., 2001).

The changes in cropping practices that have occurred on the prairies and around the world increase soil productivity and environmental sustainability, but also alter weed dynamics and crop yields (McCloskey et al., 1996; Derksen et al., 2002). Tillage intensity can affect weed emergence, seed production, vertical distribution, and weed seedbank densities (Buhler, 1995). For example, no-till systems often have greater weed seedbank populations than moldboard plow systems (Feldman et al., 1997; Barberi and Lo Cascio, 2001; Menalled et al., 2001). Similarly, crop rotations influence weed seed density and composition, both above ground (Blackshaw et al., 2001; Manley et al., 2002) and in the soil weed seedbank (Buhler, 1999; Buhler et al., 2001; Cardina et al., 2002). In most cases, weed density, both above and below-ground, were markedly lower in rotations compared to monoculture (Liebman and Dyck, 1993). However, crop-fallow systems often have lower weed density than continuous cropping systems (Derksen et al., 1994). Although diverse crop rotations with conservation tillage are preferred for long-term sustainability, they can have a negative effect on weed density and crop yield compared to the conventional tillage-based, low diversity fallow systems. Similarly, organic systems can have greater weed density and lower crop yields compared to intensive conventional farming systems (Entz et al., 2001; Ryan et al., 2004; Posner et al., 2008).

Cropping systems often differ in terms of land preparation, weed control, soil fertility management, and crop diversity, and each of these factors can affect weed population dynamics (Menalled et al., 2001; Derksen et al., 2002) and grain yield. However, most studies on weed dynamics have been limited to the individual effects of tillage, crop rotation, or fertilizers. Whether the negative effects of conservation tillage on weed density can be overcome by better crop rotations or managing inputs, is less well understood. Also, there is a lack of understanding of the interactions between various input systems and crop diversity levels on long-term weed dynamics and crop yields. Specifically, few studies have compared weed density in long-term organic and conventional cropping systems (Hiltbrunner et al., 2008; Ryan et al., 2010). Also, the effect of cropping systems on weed dynamics is difficult to generalize across regions due to climatic and geographical variability. As a result, the interaction of input system and crop diversity on long-term weed dynamics and crop productivity is not well understood.

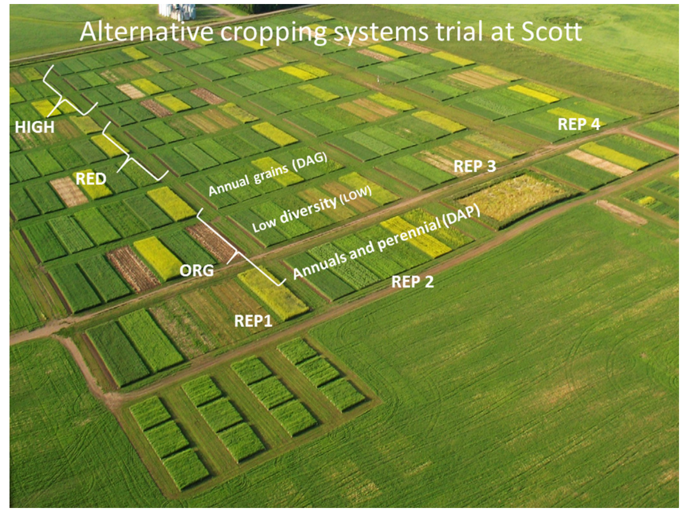

Fig. 1. Aerial view of the long-term alternative cropping systems study.

This study assesses the long-term impact of cropping systems in the Canadian prairies in a long-term (18 year) alternative cropping systems study (ACS) in Scott, Saskatchewan, Canada. The ACS study includes three levels of inputs (high, reduced and organic) and three levels of crop rotations (low diversity, annual grains, and annuals and perennial forage). The objectives of the current study is to determine if: 1) tillage and the use of agro-chemicals can be reduced without a long-term increase in weed density, weed biomass or decrease in crop yields; 2) diverse crop rotations result in lower weed density, weed biomass and higher crop yield compared to less diverse rotations over many years; and 3) weed density increases and crop yield declines over time in organic systems.

Analysis of long-term changes in weed dynamics and crop yield can provide more insights than the conventional point estimation, permitting assessment of factors such as short and long-term weather patterns (Piepho et al., 2003). Most long-term crop rotation studies have been analyzed using a static approach (looking at individual years or mean of all years). However, fluctuations in environmental conditions can influence weed dynamics (Derksen et al., 1993). Therefore, the current study used a combination of a static and dynamic statistical analysis using random spline coefficient models (Verbyla et al., 1999; Rice and Wu, 2001) to analyze the data in the ACS study.

2. Materials and methods

2.1. Site description and experimental design

The ACS trial was a long-term cropping systems study (1994–2012) located on the AAFC Research Farm near Scott, Saskatchewan (52° 22′; 108° 50′, 713 m elevation). It was near the geographical center of the Canadian prairies, in the Dark Brown soil zone between the semi-arid region to the south and the sub-humid region to the north. The details of the design and management of the ACS trial have been explained by Brandt et al. (2010), so only the materials and methods relevant to our study are presented here.

The ACS trial consisted of a split-split plot design with four replicates. The main plot treatments were three levels of inputs, and sub-plots consisting of three levels of crop rotations (Fig. 1). Each crop rotation had six crop phases, with all crop phases present in