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Wheat improves nitrogen use efficiency of maize and soybean-based cropping systems

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ABSTRACT

Integrated nitrogen (N) management strategies could make significant contributions to improving the efficiency of N use in the northern Corn Belt, particularly for maize, which has high N requirements. Using legume cover crops has been shown to increase both the soil's capacity to supply N and nitrogen use efficiency (NUE), through the reduction in the amount of N fertilizer that must be applied to the following crops. However, the impact of non-legume crops such as winter wheat (*Triticum aestivum* L.) on the diminishing return function between crop yield and N supply and its influence on N fertilizer use remains unclear. We hypothesized that maintaining wheat in short maize and soybean- based rotations is instrumental to improve cropping system performance and increase N fertilizer use efficiency while decreasing N requirements for maize. Seven maize and soybean rotations with different frequency of winter wheat with or without underseeded red clover (*Trifolium pratense L.*) were grown in two tillage systems (conventional and zone-tillage) and four long-term N regimes in Ridgetown, ON, Canada (2009–2013). Wheat in the rotation increased maize and soybean yields, negated crop yield lags due to zone-tillage, and decreased maximum economic rates of fertilizer N (MERN). The benefits of wheat in the rotation on maize yield were negated by high N rates; however, similar yields were obtained with lower N levels in rotationally grown maize, resulting in a 17% (conventional till) to 21% (zone-till) increase in partial factor productivity for N fertilizer at MERN (PFP_{MERN}). While N benefits to crops following wheat alone may be attributed to a higher indigenous plant available soil N, underseeding red clover further increased the agronomic efficiency (AE) of N fertilizer (AE_{MERN}) up to 32%. Maize yields were also less limited by N supply and less responsive to N fertilization when grown in rotation with wheat, especially in the zone-till system. These results highlight the value of wheat as a system component of dominant maize/soybean short rotations of Ontario and its potential to increase both maize and soybean productivity using less N input.

1. Introduction

Over the past several decades, crop diversity in the northern Corn Belt (Ontario and North Central US) has substantially declined and rotations consisting solely of maize and/or soybean increasingly dominate the landscape (Fig. 1). Increases in maize and soybean acreage has corresponded with reductions in acreages of grasslands, forages and other small cereal grains (Fig. 1) (Liebman et al., 2013; Nickerson et al., 2007; Wright and Wimberly, 2013).

Agronomic and environmental consequences of declining rotation diversity have been well documented. Loss of rotation diversity has been associated with reductions in soil organic matter, aggregate stability and soil quality (Dapaah and Vyn, 1998; Havlin et al., 1990; Katsvairo et al., 2002; McDaniel et al., 2014a,b; Munkholm et al., 2013; Raimbault and Vyn 1991; Van Eerd et al., 2014; Varvel, 1994), increased soil erosion (Langdale et al., 1991; Rachman et al., 2003; Tisdall and Oades, 1982), increased greenhouse gas emissions (Drury et al., 2008; Liebig et al., 2005; Meyer-Aurich et al., 2006a), decrease in yield potential and increased yield instability (Grover et al., 2009; Katsvairo and Cox, 2000; Lund et al., 1993; Meyer-Aurich et al., 2006a,b; Singer

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and Cox, 1998; Smith et al., 2008; Stanger and Lauer, 2008; Varvel, 2000; Yamoah et al., 1998a).

Many of the agronomic and environmental consequences associated with losses of crop rotation diversity also influence soil nitrogen (N) processes, N losses and crop response to N (Culman et al., 2013; Havlin et al., 1990; McDaniel et al., 2014a,b; Shipitalo et al., 2013; Stecker et al., 1995; Varvel and Peterson, 1990). For instance, there is considerable evidence that removal of legumes, such as alfalfa (*Medicago sativa* L.), red clover (*Trifolium pratense* L.) or soybean (*Glycine max* (L.) Merr.) from a maize (*Zea mays* L.) based rotation increase optimum N fertilization rates and have a significant impact on N dynamics (Bruulsema and Christie, 1987; Gentry et al., 2013; Henry et al., 2010; Hesterman et al., 1992; Liebman et al., 2012; Stecker et al., 1995; Stute and Posner, 1995; Wivstad, 1999). Furthermore, increasing N fertilization has also been shown to decrease rotational benefits of legumes on maize yields in various studies (Adams et al., 1970; Copeland and Crookston, 1992; Crookston et al., 1991; Nevens and Reheul, 2001; Peterson and Varvel, 1989; Porter et al., 1997; Riedell et al., 1998; Singer and Cox, 1998; Stecker et al., 1995). However, much less is known when non-legume species, such as winter wheat (*Triticum aestivum* L.), are removed from common maize-based rotations in the northern Corn Belt.

The potential effect of rotation diversity on crop response to N fertilization is of interest given escalating N fertilizer costs (USDA-NASS, 2014a) and continuing concerns about the negative impact of fertilizer N production and potential losses on environmental quality (Lebender et al., 2014; Peoples et al., 2004; Syswerda et al., 2012). Increasing N use efficiency (NUE) has also been a long-lasting research goal, particularly for maize, which is a major user of N. Although the amount of maize grain produced per unit of N applied (PFP_N) in the United States has increased linearly by 36% in the last 21 years (from 42 kg kg^{-1} in 1980 to 57 kg kg^{-1} in 2000), due to a combination of high yielding hybrids and improvement in crop management, the amount of N fertilizer recovered in aboveground plant biomass during the growing season (RE_N) remains relatively low (~37% across various rotations in the North-Central USA) (Cassman et al., 2002), and significant opportunities remain to improve N fertilizer use practices in maize. For instance, the impact of wheat in maize–soybean rotations on the diminishing return function between maize yield and N supply and NUE is not well understood.

We hypothesized that maintaining crop rotation diversity is instrumental to increase productivity, maize N fertilizer use efficiency and decrease crop N requirements. We used yield data (2009–2013) gathered at a long-term N regime and rotation trial to quantify benefits of maintaining wheat in short maize- and soybean-based rotations on: (1) cropping system's productivity, (2) crop N requirements, (3) NUE, and (4) whether the temporal niche provided by winter wheat for red clover or tillage system influences these responses.

2. Material and methods

2.1. Study site

Research was conducted from 2009 to 2013 on a field trial that was established at the University of Guelph Ridgetown Campus,

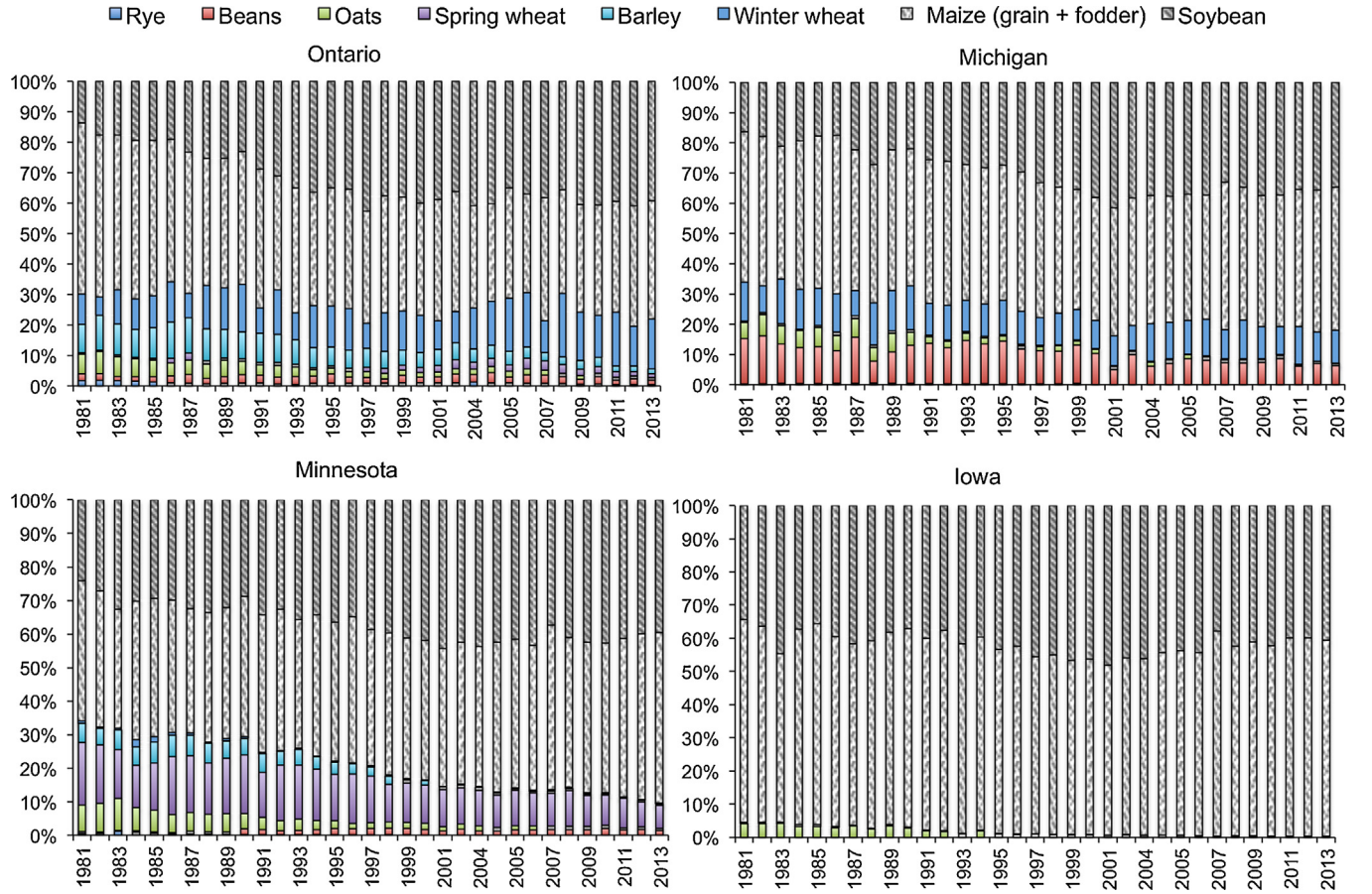

Fig. 1. Harvested areas of field crops grown in four states/provinces of the northern Corn Belt from 1981–2013. Harvested areas (hectares) of major field crops are shown as % of total harvested area from 1981 to 2013 for Ontario (OMAFRA, 2014), Michigan, Minnesota and Iowa (USDA-NASS, 2014b). Surface areas harvested in canola and hay were not included for clarity.