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Improving crop yield and N uptake with long-term straw retention in two contrasting soil types

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ABSTRACT

Retention and/or reincorporation of plant residues increases soil organic nitrogen (N) levels over the long-term is associated with increased crop yields. There is still uncertainty, however, about the interaction between crop residue (straw) retention and N fertilizer rates and sources. The objective of the study was to assess the influence of straw management (straw removed [S_{Rem}] and straw retained [S_{Ret}]), N fertilizer rate (0, 25, 50 and 75 kg N ha^{-1}) and N source (urea and polymer-coated urea [called ESN]) under conventional tillage on seed yield, straw yield, total N uptake in seed + straw and N balance sheet. Field experiments with barley monoculture (1983–1996), and wheat/barley-canola-triticale-pea rotation (1997–2009) were conducted on two contrasting soil types (Gray Luvisol [Typic Haplocryalf] loam soil at Breton; Black Chernozem [Albic Argicryoll] silty clay loam at Ellerslie) in north-central Alberta, Canada. On the average, S_{Ret} produced greater seed yield (by 205–220 kg ha^{-1}), straw yield (by 154–160 kg ha^{-1}) and total N uptake in seed + straw (by 5.2 kg N ha^{-1}) than S_{Rem} in almost all cases in both periods at Ellerslie, and only in the 1997–2009 period at Breton (by 102 kg seed ha^{-1}, 196 kg straw ha^{-1} and by 3.7 kg N ha^{-1}) for both N sources. There was generally a considerable increase in seed yield, straw yield and total N uptake in seed + straw from applied N up to 75 kg N ha^{-1} rate for both N sources at both sites and more so at Breton, but the response to applied N decreased with increasing N rate. The ESN was superior to urea in increasing seed yield (by 109 kg ha^{-1}), straw yield (by 80 kg ha^{-1}) and total N uptake in seed + straw (by 2.4 kg N ha^{-1}) in the 1983–1996 period at Breton (mainly at the 25 and 50 kg N ha^{-1} rates). But, urea produced greater straw yield (by 95 kg ha^{-1}) and total N uptake in seed + straw (by 3.3 kg N ha^{-1}) than ESN in the 1983–1996 period at Ellerslie. The N balance sheets over the 1983–2009 study duration indicated large amounts of applied N unaccounted for (ranged from 740 to 1518 kg N ha^{-1} at Breton and from 696 to 1334 kg N ha^{-1} at Ellerslie), suggesting a great potential for N loss from the soil–plant system through denitrification and/or nitrate leaching, and from the soil mineral N pool by N immobilization. In conclusion, the findings suggest that long-term retention of crop residue may gradually improve soil productivity. The effectiveness of N source varied with soil type.

1. Introduction

Soil fertility is the second most limiting production factor in dryland cropping systems (Havlin, 2005). Therefore, identifying management practices that enhance soil fertility is desirable. Crop residues are a source of soil organic matter, which is the primary source of plant nutrients and an energy source for soil microorganisms. Long-term retention rather than removal of crop residues from land and appropriate fertilization have been shown to enhance soil quality (Nyborg et al., 1995b; Janzen et al., 1998; Solberg et al., 1998; Kumar and Goh, 1999). In Australia (Queensland), USA (Colorado and Ohio), England (Rothamsted and Woburn) and in the Black (Boroll) and Gray (Cryalf) soil zones of western Canada (Alberta and Saskatchewan), retaining crop residues and N fertilization have shown improvement in soil organic C and N, and some other soil properties and potential for sustaining high crop yields (Nuttall et al., 1986; Dalal, 1989, 1992; Campbell et al., 1991; Follett et al., 1997; Lal, 1997; Malhi et al., 2006, 2011; Malhi and Lemke, 2007; Powlson et al., 2011).

Soil nitrogen (N) cycling is altered when crop residues are retained. During decomposition of retained crop residues, there is generally an initial period of net N immobilization followed by a period of net N re-mineralization (Kumar and Goh, 1999; Recous et al., 1999). The duration and kinetics of this initial immobilization period depend on the nature of the residue (i.e., C:N ratio, lignin and polyphenol contents; Reinertsen et al., 1984; Kumar and

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Goh, 1999), and initial soil mineral N concentrations (Reinertsen et al., 1984; Recous et al., 1995). In the field, pH, temperature, moisture, freezing–thawing cycles, wetting–drying cycles, salinity, soil texture and micro and macrofauna all affect the rate of crop residue decomposition and N mineralization–immobilization dynamics (Kumar and Goh, 1999). When residues are not retained, net mineralization is dominant (Recous et al., 1999). Long-term retention of crop residues has been shown to increase soil organic N content in both conventional and conservation tillage systems (Kumar and Goh, 1999; Luxhøi et al., 2007) and seed yield (Power et al., 1998). Incorporation of legume residues generally increases yield and N uptake of subsequent cereal crops (Kumar and Goh, 1999). Thus, crop residues are a source of N for the microbial biomass and for plants and their retention may result soil N cycling that enhances crop yield and N uptake, but so far there are few long-term studies that report the impact of crop residue retention.

Because of N immobilization by straw, incorporation of straw into soil is expected to cause decrease in crop yield and N uptake compared to its removal from the field, but the magnitude and frequency of reduction in yield and N uptake depends upon the amount of straw retained, C:N ratio of straw, rate of applied N, soil type and climatic conditions. For example, in an 11-year study with continuous barley monoculture in north-central Alberta, retention and incorporation of straw into soil reduced barley yield and N uptake in the initial six years on a low organic matter Gray Luvisol soil and in only two years on a Black Chernozem soil with high organic matter (Nyborg et al., 1995a). Similarly, in a 10-year study on a Dark Gray soil in northern Alberta, Soon (1999) reported lower annual barley yield and N uptake in straw ploughed-in treatments compared to straw removal treatments. In another study on a Dark Brown soil in southern Alberta with cereals and oilseeds grown for 16 years, incorporation of straw by ploughing reduced seed yield, straw yield and N uptake compared to straw removed by baling at low N rates (0 and 50 kg N ha^{-1}) but not at high N rates (100 and 200 kg N ha^{-1}) (Smith et al., 2004). In a 12-year study with continuous barley receiving N fertilizer at 30–160 kg N ha^{-1} in Denmark, incorporation of straw caused a yield depression in 2 of the 4 soils at low N rates, but the negative effect of straw decreased with increased N rate (Schjonning, 1986). In a one-year field experiment in South Africa, seed yield of wheat decreased with incorporation of straw at 3 Mg ha^{-1} at 0 and 60 kg N ha^{-1} rates but not at the 120 kg N ha^{-1} rate (Agenbag et al., 1998). In a 5-year study in England, incorporation of straw at 10 Mg ha^{-1} reduced seed and straw yield of winter-wheat only in the first year (Jenkyn et al., 2001). In other studies in the Canadian prairies (Saskatchewan), there was no reduction in crop yield and N uptake observed with straw incorporation compared to its removal over 8 years, and in fact there was an increase in crop yield and N uptake in some years due to straw addition, particularly in years with below average precipitation (Malhi et al., 2006; Malhi and Lemke, 2007). Similarly, in a long-term study with winter-wheat on an Alfisol soil in Denmark, seed and straw yields increased following annual incorporation of straw at 8 and 12 Mg ha^{-1} over a period of 18 years (Thomsen and Christensen, 2004). The preceding literature suggests uncertainty in crop yield and N uptake with straw addition, and supports the need for long-term results under varied soil-climatic conditions.

In addition to the uncertainty about yield and N uptake benefits of long-term crop residue retention, interactions between type, rate and placement of N fertilizer are not well-studied. Information about the interaction between slow-release forms of N fertilizer and retained crop residues is especially scarce. In China, research has shown increased yield of cereals fertilized with coated urea (Fan et al., 2004). In Canada, spring-applied polymer-coated urea (called ESN) also produced greater seed yield, N recovery and N-use efficiency (NUE) than urea in 2 site-years (relatively wet conditions), while no differences between the two N sources in 5 other site-years (Malhi et al., 2010). These workers suggested that the ability of ESN to increase crop yield and N recovery compared to similarly applied urea depends upon soil moisture conditions. Other studies have reported no improvement in the performance of cereals with coated urea (Zhang et al., 2000), or reduction in crop yield in some years (Malhi et al., 2010). These studies, however, did not investigate the interaction between crop residue management (retention or removal) and N source. The objective of this study was to determine the influence of straw management, N fertilizer rate and N source on seed yield, straw yield, total N uptake in seed + straw and N balance sheet over 27 years (from 1983 to 2009) in two contrasting soil types under conventional tillage.

2. Materials and methods

2.1. Location and experimentation

Field experiments were conducted on an Orthic Gray Luvisol (Typic Haplocryalf) at Breton (53°07′N, 114°28′W; elevation 830 m) and a Black Chernozem (Albic Argicryoll) at Ellerslie (53°25′N, 113°33′W; elevation 692 m), Alberta, Canada. At Breton, the soil (0–15 cm) had loam texture, pH of 6.6, 0.4 mg nitrate-N kg^{-1} and initial total C concentration of 13.1 g C kg^{-1}. At Ellerslie, the soil (0–15 cm) had silty clay loam texture, pH of 6.0, 0.7 mg nitrate-N kg^{-1} and initial organic C concentration of 60.9 g C kg^{-1}. The mean annual precipitation is about 475 mm in the Breton area and 450 mm in the Ellerslie area. In both areas, the growing season is from May to August, and approximately 60% of the total precipitation occurs in the growing season. Growing season precipitation (GSP—May to August, in each year from 1983 to 2009) and total annual precipitation (September to August, in each year from September 1, 1983 to August 31, 2009) at both sites are presented in Fig. 1.

The experiments were initiated in the autumn of 1982. The treatments included two straw managements (straw removed [S_{Rem}] and straw retained [S_{Ret}]), four N rates (0, 25, 50 and 75 kg N ha^{-1}) and two N sources (urea and polymer-coated urea [called ESN]) under conventional tillage (Table 1). The treatments were arranged in a randomized complete block design (RCBD) in four replications. Individual plots were 2.8 m × 6.9 m. All plots were tilled twice, once in the autumn and once in the spring prior to seeding, with a chisel cultivator followed by a coil packer. The plots were planted to barley (*Hordeum vulgare* L.) monoculture from 1983 to

Table 1
Description of treatments under conventional tillage in field experiments established in the autumn of 1982 at Breton (Gray Luvisol) and Ellerslie (Black Chernozem), Alberta, Canada.

Treatment[a]		N source[a]	Rate of N (kg N ha^{-1})	Straw management
No.	ID			
1	S_{Rem}25–ESN	ESN	25	Straw removed
2	S_{Ret}25–ESN		25	Straw retained
3	S_{Rem}50–ESN		50	Straw removed
4	S_{Ret}50–ESN		50	Straw retained
5	S_{Rem}75–ESN		75	Straw removed
6	S_{Ret}75–ESN		75	Straw retained
7	S_{Rem}25–U	Urea	25	Straw removed
8	S_{Ret}25–U		25	Straw retained
9	S_{Rem}50–U		50	Straw removed
10	S_{Ret}50–U		50	Straw retained
11	S_{Rem}75–U		75	Straw removed
12	S_{Ret}75–U		75	Straw retained
13	S_{Rem}0	No N	0	Straw removed
14	S_{Ret}0		0	Straw retained

[a] ESN: polymer-coated urea supplied by Agrium; U: urea; S_{Rem}: straw removed; S_{Ret}: straw retained.