LONG-TERM STRAW MANAGEMENT AND N FERTILIZER RATE EFFECTS ON CROP YIELD, N UPTAKE AND N BALANCE SHEET IN A BLACK CHERNOZEM

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Abstract

A field experiment with barley monoculture (1983-1996), and wheat/barley-canola-triticale-pea rotation (1997-2009) was conducted on a Black Chernozem [Albic Argicryoll] silty clay loam at Ellerslie, Alberta, 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. 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 (by 5.2 kg N ha^{-1}) than S_{Rem} in almost all cases in both periods for both N sources. There was a considerable increase in yield and total N uptake up to 75 kg N ha^{-1} rate. Urea produced greater straw yield (by 95 kg ha^{-1}) and total N uptake (by 3.3 kg N ha^{-1}) than ESN in the 1983-1996 period. The N balance sheets over the 1983-2009 study duration indicated large amounts of applied N unaccounted for ranging from 696 to 1334 kg N ha^{-1}, 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.

Rationale and Objective

Crop residues are a source of soil organic matter, which is the primary source of plant nutrients and energy source for soil micro-organisms. Long-term continuous cropping, retaining crop residues and improved fertilization can improve soil quality/fertility and sustain productivity. There is limited information on the long-term effects of crop residue and N fertilizer management on crop production and nutrient uptake. The objective of this study was to determine the long-term effects 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) on a Black Chernozem soil under conventional tillage.

Materials and Methods

Field experiment was conducted at Ellerslie (53°25'N, 113°33'W; elevation 692 m), Alberta, Canada, on a Black Chernozem (Albic Argicryoll), with loam texture, pH of 6.0 and initial organic C concentration of 56.45 g C kg^{-1}. This area has growing degree days (GDD) of 2419 at >0°C and GDD of 1402 at >5°C, a 120 day frost free period, and a mean daily temperature of 14°C (8°C to 21°C) in the growing season. The mean annual precipitation is about 450 mm in this area. The growing season is from May to August, and approximately 60% of the total precipitation occurs in the growing season (335 mm, with a range of 190 to 440 mm). The experiment was initiated in the autumn of 1982.

The treatments included two straw managements (straw removed [SRem] and straw retained [SRet]), 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 in a randomized complete block design in four replications. All plots were tilled twice, once in autumn and once in spring, with a chisel cultivator followed by a coil packer. The plots were planted to barley (*Hordeum vulgare* L.) monoculture from 1983 to 1996 (Solberg et al. 1997). However, after 1996, barley (2002, 2009) was rotated with other crops to include spring wheat (*Triticum aestivum* L.; 1997, 1998, 2006), canola (*Brassica napus* L.; 1999, 2003, 2007), triticale (X *Triticosecale*, Wittmack; 2000, 2004, 2008), or pea (*Pisum sativum* L.; 2001, 2005). Data were collected on seed and straw yield, and total N uptake. For N balance sheet, N fixed by pea was estimated based on the published information in the region (Annonymous 2005), with slight modifications after taking into account for variations in crop yield.

Summary of Results

Growing conditions

Precipitation during the growing season (May, June, July and August) was substantially below the long-term average in 6 years (1984, 1985, 1992, 1995, 2002, and 2009) and above average in 5 years (1987, 1988, 1989, 1990, and 2008). In other years, the GSP was either slightly below average or slightly above average.

Seed and straw yield, and total N uptake (Figures 1 to 6)

On the average of 1983 to 1996, straw yield and total N uptake in seed + straw increased up to 75 kg N ha^{-1} rate, but seed yield increased only up to 50 kg N ha^{-1} rate. Seed and straw yield tended to be greater with SRet than SRem, but total N uptake was similar for S_{Ret} and S_{Rem}. The response of seed and straw yield to applied N was greater with S_{Ret} than S_{Rem}. Seed and straw yield, and total N uptake were slightly greater (not significant) with urea than ESN. There was greater seed and straw yield and total N uptake with urea than ESN under S_{Ret} but no effect of N source under S_{Rem}. Urea tended to be superior than ESN at 50 kg N ha^{-1}, but the opposite occurred at 75 kg N ha^{-1}, while no effect at 25 kg N ha^{-1}. The response trends of seed and straw yield, and total N uptake to straw management, N rate and N source during the period from 1997 to 2009 were generally similar to that during 1983 to 1996, with only few exceptions. For example, during 1997 to 2009 period, seed yield increased up to the 75 kg N ha^{-1} rate.

Nitrogen balance sheet (Table 1)

The estimated amounts of nitrate-N recovered in soil + N removed in seed in all treatments and in straw in SRem treatments ranged from 1173 to 2212 kg N ha^{-1} in various treatments. The estimated amounts of N applied as inorganic fertilizer in 24 years, plus BFN (biologically fixed N) in 3 years when pea was grown + N added in seed in 27 years ranged from and 420 to 2204 kg N ha^{-1}. The amounts of N that could not be accounted for ranged from -822 to 161 kg N ha^{-1}. The amounts of unaccounted N from N applied/fixed/added ranged from 696-1344. The moderate amounts of residual nitrate-N recovered in the 30-60 and 60-90 cm soil layers in autumn 2009 suggest that a portion of applied N may have leached below the 90 cm depth, particularly at the 75 kg N ha^{-1} rate. This suggests the need for deep soil sampling in future to make valid conclusion related to nitrate leaching losses in the soil profile. Our results suggest no over-application of N compared to crop requirement for this region where soil moisture usually is not a limiting factor for normal crop growth. It is possible that a portion of the applied N in N treatments may have been immobilized in soil organic N, as evidenced by higher amount of soil N in LFON especially in SRet than SRem treatments (Malhi et al. 2011). In addition, it is also possible that a small portion of the applied N may have been lost from the soil-plant system through denitrification (e.g., nitrous oxide and other N gases) due to wet soil conditions which temporarily exist in the present study in some years in early spring after snow melt or after occasional heavy rainfall during summer and/or autumn.

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Balance sheets of long-term straw management and N rate treatments from 1983-2009 in field experiments established in the autumn of 1982 at Ellerslie, (Black Chernozem), Alberta, Canada.

Site/parameter	Treatments							
	[z]S_{Rem}25-U	S_{Ret}25-U	S_{Rem}50-U	S_{Ret}50-U	S_{Rem}75-U	S_{Ret}75-U	S_{Rem}0	S_{Ret}0
Black Chernozem - Ellerslie								
Nitrate-N recovered in soil (0-90 cm) in autumn 2009 (kg N ha^{-1})	18	34	40	78	16	27	43	60
N removed in seed in 27 years (kg N ha^{-1})	1360	1473	1763	1911	1908	2016	1074	1113
N removed in straw in S_{Rem} treatments in 27 years (kg N ha^{-1})	171	0	239	0	288	0	125	0
N removed in seed in all treatments and in straw in S_{Rem} treatments in 27 years (kg N ha^{-1})	1531	1473	2002	1911	2196	2016	1199	1113
N recovered in soil after 27 years + N removed in seed + in straw in 27 years (kg N ha^{-1})	1549	1507	2042	1989	2212	2043	1242	1173
Inorganic N applied in fertilizers in 24 years (kg N ha^{-1})	600	600	1200	1200	1800	1800	0	0
Organic N fixed when pea was crop in 3 years in 2001, 2005 and 2009 (kg N ha^{-1})	343	386	347	366	327	344	360	421
Organic N added in seed in 27 years (kg N ha^{-1})	60	60	60	60	60	60	60	60
N applied in 24 years + N fixed in 3 years + N added in seed in 27 years (kg N ha^{-1})	1003	1046	1607	1626	2187	2204	420	481
N balance (N applied/fixed/seed – N removed in seed/straw) (kg N ha^{-1})	-528	-427	-395	-285	-9	188	-779	-632
Unaccounted N (N applied/fixed/seed – N recovered in soil + seed/straw) (kg N ha^{-1})	-546	-461	-435	-363	-25	161	-822	-692
N removed in seed/straw in 27 years from applied N (kg N ha^{-1})	332	360	803	798	997	903		
N recovered in soil after 27 years + seed/straw in 27 years from applied N (kg N ha^{-1})	307	334	800	816	970	870		
N balance (N applied/fixed/seed – N removed in seed/straw from applied N) (kg N ha^{-1})	671	686	804	828	1190	1301		
Unaccounted N (N applied/fixed/seed – N recovered in soil + seed/straw from applied N) (kg N ha^{-1})	696	712	807	810	1217	1334		
Recovery of applied N in seed over 27 years (%)	47.7	60.0	57.4	66.5	46.3	50.2		

[z]S_{Rem} = Straw removed; S_{Ret} = Straw retained; 0, 25, 50 and 75 kg N ha^{-1}. U = urea.

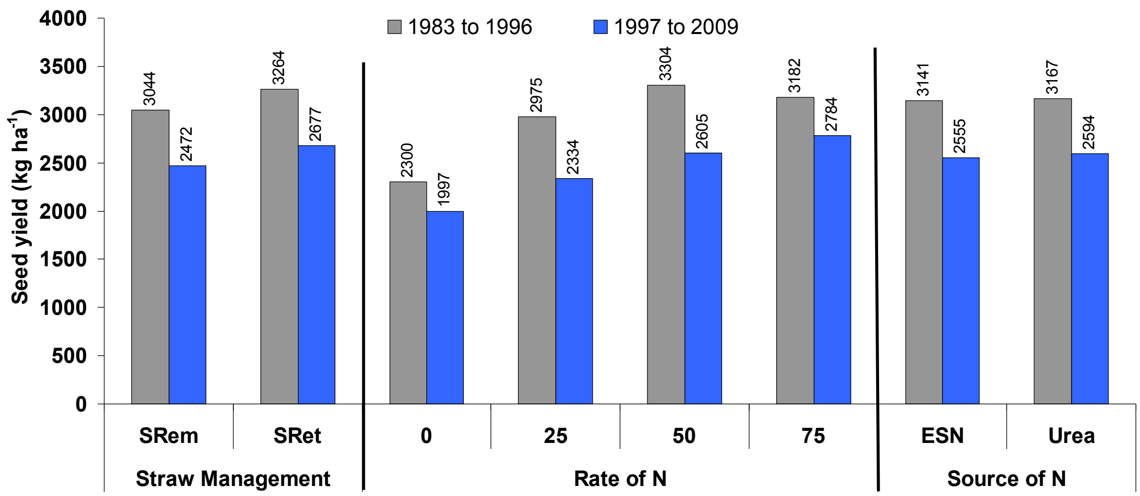

Figure 1. Effect of long-term straw management, N source and N rate on mean seed yield, from 1983 to 1996 and 1997 to 2009 at Ellerslie, Alberta, Canada (Black Chernozem soil, experiment established in autumn, 1982).

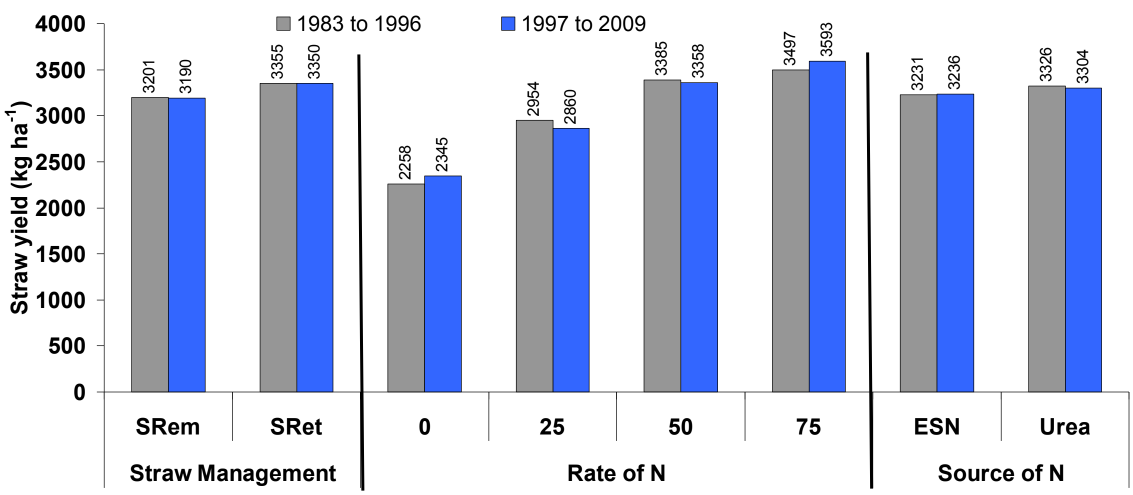

Figure 2. Effect of long-term straw management, N source and N rate on mean straw yield from 1983 to 1996 and 1997 to 2009 at Ellerslie, Alberta, Canada (Black Chernozem soil, experiment established in autumn, 1982).

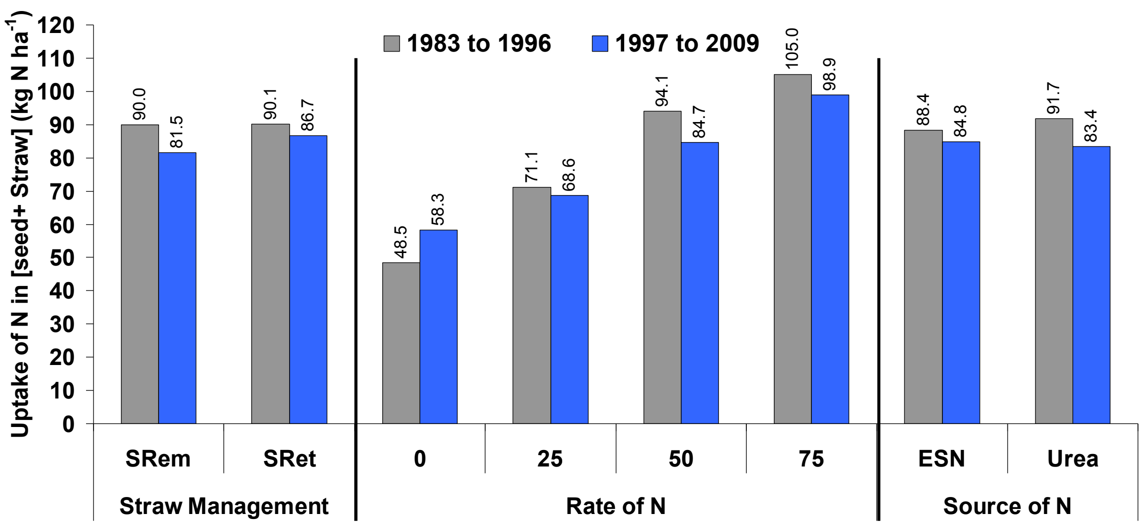

Figure 3. Effect of long-term straw management, N source and N rate on mean total N uptake in seed + straw from 1983 to 1996 and 1997 to 2009 at Ellerslie, Alberta, Canada (Black Chernozem soil, experiment established in autumn, 1982).

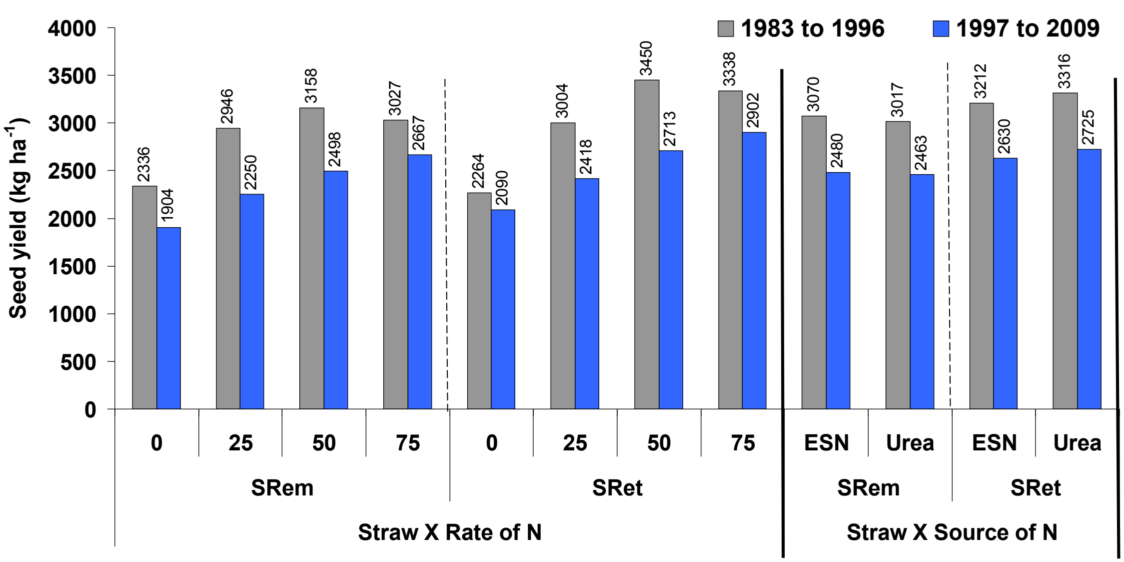

Figure 4. Effect of long-term straw management, N source and N rate interactions on mean seed yield from 1983 to 1996 and 1997 to 2009 at Ellerslie, Alberta, Canada (Black Chernozem soil, experiment established in autumn, 1982).

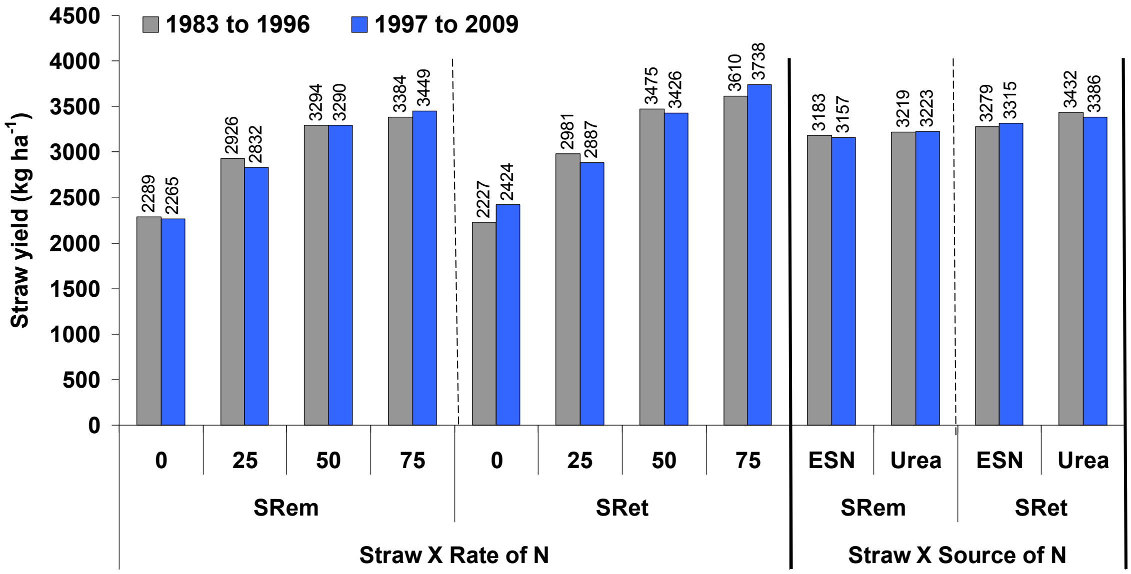

Figure 5. Effect of long-term straw management, N source and N rate interactions on mean straw yield from 1983 to 1996 and 1997 to 2009 at Ellerslie, Alberta, Canada (Black Chernozem soil, experiment established in autumn, 1982).

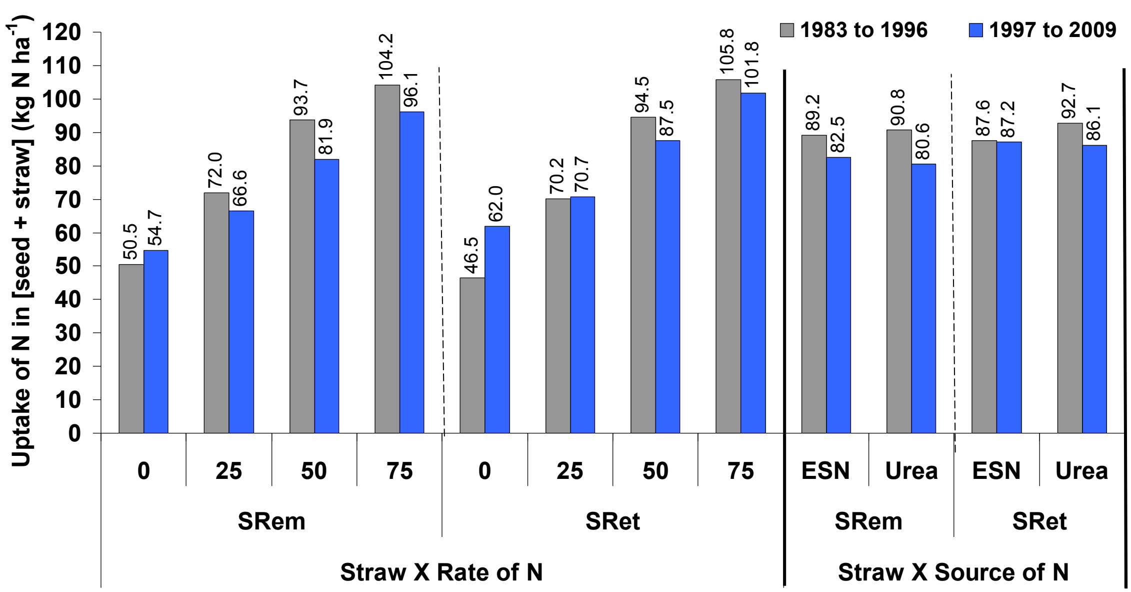

Figure 6. Effect of long-term straw management, N source and N rate interactions on mean total N uptake in seed + straw from 1983 to 1996 and 1997 to 2009 at Ellerslie, Alberta, Canada (Black Chernozem soil, experiment established in autumn, 1982).