Management Strategies to Improve Yield and Nitrogen Use of Spring Wheat and Field Pea in the Semi-Arid Northern Great Plains USA.

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Abstract
Available water and N fertility are primary constraints to crop production in the northern Great Plains of the USA. A field trial was initiated in 2004 to compare four crop rotations in a complete factorial of two tillage and two management systems. Rotations were continuous spring wheat (SW), pea-SW, barley hay-pea-SW, and barley hay-corn-pea-SW. Tillage systems were no till and field cultivator tillage, while management systems were conventional and ecological. Conventional management included broadcast nitrogen fertilizer, standard seeding rates, and short stubble height. Ecological management practices varied by crop, and included banded nitrogen fertilizer for cereals, increased seeding rate, delayed planting date for SW, and taller stubble height. Continuous SW grain yield was 26% lower than SW in more diverse rotations. Pea grain yield was 18% lower in 2-yr rotations than in more diverse rotations. Ecologically managed SW yielded 29% less than conventionally managed SW, presumably due to the delayed planting date. Ecological management of pea resulted in 12% greater yield compared to conventional management. Tillage system rarely impacted crop yield. Yield increases in SW were related to increased N use efficiency.

Key Words
Crop rotation; Zero tillage; Nutrient management; Long term experiment; Wheat production, Pea production.

Introduction
Crop productivity in the semi-arid northern Great Plains (NGP) of the USA and Canada typically is limited by available soil water and plant available N. A SW-fallow rotation is most common to increase storage of soil water for the subsequent crop, but this practice increases the risk of soil erosion from wind and water and typically reduces soil C and other measures of soil quality. Another challenge facing producers is the reliance on expensive N fertilizer. Diversified crop rotations and inclusion of legumes could improve rotational productivity and nutrient cycling, lower rotational N requirements, and reduce input costs. Further research is warranted to identify farming systems that lower production risk, improve productivity, and provide sustainable environmental benefits. Management practices that alter planting date, fertilizer placement, and seeding rate could contribute to more sustainable and competitive cropping systems. This report addresses N use and crop yield results for different crop rotations and tillage and management systems for the first four years of a long-term, multidisciplinary project. Other components under consideration, but not reported here, are influences of crop diversification, tillage, and management system on crop yield and quality, water and nitrogen use, soil quality, microbial diversity, carbon sequestration, and pest dynamics.

Methods
Site and soil description
The field site location was approximately 8 km northwest of Sidney, Montana, USA (latitude 47°46'N; longitude 104°15'W; altitude 690 m) with a slope of 0.5%. Soil was a Williams loam (fine-loamy, mixed, superactive, frigid Typic Argiustolls) formed in glacial till with a pH of 6.9, organic matter of 1.8%, and soil-test P (Olsen) of 12 mg/kg for the 0-15 cm depth.

Experimental design, statistics, and treatments
The long-term dryland field trial initiated in 2004 compared four crop rotations with two tillage and two management systems. The experimental design was a randomized complete block in a split-plot arrangement with tillage system (no-tillage versus single-pass preplant tillage using a field cultivator) as the whole-plot factor. Subplots were a complete factorial of management system (conventional versus ecological) and rotation components (1, 2, 3, or 4 yr crop rotation). Rotations were continuous SW, SW-pea, SW-barley hay-

pea, and SW-barley hay-corn-pea, with all phases present each year. Conventional and ecological management practices varied by crop. Conventional management included standard seeding rates and broadcast nitrogen fertilizer for cereals and corn, and short stubble height at SW harvest. Ecological management included seeding rates 33% above conventional levels, banded nitrogen fertilizer for cereals, delayed planting date for SW, and taller stubble height at SW harvest. Plot size was 12.2 m by 12.2 m, with three replicates of each treatment combination for a total of 120 plots. Data were analysed with SAS using Proc Mixed with year and rep as random effects (SAS Institute, Cary, NC). Regression analysis using individual plot values was used to describe relationships between wheat yield and nitrogen use. Significant differences among treatments are reported at $P<0.05$.

Urea was broadcast at 67 and 101 kg N/ha for barley and SW, respectively, in April prior to preplant tillage or no till planting. Corn plots received 78 kg N/ha as urea in May. Preplant conventional tillage to a 7-8 cm depth was with C-shank sweeps spaced 45-cm apart and 60 cm length coil-tooth spring harrows. Conventional- and ecological management barley 'Haybet', green field pea 'Majoret', and conventional management SW 'Reeder' were planted in early-mid April on 20-cm row spacing with double-shoot Barton disk openers for low disturbance planting and single-pass seeding and fertilization. Ecologically managed barley received 67 kg N/ha as urea banded at planting. Phosphorus (N-P_2O_5-K_2O: 11-52-0) and potash (0-0-60) were banded 5 cm below and to the side of seed at 56 and 48 kg/ha, respectively, when planting all wheat, barley, and pea plots. Barley and pea plots were rolled just after planting to push rocks back into soil after seeding to protect grain and forage harvest equipment. Ecologically managed SW was planted about three weeks after conventionally managed SW to allow the first emergence flush of wild oat (*Avena fatua*). Urea was banded at planting for ecologically managed SW at the same rate as conventionally managed SW. Pioneer '39T67-RR' hybrid corn was planted in mid-May. Barley, SW and corn were treated with labelled fungicide seed treatments.

Soil samples (5-cm diameter) were taken each spring and fall (except Fall 2006) to depth of 120 cm in 15 cm increments for the surface 30 cm and in 30 cm increments thereafter. Soil was dried at 25° C and analysed for nitrate and ammonium by flow injection. Nitrogen use was evaluated using data from 2006 and 2008 for a nitrogen harvest index (NHI) and for all years for a nitrogen removal index (NRI) and a nitrogen mass balance approach. The NHI represents the proportion of grain N in total biomass N, and the NRI represents the proportion of grain N relative to total N inputs (fertilizer N and preplant nitrate to 60 cm depth). The nitrogen mass balance was calculated by subtracting inputs (fertilizer and spring soil nitrate) from outputs (crop N uptake and residual fall soil nitrate), such that a negative value signifies N evolution while a positive value signifies N consumption by soil.

Yield

Biomass samples for pea, SW, and barley hay were harvested by hand clipping two 0.5 m^2 quadrats per plot. Yield samples for pea and SW were taken with a self-propelled combine equipped with a 1.5-m header harvesting a 10-m length. Crop biomass and grain samples were dried at 55° C and weighed. Yield and biomass data are presented on a 100% dry matter basis. Plot clean-off was done with a self-propelled combine equipped with a 4-m wide header and a straw chopper to evenly distribute residue. Stubble height was about 15-20 cm and 25-30 cm for conventionally- and ecologically managed SW, respectively.

Results

Weather

Growing season (April through September) precipitation and air temperature varied by year. The 2005, 2007, and 2008 growing seasons were characterized by average precipitation levels 8%, 6%, and 46% below the long term (48 yr) average of 272 mm rainfall, respectively, while 2006 was 14% above normal. The average air temperature during the growing season was 3%, 9%, and 4% warmer than the long term average for 2005, 2006, and 2007, respectively, while 2008 was 3% cooler than normal.

Spring wheat yield

Grain yield of continuous spring wheat was 26% lower than that of wheat grown in two, three, and four-year rotations (Figure 1). Additional increased rotational diversity did not impact grain yield, as wheat yields were similar in the two, three, or four year rotations and averaged 2.4 Mg/ha. Tillage treatment had little effect on wheat grain yield, as tilled and no till plot yields were similar and averaged 2.2 Mg/ha (Figure 1). However, grain yield was different between management systems where ecological management was 29% lower than conventional management. The yield reduction in ecological managed wheat was most likely due to the delayed planting date. The interactions for wheat and pea yield were not significant at the 0.05 level for tillage×management, tillage×rotation, rotation×management, or tillage×management×rotation.

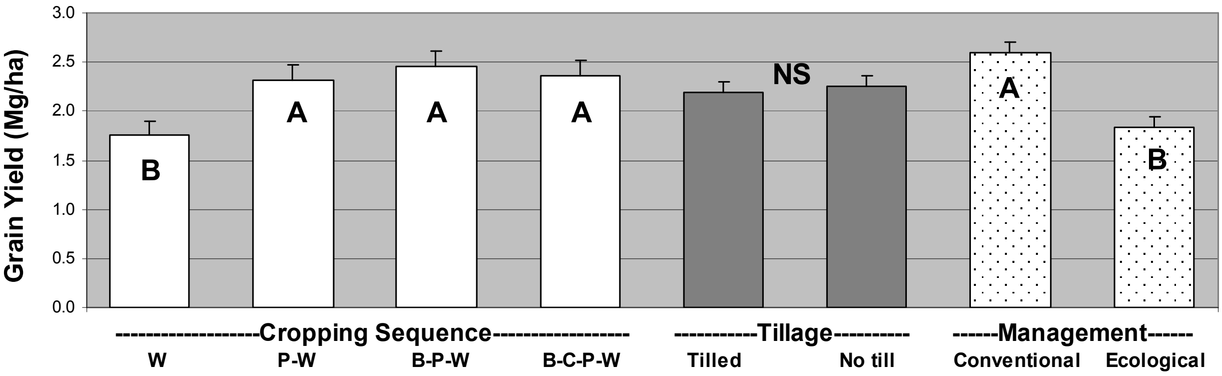

Figure 1. Mean spring wheat yield (SE) from four cropping sequences, two tillage systems, and two management systems. Different letters indicate a significant difference (P<0.05) between treatments. NS is not significant. Note crop sequences are continuous wheat, pea-wheat, barley hay-pea-wheat, and barley hay-corn-pea-wheat.

Pea yield

Pea yield averaged 2.2, 2.0, 2.5, and 0.5 Mg/ha for 2005, 2006, 2007, and 2008 respectively. Greater yield in 2007 than other years was most likely related to the 79 mm above normal precipitation during May. Reduced pea yield in 2008 was reflective of the drought conditions, and grain yield was 77% lower than the 2005-2007 average. Grain yield of pea in the two-year rotation was 18% lower than that of pea grown in three and four-year rotations (Figure 2). Increasing the level of rotational diversity beyond the three yr did not impact grain yield, as pea yields were similar in the three and four year rotations and averaged 1.9 Mg/ha. Tillage treatment had little effect on pea grain yield, as tilled and no till plot yields were similar and averaged 1.8 Mg/ha (Figure 2). However, grain yield was different between management systems where ecological management was 12% greater than conventional management. The yield increase in ecological managed pea was most likely due in part to the greater seeding rate and to the increased stubble height of previous crops.

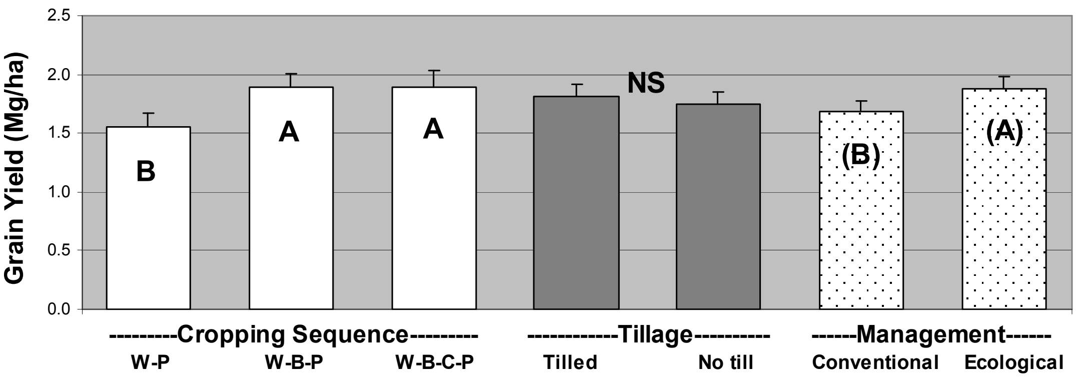

Figure 2. Mean pea yield (SE) from three cropping sequences, two tillage systems, and two management systems. Different letters indicate a significant difference (P<0.05) between treatments. Letters in parenthesis indicate a significant difference at P<0.10. NS is not significant, Note crop sequences are wheat-pea, wheat-barley hay-pea, and wheat-barley hay-corn-pea.

Wheat N use

Wheat yield was highly related (P<0.001; r^2 = 0.89) to NRI, indicating the importance of N use efficiency in dryland wheat production. Indicators of N use efficiency were less favorable for continuous spring wheat than for wheat grown in two, three, and four-year rotations (Table 1). Increasing levels of rotational diversity did not impact nitrogen use efficiency as grain N, biomass N, residual soil nitrate, N balance, NHI, and NRI were similar in the two, three, or four year rotations. Tillage treatment generally had little effect on indicators of N use efficiency (Table 1). However, differences were apparent between management systems where ecological management typically used N less efficiently than conventional management (Table 1). A rotation×management interaction (P<0.05) for grain N removal indicated conventional continuous wheat was similar to that of ecological wheat in two, three, and four-year rotations.

Table 1. Spring wheat grain N, biomass N, residual Fall soil nitrate (0-60 cm), N balance, nitrogen harvest index (NHI), and nitrogen removal index (NRI) means for 2005-2008.

Treatment	Grain N	Biomass N	Residual NO_3^-	N balance	NHI	NRI
	---------------------------kg/ha---------------------------					
Crop Sequence						
W	50.2 b	64.0 b	54.1	48.7 a	0.50 b	0.35 b
P-W	64.6 a	68.0 a	47.7	27.9 b	0.78 a	0.49 a
B-P-W	66.9 a	76.9 a	44.3	28.7 b	0.74 a	0.49 a
B-C-P-W	65.8 a	72.3 a	47.9	30.9 b	0.70 a	0.47 a
Tillage						
Tilled	60.8	70.7	55.3	27.0	0.65	0.45
No till	63.0	70.0	41.7	41.1	0.71	0.45
Management						
Conventional	71.2 a	69.9 b	54.4 a	19.2 b	0.82 a	0.52 a
Ecological	52.5 b	70.8 a	42.6 b	48.9 a	0.54 b	0.38 b

Pea N use

Increased levels of rotational diversity had variable effects on indicators of nitrogen use efficiency in pea (Table 2). Grain N was greater in three and four-year than two-year rotations. Biomass N was greater in four-year than either of the less diverse rotations. The NHI was greater in three-year than two and four-year rotations, though this difference could be attributed in part to a different crop preceding pea in each rotation. Residual soil nitrate, N balance, and NRI were similar among the three rotations. Tillage treatment and management system generally had little effect on indicators of N use efficiency, though grain N in pea was greater ($P<0.10$) in ecological than conventional management (Table 2).

Table 2. Pea grain N, biomass N, residual Fall soil nitrate (0-60 cm), N balance, nitrogen harvest index (NHI), and nitrogen removal index (NRI) means for 2005-2008.

Treatment	Grain N	Biomass N	Residual NO_3^-	N balance	NHI	NRI
	---------------------------kg/ha---------------------------					
Crop Sequence						
W-P	60.1 b	76.9 b	31.8	-58.1	0.64 b	2.5
W-B-P	72.0 a	83.2 b	28.8	-65.4	0.80 a	2.2
W-B-C-P	73.3 a	91.2 a	31.6	-59.6	0.68 b	2.1
Tillage						
Tilled	69.3	82.0	33.8	-62.9	0.70	2.3
No till	67.6	85.6	27.7	-59.2	0.70	2.3
Management						
Conventional	64.5 (b)*	80.5	29.5	-59.2	0.69	2.3
Ecological	72.5 (a)*	87.0	32.0	-62.9	0.72	2.3

*Letters in parenthesis indicate a significant difference at P<0.10

Conclusion

Diversification beyond a two-year rotation did not improve spring wheat yield, however pea may yield higher when planted every third or fourth year compared to planting every other year. Ecological management practices increased yields of pea, but decreased yields of spring wheat, most likely due to a delayed planting date. Results from the transition phase of this long-term study suggest that increased level of rotation diversification in wheat and pea and ecological management in pea improve yield, in part through improved N use efficiency.