EFFECT OF NITROGEN RATE AND CROPPING SYSTEM ON SOIL NUTRIENT LEVELS IN A LONG-TERM STUDY

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ABSTRACT

Diversified continuous cropping systems in semi-arid regions of the northern Great Plains may enhance sustainability. A study initiated in 2000 in southwest Montana was designed to evaluate crop productivity and economic returns for no-till and organic rotations that included small grains, pulses, and oilseeds. Our specific objective presented here was to compare soil nutrient differences from 2004 to 2012, to learn if economically superior rotations were building or depleting soil nutrients. We also wanted to learn if nitrogen (N) rate (full vs ½ rate) affected soil nutrient changes. Soils were collected from all 68 plots in early spring in 2004 and 2012. Differences in soil organic matter (SOM), soil organic nitrogen (SON), and Olsen phosphorus (Olsen P) concentrations were evaluated between 2004 and 2012. Apparent N fertilizer recoveries (excluding legumes) were compared between rotations and N rates for 2008 to 2011 to determine if some rotations were more efficient than others at using fertilizer N. Crop rotation significantly ($P<0.05$) affected changes in SOM, SON, and Olsen P with organic rotations consistently having among the lowest gains, whereas N rate did not affect changes in any of these three soil parameters. Apparent N fertilizer recovery was higher for the ½ N rate than the full N rate, yet was not different between continuous wheat and each of the diverse rotations.

INTRODUCTION

Diversified, no-till cropping systems are beneficial for pest control and soil quality, and can produce higher net economic returns than no-till continuous wheat (Miller et al. 2008). However, nitrogen needs and long term effects of these systems on soil fertility are largely unknown in the northern Great Plains. The Crop Diversification Rotation Study (CDRS) at the Agronomy Post Farm represents a unique opportunity to determine the long-term effects of rotation and N rate on long term soil fertility and health. The CDRS study was initiated in 2000, and was split into “low” and “high” management treatments in the 2004 crop year, with N rate being the most consistent low vs high management difference. The objectives of our study were to 1) determine the effect of crop rotations and N rate on 2004 to 2012 changes in soil nutrient concentrations, and 2) calculate the ratio of N removed at harvest to the amount of N fertilizer applied as an estimate of the efficiency of N fertilizer use from 2008 to 2011.

MATERIALS AND METHODS

This study evaluated changes in soil nutrient status from the 4th to 12th year of the CDRS study funded by the Montana Agricultural Experimental Station (MAES) and the Montana Wheat and Barley Committee (MWBC). The field study, conducted at the Agronomy Post Farm near Bozeman, was initiated in 2000 as a fully phased design with broadleaf and cereal crops grown concurrently, but converted to a dual phased design in 2004, with alternate year legume-cereal rotations, to increase the spatio-temporal isolation of crops and minimize pest problems. All treatments had 4 replicates. From 2004 to 2007 five annual cropping systems were represented (Table 1); no-till diversified (NTD), no-till winter (NTW) emphasizing winter crops, no-till spring (NTS) with cool-season spring crops, no-till continuous wheat (CW) alternating between winter and spring wheat, and a complementary system of organic (ORG) and pesticide-free production (PFP) rotations differentiated primarily by tillage type, pesticide use, and N regime. As a counterpart to the ORG rotation, the PFP rotation avoids soil residual and in-crop pesticides compared with conventional no-till systems. Each rotation, except ORG, PFP, and CW, has a high (H) and low (L) input strategy based largely on recommended N treatment, with L input rotations receiving half the recommended N fertilizer rate. Recommended N rates per 100 lb of targeted yield were 3, 5, 6 and 6.5 lb N for corn, wheat, safflower, and canola/flax, respectively. For wheat this equates to 3 lb N/bu (compared to MSU's guideline of 2.6 for winter wheat and 3.3 for spring wheat). The PFP and CW received only the higher N rate. Crops grown after pulses cut for grain were credited with 20 lb N/ac and legume green manures were credited with 40 lb N/ac. Urea N fertilizer was typically mid-row banded with the seed, although there were a few occasions where supplemental urea was hand-broadcast. All rotations, except the ORG rotation, were treated with 23 lb P_2O_5/ac, 22 lb K_2O/ac, and 8 lb S/ac, respectively. Each rotation, except CW, was a four-year crop rotation with phases 1 and 3 (broadleaf crops) and phases 2 and 4 (cereal crops) grown in alternate years.

In 2008, changes to rotations (Table 2) were adopted largely to address weed issues (i.e. downy brome and prickly lettuce in the NTW system and Canadian thistle in the organic system) and to enhance the comparison between legume broadleaf and non-legume broadleaf inclusive systems. For example, safflower replaced sunflower in the NTD rotation, and sweet clover green manure replaced winter pea manure/forage in the ORG and PFP systems. The NTS system was converted to a no-till pulse (NTP) rotation containing pulse and cereal crops with both spring and winter growth habits and the NTW system was replaced with a no-till oilseed (NTO) rotation.

Table 1. Crop Diversification Rotation Study: 2004-2007

System	Rotation
1. ORG	(1) AWPea manure - (2) W Wheat - (3) Lentil - (4) Barley
2. PFP	(1) AWPea manure - (2) W Wheat - (3) Lentil - (4) Barley
3. NTW -L	(1) Winter Pea - (2) W Wheat - (3) Dormant Mustard - (4) W triticale
4. NTW-H	(1) Winter Pea - (2) W Wheat - (3) Dormant LL Canola - (4) W triticale
5. NTS-L	(1) S Pea - (2) S Wheat - (3) Mustard - (4) S triticale
6. NTS-H	(1) S Pea - (2) S Wheat - (3) LL Canola - (4) S triticale
7. NTD-L	(1) S Pea - (2) W Wheat - (3) Sunflower - (4) OP Corn
8. NTD-H	(1) S Pea - (2) W Wheat - (3) Sunflower - (4) Hybrid Corn
9. CW	(1) S Wheat- (2) W Wheat

Table 2. Crop Diversification Rotation Study: 2008-2011

System	Rotation
1. ORG	(1) Sweet clover manure - (2) W Wheat - (3) S Lentil - (4) Safflower
2. PFP	(1) Sweet clover manure - (2) W Wheat - (3) S Lentil - (4) Safflower
3. NTO-L	(1) Flax - (2) S Wheat - (3) W canola* - (4) W Wheat
4. NTO-H	(1) Flax - (2) S Wheat - (3) W canola* - (4) W Wheat
5. NTP-L	(1) W Pea* - (2) W Wheat - (3) S Lentil- (4) S Wheat
6. NTP-H	(1) W Pea* - (2) W Wheat - (3) S Lentil- (4) S Wheat
7. NTD-L	(1) S Pea - (2) W Wheat - (3) Safflower- (4) OP Corn
8. NTD-H	(1) S Pea - (2) W Wheat - (3) Safflower - (4) Hybrid Corn
9. CW	(1) S Wheat- (2) W Wheat

* Winter canola and winter pea rarely produced adequate stands and were most often reseeded to their spring counterparts.

Evaluate Soil Test Nutrient Levels

To evaluate soil test nutrient levels, four soil samples were collected with a 1.38 inch diameter soil core in early spring in 2004 and 2012 (near the time of seeding) to a depth of 2 feet from each of the 68 plots. The cores were separated into 0-6, 6-12, and 12-24 inch sections and each of the four sub-samples was mixed to form a single sample per depth per plot. Soil was dried, ground, and submitted to a laboratory for analysis of total N, Olsen P, and SOM in the upper 6 inches, and for nitrate-N at all depths. SON was calculated as Total N – nitrate-N. Soil test levels were compared between 2004 and 2012 to determine which rotations and N rates were building and/or depleting nutrient levels.

Determination of N fertilizer use efficiency

Estimates of N fertilizer use efficiency were obtained using the method of ‘apparent’ N fertilizer recovery which is calculated as the ratio of aboveground N removed at harvest to the amount of N fertilizer applied to the soil expressed as a percentage

$$\text{Apparent N Fertilizer Recovery (\%)} = \frac{NR}{NA} \times 100$$

where NR=nitrogen removed (lb N/ac), and NA = nitrogen applied (lb N/ac). Because legumes artificially inflate apparent N fertilizer recovery, we only assessed recovery for non-legumes within a rotation. To determine N fertilizer recovery for each rotation, fertilizer N amounts (N input) and grain N yield (N output) for 2008 to 2011 were compiled. Organic treatments were excluded from analysis as no N fertilizer was applied. Data were analyzed using SAS JMP 8.0 statistical software. Mean separation for individual treatments was completed using the Fisher’s Protected LSD test at the P= 0.05 level (i.e. 95% confidence level).

Project Results

Objective 1 (Soil nutrient changes)

Soil organic matter increased more in the oilseed rotation (NTO) than in the diverse (NTD), pulse (NTP), or organic system (ORG), and increased by similar amounts as CW and PFP, between 2004 and 2012 (Figure 1). The NTO system was dominated by winter grains from 2004 and 2007 and had no pulses from 2008 to 2011, likely increasing biomass returned to the soil compared to the other rotations. Others have found that total residue carbon returned is more important than crop (and C:N ratios) at affecting SOM anges (Halvorson and Schlegel, 2012; Shrestha et al. 2013). To build SOM in semi-arid southwest Saskatchewan, it took at least 1.8 tons/ac of total residue returned (shoot plus root) per year to build SOM (Shrestha et al. 2013). Given typical stubble:grain and root:shoot ratios, this 1.8 tons/ac 'critical level' to increase SOM equates to approximately 29 bu/ac of wheat per year, which is substantially lower than wheat yields obtained in most years of this study. The ORG rotation was the only treatment where the SOM change was not positive. The pesticide free production (PFP) treatment, which has had identical crops as the ORG treatment since the study started in 2000, yet has been fertilized since 2004, had a significantly higher increase in SOM than the ORG treatment. This demonstrates the importance of fertilization and no-till in building SOM.

Soil organic N increases were higher in the CW rotation than in NTD, NTP, PFP, and ORG rotations (Figure 1). The CW was fertilized with more N than the other rotations and produced high amounts of residue, likely with high C:N ratios, which would have promoted immobilization. SON increases were not different between CW and NTO, the only two treatments without pulses, suggesting higher C:N ratios and/or more years with N fertilization, apparently helped build SON. Olsen P concentrations in the five NT rotations increased between 3 and 9 ppm, though the increases were not different among those rotations (Figure 2). Not surprisingly, NT rotations had significantly higher Olsen P concentrations than the unfertilized ORG rotation. The ORG treatment's Olsen P concentration decreased by

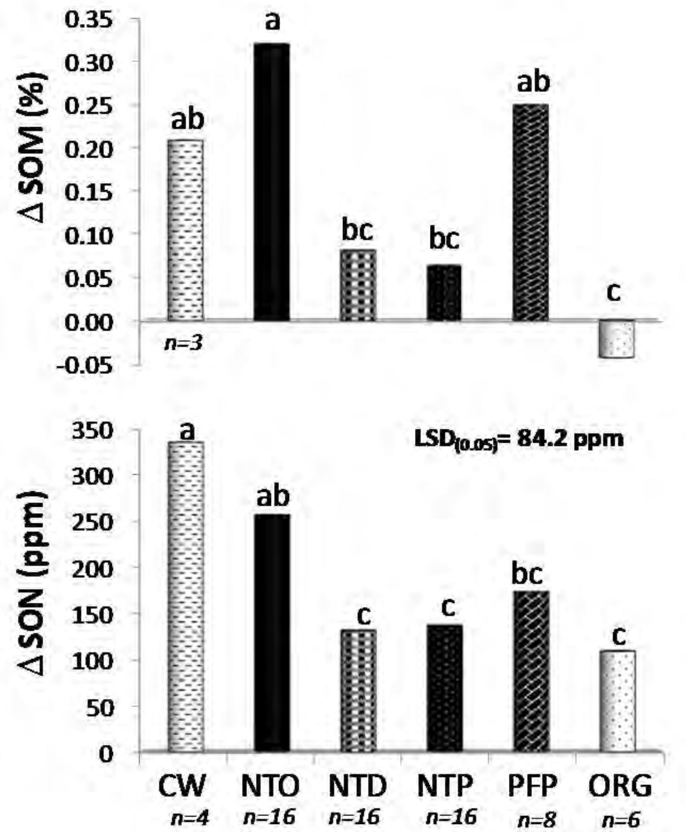

Figure 1. Mean change (Δ) in SOM and SON levels for six annual cropping systems in CDRS experiment. Bars within each graph with same letter are not different with 95% confidence.

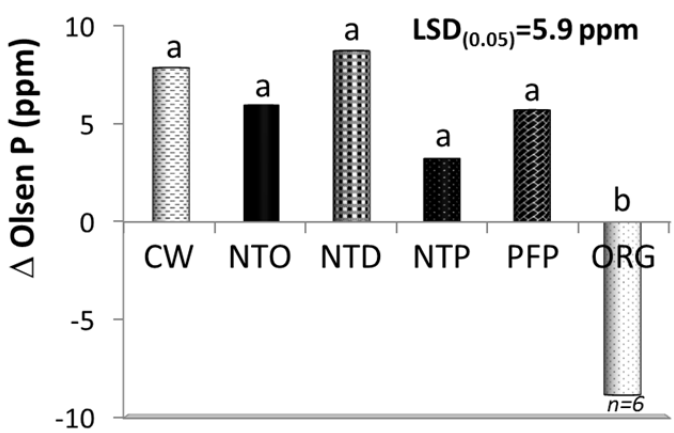

Figure 2. Mean change (Δ) in Olsen-P for six annual cropping systems in CDRS study. Bars with same letter are not different with 95% confidence.

almost 9 ppm and is now near 10 ppm; well below the critical level of 16 ppm.

The N rate (full vs ½) did not significantly affect the 8-year changes in SOM, SON, or Olsen P (data not shown). The ½ N rate often produced similar yields as the full N rate (at least in drier years) in our study, so perhaps our results should not be overly surprising at least for SOM and Olsen P. A large review of SOM changes from N fertilization in long term experiments found generally small increases in SOM and SON (<10%) from N fertilization above the 0 N control (Ladha et al. 2011). In summary, crop rotation had a much larger effect on SOM, SON, and Olsen P than N rate.

Objective 2 (Apparent N fertilizer recovery)

Significant differences ($P < 0.001$) in apparent fertilizer N recovery estimates were observed among the 5 crop rotations for the high N input system (Figure 3). Notably, the NTO, NTD, and NTProtations had significantly higher recoveries (~50-60%) than the PFP (37%) rotation. The CW rotation had an intermediate recovery (46%). The recoveries were substantially decreased because of a hail storm in 2008 which decreased expected oilseed yields (in PFP) by about 90% and wheat yields by at least 50%. The apparent N fertilizer recovery efficiency for the five rotations averaged about 50% which is considerably higher than single-year average N recovery efficiencies of 37% reported for corn from on-farm experiments in the north-central U.S. (Cassman et al., 2002) and within the range of 33 to 57% reported for cereals worldwide (Raun and Johnson, 1999; Ladha et al., 2005). Fertilizer recoveries for the three low N input systems were about 1.5 to 2-fold higher than in high N input systems (data not shown); this is not surprising given that lower N rates should result in better N scavenging and fewer N losses. The recoveries in the low input systems were not different among cropping systems, which is somewhat surprising given that the NTO system has no pulses and the other two NT systems do.

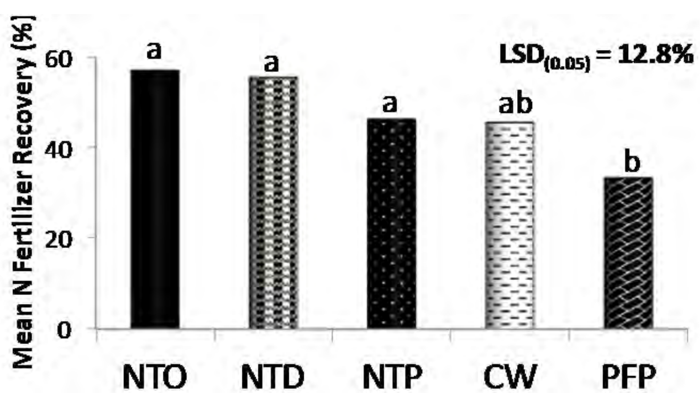

Figure 3. Apparent N fertilizer recovery for only high N rate systems (2008-2011) excluding pulse N removal. Each mean is an average recovery for both phases of each rotation. Bars with same letters are not different with 95% confidence.

It's noteworthy that despite apparent N 'losses' based on N recoveries, that all fertilized rotations built SON between 2004 and 2012. This is notable because most work on nitrogen use efficiency and recovery ignores changes in soil N levels, likely becauseSON differences often cannot be detected in short term studies (often one year) or are assumed to be negligible. SON gains are not unexpected in this study because the conversion from tilled fallow (prior to 2000) to no-till recrop should have built SOM and SON especially at the surface. Our results strongly suggest that in semi-arid environments total fertilizer N recoveries are higher than typically reported nationally and globally, although we need to determine if SON in the entire top 2 ft. also increased.

It is clear that agronomic factors, such as crop selection and nutrient management can either beneficially or adversely affect fertilizer N recovery estimates. Certainly climate and crop pests can also affect the outcome. The CDRS study has experienced serious crop damaging weather events and weed infestations which both can affect yield and fertilizer N recovery. The results demonstrate that one-year recoveries, which are often reported in the literature, are problematic, and indicate a long-term approach is likely more accurate at estimating fertilizer recovery, especially in semi-arid regions.

SUMMARY

Nitrogen fertilizer represents the single greatest energy expenditure and often the largest economic input for Montana growers (Burgess, 2012). Interest in no-till diversified cropping systems has increased as an alternative to continuous no-till wheat systems due to beneficial effects on soil quality, greater pest control, and higher net economic returns (Miller et al., 2008). Yet, less is known about N use efficiency in diverse rotational systems, particularly when N_2 fixing crops are incorporated into the rotation. Our preliminary findings suggest that diverse crop rotations use N as efficiently as rotations containing only cereals, yet cereals build SON faster than diverse rotations. In addition, low N input strategies can substantially enhance fertilizer N recovery. Finally, non-fertilized organic systems are not sustaining available phosphorus levels.

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