DEEP SOIL NITRATE LEVELS FOLLOWING FOUR YEARS OF DIFFERING NITROGEN RATES AND CROPPING SYSTEMS

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ABSTRACT

Nitrate leaching into groundwater is a growing concern in many agricultural systems, including dryland systems in semiarid regions of the northern Great Plains (NGP) of North America, where summer fallow is common. Despite this concern, the effects of agricultural practices on nitrate leaching have been relatively unstudied. Nitrate concentrations were measured after winter wheat in a sandy clay loam at 1-ft increments to a depth of 6 ft after the fourth year of a study investigating effects of cropping system and available nitrogen (N) rate (0, 0.5x, 1x, and 1.5x the recommended rate of 3 lb N bu^{-1}) on yield, quality, and net revenue. Based on soil water content, the effective rooting depth was approximately 3.5 ft. The mean nitrate-N pool in the 3-4 ft depth increment for fallow-wheat was 18 lb ac^{-1}, more than two-fold greater (P=0.08) than for the annual legume grain-winter wheat system when analyzed across N rate, suggesting fallow increased nitrate leaching potential. At that same depth, nitrogen rate also affected the nitrate-N pool, with about 30% greater soil nitrate (19 lb N ac^{-1}) at the 1.5x rate than at the recommended rate. Cropping system did not have an effect in the two lowest depths (4-5 ft and 5-6 ft), likely because of insufficient deep percolation to move much nitrate that far after four years. Notably, the highest soil nitrate-N levels across all treatments were in the 5-6 ft depth increment (13-25 lb N ac^{-1}), below the effective root zone, suggesting the long-term practice of summer fallow-cereal (at least 30 years prior to the study) had accumulated nitrate at that depth. The annual legume grain-winter wheat system produced higher net revenue than fallow-winter wheat across N rates during this 4-year period, suggesting this system could be a win-win from both an environmental and economic perspective.

INTRODUCTION

Nitrate leaching represents an economic loss to producers, and can be harmful to human health and the environment when that nitrate enters ground and surface water. Nitrate-nitrogen (nitrate-N) concentrations in the nation's shallow groundwater have risen from less than 2 mg/L in the 1940s to over 10 mg/L (the EPA drinking water standard) in recent years (Puckett et al., 2011). In Montana, numerous wells exceed the EPA standard (Figure 1), with a higher proportion of exceedances in the northern portion of the state where cropland is denser, and summer fallow is common. Notably, approximately 29% of samples from 45 wells screened at less than 50 ft exceed the EPA standard (Montana Dept. of Agriculture, unpub data). Based on a recent study in central Montana, an estimated ~10-20 lb nitrate-N ac^{-1} is lost annually from the rooting zone of cultivated soils when averaged across year and cropping system (Sigler et al., 2018). Despite the potential cost of these N losses, relatively little is known about effects of management practices on leaching amounts in Montana. A 2011-2015 study conducted in central Montana, where soils have shallow depths to gravel (1 to 3.5 ft), found that replacing fallow with pea grown for grain could reduce nitrate leaching while benefiting net revenue (John et al., 2017); however, it is unknown if this effect would hold on more typical Montana soils across a range of N rates. A four-year cropping system and N rate study in Big Sandy, Montana (Figure 1) provided an opportunity to determine how management practices affect the nitrate leaching potential in a soil that lacks a shallow gravel contact.

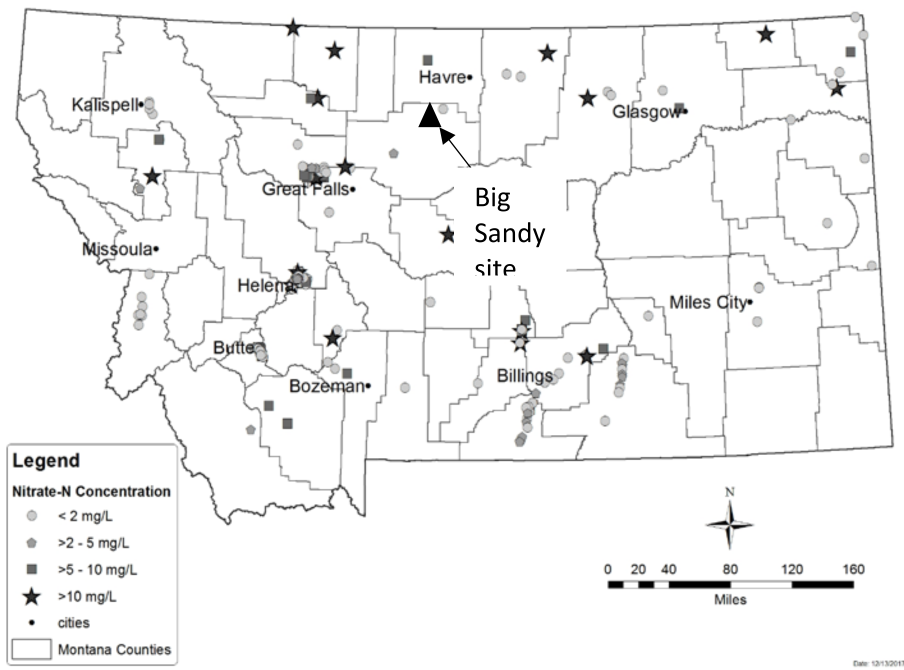

Figure 1. Nitrate-N concentrations in wells sampled at least annually from 2012-2017 (Provided by the Montana Department of Agriculture, Groundwater Protection Program).

MATERIALS AND METHODS

Study Design

In 2012, a plot study was initiated that contained four crop treatments grown in even years (fallow, pea green manure, annual legume crop grown for grain, and spring wheat) followed by a winter wheat test crop grown in odd years. The focus of this study was on fallow-wheat (given its prevalence in Montana) and legume grain-wheat (the most common fallow replacement). The annual grain was lentil in 2012 and dry green pea in 2014. Subplots were treated with one of four available N rates (0, 0.5x, 1.0x and 1.5x of a typical 3 lb available N bu^{-1} rate) where available N is soil nitrate-N (tested the previous fall) plus fertilizer N. The winter wheat grain yield goal on fallow was set at 45 bu/ac based on conversations with the collaborating farmer. Yield goal following each legume grain crop was set at 34 bu ac^{-1} yield goal based on a typical 25% yield reduction after pulses compared to fallow. Recommended fertilizer rates were decreased by 13 lb N ac^{-1} (the N credit) following legume crops grown for grain. Plot size was 25 x 80 ft and subplot size was 6 x 80 ft. The experimental design is a randomized complete block in split-plot arrangement with four rotation-phases as main plots and four fertilizer treatments as subplots, with four replicates.

Soil Sampling

Soil was sampled (2-in diam. core in 1 ft increments to 6 ft) on all fallow and legume grain sub-plots (at all four N rates) in early March 2016 (2015 was winter wheat year) with a Giddings soil probe. Because of a ‘bulge’ of nitrate observed in the fourth foot under fallow-winter wheat at the 1.5x N rate, soil was re-sampled in the 1.5x subplots of both pea and fallow cropping systems in August 2016 again to 6 ft, to see if the bulge moved lower in the profile. Two cores were collected to 6 ft, mixed, and analyzed for soil texture using the hydrometer method.

Analyses

Soils were analyzed for soil water and soil nitrate (colorimetric, Lachat autoanalyzer). Nitrate pools (in lb N ac^{-1}) were calculated using nitrate contents and bulk densities. Revenue was calculated based on yield and protein at both flat (low) and steep (high) protein discounts based on 42 actual Montana elevator prices from 2001 to 2012. Costs included fertilizer N, seed/seeding, pesticide/spraying, harvesting, and trucking. Net revenue was calculated from gross revenue and costs from 2012-15 and reflects returns to land and management, before any government or crop insurance payments. ANOVA was conducted on N pools and net revenue using block as a random effect and cropping system and N rates as fixed effects to determine significant differences ($P<0.10$).

RESULTS AND DISCUSSION

Soil texture in the top foot was a sandy clay loam (51% sand, 25% clay). In the 1-2 ft and 5-6 ft depths, the soil was a clay loam and in the 2-5 ft depths, it was a loam. We observed a calcium carbonate layer in the 2-3 ft. depth.

Soil nitrate pools were affected by N rate in the 2-3, 3-4, and 5-6 ft depths when fallow-wheat and legume grain-wheat systems were analyzed together (Figure 2). Notably, the 1.5x N rate resulted in about 10 lb N ac^{-1} more nitrate than the 0.5x N rate in both 2-3 and 3-4 ft depths. There was no cropping

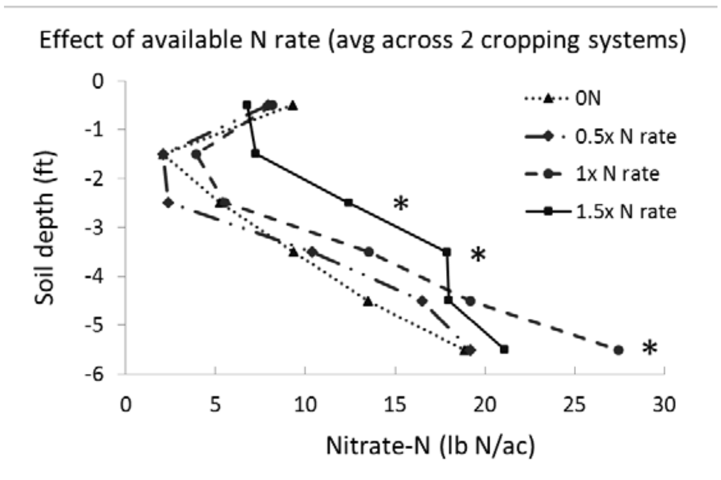

Figure 2. Effect of available N rate on March 7-8, 2016, nitrate-N pool averaged for legume grain and fallow systems. An asterisk indicates that there was an N rate effect ($P<0.10$).

system by N rate interaction. Soil water contents in March 2016 were near or below the wilting point from 1-3 ft, near field capacity from 5-6 ft, and intermediate in the 3-4 ft depth, thus the effective rooting depth of winter wheat in 2015 was apparently about 3.5 ft. Since nitrate leaching is generally defined as nitrate that has moved below the root zone, we cannot definitively state that nitrate differences observed in the 2-3 or 3-4 ft depths (primarily within the root zone) indicate nitrate leaching differences. Higher nitrate at these depths do, however, indicate the potential for nitrate leaching differences, especially if there is sufficient precipitation prior to when the subsequent winter wheat crop is actively growing. The lack of consistent or expected differences in nitrate pools in the 4-5 ft and 5-6 ft depths among N rates suggests that study treatments did not substantially influence nitrate at those depths, but instead that high levels of nitrate existed at those depths prior to initiating the study (Figure 2).

When all N rates were analyzed together, soil nitrate pools were higher in the legume grain-wheat system than fallow-wheat system in the top foot, likely due to pea residue mineralization, and lower in the legume grain system in the 3-4 ft. depth (data not shown). Soil nitrate was not higher at any depth in the fallow system than in the pea system for the 0x N rate but was 9 to 15 lb N ac^{-1} higher in the 3-4 ft depth for the other three N rates (Figure 3). Pea grown for grain would have lowered soil water content and nitrate compared to fallow, decreasing downward movement of nitrate and

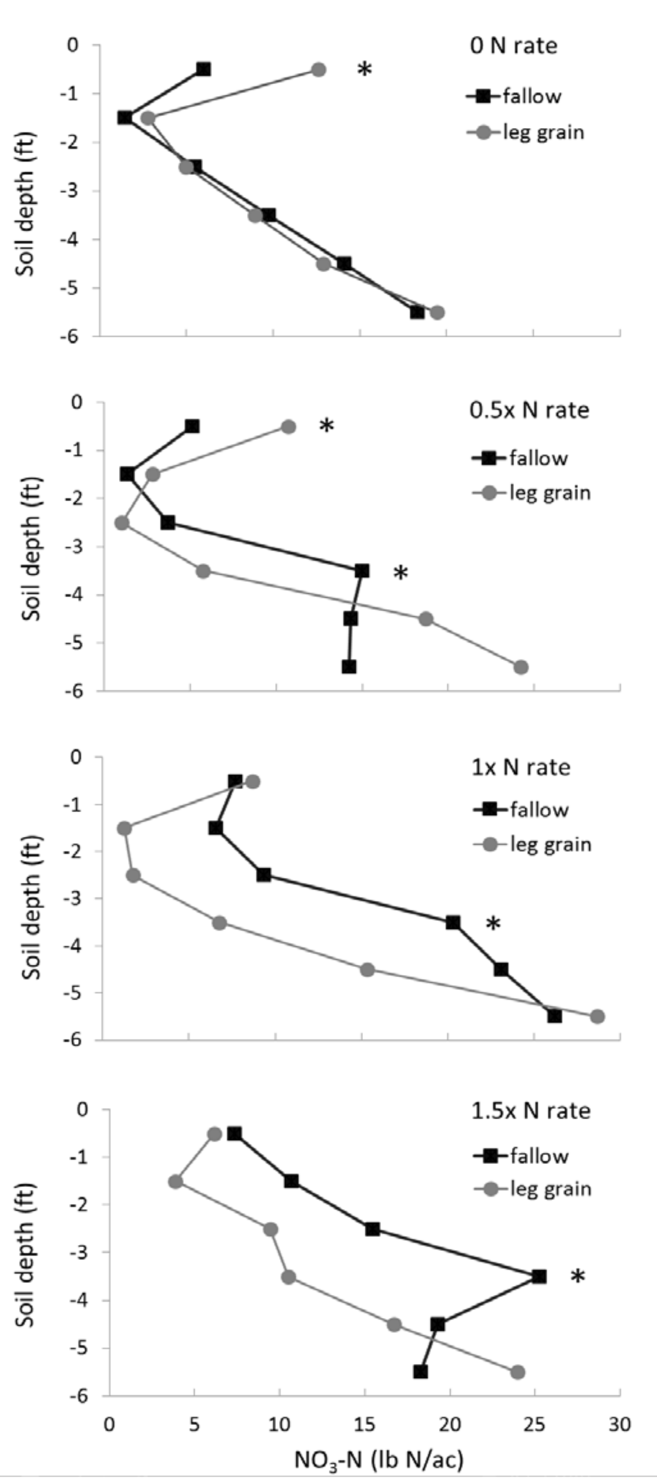

Figure 3. Effect of cropping system on March 7-8, 2016, soil nitrate to 6 ft for each N rate. Across all N rates, cropping system had an effect only in the 1st and 4th foot. An asterisk shows where cropping system affected the soil nitrate amount (P<0.10).

minimizing mineralization of soil organic nitrogen. Differences could have also occurred if actual yields were substantially different than targeted yields between treatments; however, yields in 2015 at the 1x rate were 49.3 and 39.7 bu ac^{-1} (data not shown) for post-fallow and post-legume grain, respectively, only slightly more than targeted for both systems, ruling out this possibility. August 2016 nitrate pools (collected only for the 1.5x N rate) showed that the 'bulge' in the 3-4 ft depth in the fallow-wheat system did not move down (Figure 4) despite 9.5 inches of precipitation falling at this site between sampling dates. Very dry soil above this depth in March 2016 would have absorbed a substantial fraction of this precipitation. In addition, most of the precipitation events were small, causing them to evaporate rather than percolate very far.

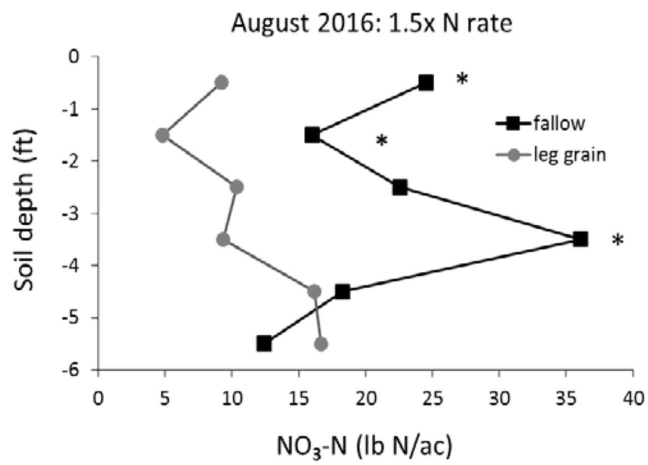

Figure 4. Effect of cropping system on Aug 16-17 2016 soil nitrate to 6 ft for 1.5x N rate. An asterisk shows where soil nitrate for fallow-wheat was higher than for legume grain-wheat ($P<0.10$).

Overall, nitrate leaching potential was higher as N rate increased and was higher in fallow-wheat systems than legume grain-wheat systems (in the 3-4 ft depth). Notably, at the 1x N rate (3 lb available N bu^{-1}), the whole 6-ft profile had 30 lb more nitrate-N ac^{-1} in the fallow-wheat system than the legume grain-wheat system. The legume grain-wheat system also produced more total net revenue than fallow-wheat from 2012-2015 at each N rate for both flat and steep discounts, with the 1x rate producing the same revenue as the 0.5 and 1.5x rates in both cropping systems at both flat and steep protein discounts (Figure 5). In the fallow system at steep discounts, the highest N rate produced the most net revenue. In contrast, providing more than the recommended N rate in the legume grain system did not increase net revenue.

The combined leaching and economic results suggest that replacing fallow with a legume grown for grain and fertilizing close to the 1.0x rate is a win-win from an economic and environmental perspective. Notably, the largest net revenue for fallow-wheat systems at steep discounts was obtained at the 1.5x N rate where leaching potential was high, demonstrating the challenge producers face when trying to maximize net profit while protecting groundwater when using fallow.

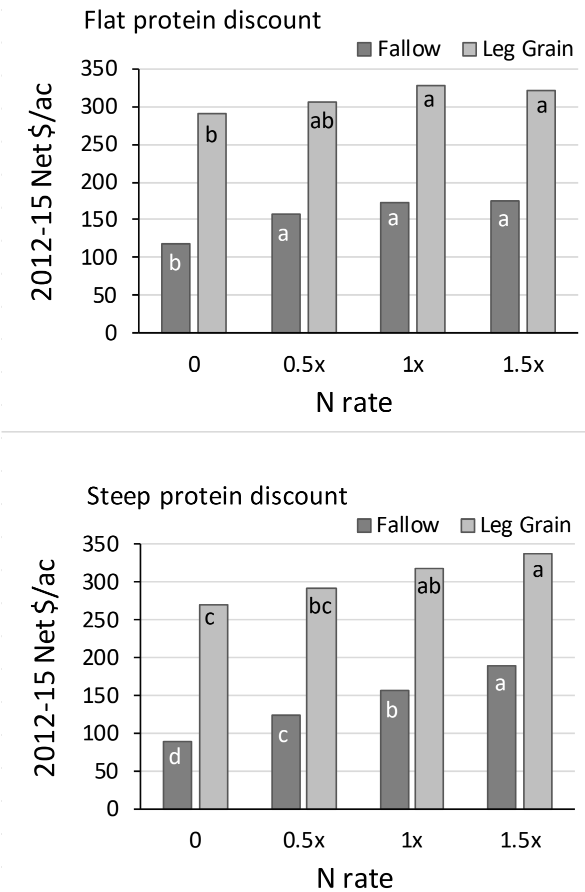

Figure 5. Four-year net revenues (not including land or management) for fallow-winter wheat and legume grain-winter wheat systems at four N rates. Net revenues were higher for legume grain system than fallow system at each N rate; letters indicate differences ($P<0.10$) within a cropping system not between cropping systems.

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