MEASURED AND PREDICTED TEMPORAL CHANGES IN SOIL NITRATE-N LEVELS FROM LATE SUMMER TO EARLY SPRING IN MONTANA

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ABSTRACT

Most soil sampling is conducted from August to November in Montana because of better soil sampling conditions and because it provides more time for growers to make fertilizer decisions prior to application. Fertilizer guidelines in Montana are based on spring nitrate-N levels in the upper 2 ft because they are more indicative of growing season available N than fall nitrate-N levels. It is not known how much nitrate-N levels change between late summer and spring, nor is it known what factors affect these changes, and large changes could result in either over-application of N fertilizer or sub-optimal yields. A three-year study was initiated in August 2007 at eight locations in Montana to determine differences in nitrate-N levels for late summer, late fall and early spring sampling. A primary goal of the study was to model nitrate-N changes based on previous crop, soil characteristics, and weather conditions to enable producers to adjust their N rates based on fall soil sampling. Soil samples (0 to 6; 6 to 24 inches unless rocks prevented coring) were collected in late August/early September and mid-November following four previous crop types (annual legume, fallow, oilseed, and small grain), and the sampling was repeated within 1 foot of the initial sampling points in early April of the subsequent year. Soil samples were analyzed for parameters that would typically be included in a soil test (producer model) and/or might influence temporal nitrate changes such as soil texture and soil water content (full model). Additive mixed models were used to predict changes in nitrate-N levels (in lb/ac) using these soil parameters, previous crop, precipitation amounts and average air temperatures as fixed effects. Random effects for both study location and year were used to account for systematic differences among locations and years. When averaged over previous crop, locations and years, nitrate-N levels increased by 18 lb ± 21 N/ac from late summer to early spring and by 5 lb ± 28 lb N/ac from late fall to early spring. These standard deviations demonstrate that nitrate changes in individual site-years can be much different than averages, and could result in substantial under or over fertilization if late summer or late fall soil samples were only adjusted with average differences. The predictive models indicated that initial nitrate and soil depth were the most important fixed effects at influencing overwinter nitrate changes, yet most of the variability in nitrate changes was not explained by the models.

OBJECTIVES

1) Determine the difference in soil nitrate-N levels between late summer, mid-fall, and early spring sampling
2) Develop models that can be used to predict differences in nitrate levels between seasons, and therefore allow the crop adviser or producer to adjust fertilizer rates

MATERIALS AND METHODS

This project was conducted at eight soil sampling sites in Montana: Western Triangle (WTARC), Western (WARC), Northwestern (NWARC), Northern (NARC), Southern (SARC), Eastern (EARC), and Central Ag. Research Centers (CARC), plus the Agronomy Post Farm (PF).

At each site, specific soil sampling locations were identified where the previous crop was 1) a small grain, 2) a cool season oilseed, 3) an annual legume, or 4) fallow. For each previous crop, two soil samples were collected that differed in soil texture, and/or, if known, in organic matter at the 0-6 in. and 6-24 in. depths in August to early September (2007-2009), mid-November (2007-2009), and early April (2008-2010). Late summer sampling occurred in September only in 2009 due to a late harvest at many sampling locations. The April soil samples were collected one foot from each of the late summer and November sampling points. A total of 16 soil samples (4 crops x 2 samples/field x 2 depths) at each sampling time were collected, except for the Post Farm where a suitable fallow site was not identified. Sampling times were picked to match approximate times for pre-winter grain sampling, pre-spring grain sampling, and spring seeding times, respectively. The latitude and longitude of each sampling location was recorded using a GPS receiver and/or flags, and each location was well marked for re-location at the subsequent sampling time. Soils at both EARC and CARC were often not able to be sampled to 24 inches, largely due to cobbles. Soil depth was noted in these cases. To assess whether there was spatial variability within a one foot distance, 16 paired samples were collected immediately adjacent to two of the April 2010 sampling locations at each site. These paired samples were located one foot from each other.

All samples were dried at 104º F for one week and shipped to AgSource Harris Laboratories (Lincoln, NE) for analyses. August samples were analyzed for organic matter, pH, nitrate-N, Olsen P, exchangeable K, cation exchange capacity (CEC), soil texture, and soil water content in the upper 6 in., and nitrate-N, soil texture, and soil water content in the 6-24 in. layer. Samples collected in November and April were only analyzed for nitrate-N and soil water content (both depths). Soil water content was determined on sub-samples by drying at 221º F for 24 hours.

The nitrate differences were modeled with additive mixed models to produce multiple linear (or non-linear) regressions using the software R (R Development Core Team, 2009) package gamm4 (Wood, 2009) with two different data sets: 1) a producer data set that contains data that producer swould have from their own knowledge (previous crop), a typical soil test report (soil depth, Olsen P, exchangeable K, OM, pH, initial nitrate), and a weather station (monthly precipitation and temperature) and 2) a full data set that used the producer data set plus soil texture, CEC, and soil water content. These variables were all included as fixed effects in the modeling effort whereas location and year were modeled as crossed random effects (Faraway, 2006). Soil depth was treated categorically as either greater than 2 ft. or less than 2 ft. Variables that did not explain a significant amount ($P<0.10$) of the variability were excluded from the models. The full models did not improve the accuracy of the models, so are identical to the producer models, and will be called “the models” here.

Seven observations were determined to be heavily influential and/or outliers based on unusually high OM, nitrate levels or nitrate changes. Two additional observations were removed from the August to April models due to high residuals and one observation was removed from the November to April models due to a high residual.

RESULTS AND DISCUSSION

August to April nitrate-N differences across the three years averaged 18 ± 21 lb/acre (meaning April nitrate-N was 18 lb N/acre more than the previous August nitrate-N). The high standard deviation simply means that there was substantial variability, and that some soils lost nitrate from August to April. Specifically, NWARC was the only site where nitrate consistently decreased over time, likely due to sandy soils and somewhat higher precipitation. The results suggest that growers who used August or September nitrate-N levels to determine N rates could have fertilized more than they intended by an average of about 18 lb N/acre, but the range of either under or over-fertilization was much higher.

Averaged across site and year, the August to April nitrate differences were 12, 14, 20, and 26 lb N/acre following fallow, small grains, oilseeds, and annual legumes, respectively (Fig 1). Late summer/early fall to April nitrate-N differences were lower following fallow and harvested wheat than following harvested pea and mustard in a previous study (Miller, unpub. data).

Study year had a significant effect. Averaged across site and crop, August to April nitrate differences were 14, 25, and 16 lb N/ac for 07-08, 08-09, and 09-10, respectively. The middle year was the wettest of the three; when averaged across site, approximately 5.9 inches fell between September and March, compared to about 4.4 inches the other two years. More moisture could either directly increase N mineralization rates, or result in more insulating snow cover, thereby indirectly enhancing decomposition by keeping the soil warmer; however, precipitation was not found to significantly affect nitrate-N differences, so other factors, such as growing season climate and yield may have caused the year effect. Location was not related to nitrate changes, suggesting soil properties were more important than location.

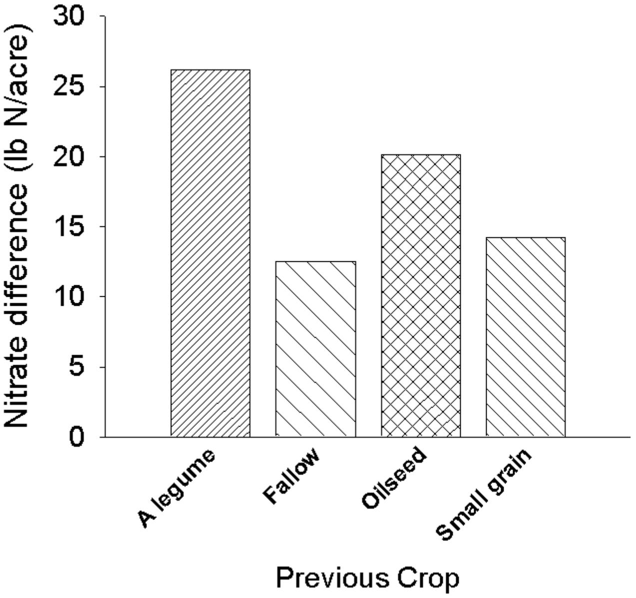

Figure 1. August/Early September to April (April – previous August) nitrate-N changes for each previous crop averaged across 8 sites and 3 years.

Table 1. August to April nitrate difference model coefficients for each independent variable, 95% confidence interval (CI) of estimate, and each P-value. A P-value <0.1 is considered significant for this study (bolded); P-values closer to 1 suggest that that variable is not important.

Independent variable	**Coefficient estimate**	**95% Confidence Interval**	**P-value**
Aug nitrate (lb N/ac)	-0.46	-0.59 to -0.33	**<0.0001**
Aug soil depth (if < 2 ft, add this estimate)	-9.08	-15.94 to -2.22	**0.0099**
Previous crop (4 levels)	--	--	**0.0775**
ln (Olsen P; mg/kg)	-4.59	-9.46 to 0.28	**0.0030**
Year (random effect, 3 levels)	--	--	**0.0010**
Site (random effect, 8 levels)	--	--	1
Sand content (6 to 24 in; %)	--	--	0.1117
Potassium (0 to 6 in.)	--	--	1
Cation Exchange Capacity (0 to 6 in.)	--	--	1
Soil pH (0 to 6 in.)	--	--	1
Sep to Feb Monthly Air Temp (F)	--	--	1
ln (Total Sep to Feb Precip; in.)	--	--	1
Organic matter content (0 to 6 in.)	--	--	1
Soil water content (6 to 24 in.)	--	--	1
Interaction: Sand content*ln(Total Precip)	--	--	1
Interaction: Aug nitrate*ln(Total Precip)	--	--	1

The August to April model found that August nitrate, ln (Olsen P), and soil depth were highly associated with nitrate changes (Table 1) and previous crop was somewhat related (P=0.078). Higher August nitrate levels were related to lower nitrate changes, likely because more was available to be lost (to leaching, denitrification, or immobilization), offsetting gains from mineralization. Soil depth less than 2 ft also was related to lower nitrate changes (by about 9 lb N/ac), either because these sites were more prone to leaching or there was less organic N to become available over a smaller depth. Higher Olsen P was related to lower nitrate changes. Soils with high Olsen P are often coarse textured, because finer textured soils sorb P stronger, making it unavailable, and often are high in calcium which precipitates with P. Coarse textured soils will be more prone to leach nitrate, counteracting gains from N mineralization.

Somewhat surprisingly, OM, pH, K, precipitation, soil water content, sand content, and air temperature were not found to be important in the model of August to April nitrate changes. Increased moisture and temperature are known to increase mineralization. However, increased precipitation and moisture could also increase leaching potential or denitrification, counteracting nitrate increases from mineralization. Also, soil temperature is highly dependent on both solar radiation and snow cover, neither of which is reflected by air temperature. Although higher OM is generally thought to increase nitrate release, a study in North Dakota found that OM wasn’t important in affecting N availability at OM levels less than 5% (Franzen, unpub data), higher than all but one sample in this study.

Despite many significant model components, plotting predicted vs measured nitrate-N changes shows that the model predictions were often quite poor, especially at very low and high measured nitrate changes (Fig 2). A portion of the poor agreement may have been due to spatial variability; the average absolute difference in nitrate levels of the 16 paired samples was 14 lb N/acre. This was a larger difference than expected given that nitrate is very soluble and mobile and does explain a portion of the difficulty in modeling the nitrate changes. This difference is relatively small compared to the range of nitrate changes observed (-60 to +64 lb N/acre).

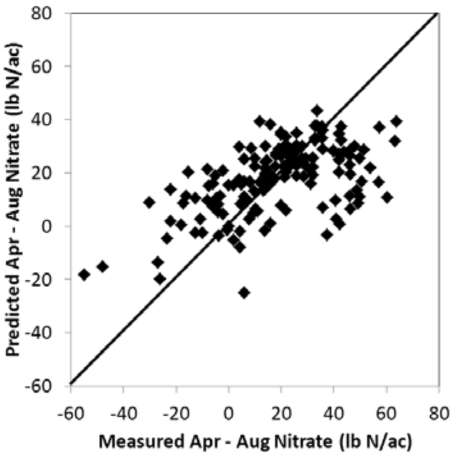

Figure 2. Predicted vs measured April – previous August nitrate change. Also shown is a 1:1 line. The random year effect was not included in the prediction.

November to April nitrate changes averaged 5 ± 25 lb N/ac over the three year study, demonstrating that the majority of the August to April nitrate change occurred from August to November, when soils were warmer and residues 'fresher'. The November to April model found that November nitrate, depth, surface pH, and ln(Aug to Feb Precip) were significantly related to nitrate change (Table 2). Nitrate amounts and depth were negatively and positively related to nitrate changes, though the November nitrate effect was non-linear, unlike in the August model where it was linear. Soil pH was positively related ($P<0.01$) to nitrate change, meaning higher soil pH levels increased the amount of nitrate change. Higher pH soils are apt to contain more clay and/or receive less precipitation and are less prone to leach nitrate. Precipitation was negatively related to nitrate change, unlike in the August model where

Table 2. November to April nitrate difference model coefficients for each independent variable, 95% confidence interval (CI) of estimate, and each P-value. A P-value <0.1 is considered significant for this study (bolded); P-values closer to 1 suggest that that variable is not important.

Independent variable	Coefficient estimate	95% Confidence Interval	P-value
Nov nitrate (lb N/ac)	Non-linear	--	**<0.0001**
Nov soil depth (if < 2 ft, add this estimate)	-14.55	-21.19 to -7.92	**<0.0001**
Soil pH (0 to 6 in.)	5.22	1.17 to 9.26	**0.0125**
ln (Total Aug to Feb Precip; in.)	-11.54	-20.79 to -2.29	**0.0156**
Year (random effect, 3 levels)	--	--	**0.0038**
Site (random effect, 8 levels)	--	--	0.1836
Previous crop (4 levels)	--	--	0.1927
Sand content (6 to 24 in.; g/g)	--	--	0.1763
Interaction: Sand content*ln (Precip)	--	--	0.3428
Potassium (0 to 6 in.)	--	--	1
Cation Exchange Capacity (0 to 6 in.)	--	--	1
ln (Olsen P; mg/kg)	--	--	1
Sep to Feb Monthly Air Temp (F)	--	--	1
Organic matter content (0 to 6 in.)	--	--	1
Soil water content (6 to 24 in.; g/g)	--	--	1
Interaction: Nov nitrate*ln (Precip)	--	--	1

it was unrelated to nitrate change. Increased precipitation is known to increase leaching and mineralization, yet after mid-November, mineralization rates are likely more limited by soil temperature than moisture. There was also a year effect (P = 0.004). Unlike in the August to April model, there was not a significant previous crop treatment effect, possibly because easily degraded residues would have already mineralized in the August to November period. The November to April model performed somewhat better than the August to April model, with more points on a predicted vs measured graph closer to the 1:1 line (plot not shown). Unfortunately, the usefulness of the November to April model is less, meaning there is less incentive to use this model if sampling occurs in November or later, because mean nitrate changes were closer to zero.

The models were unfortunately not accurate enough to have confidence in utilizing them for predictive purposes by producers and crop advisers. Nitrate changes are dependent on a large number of processes including mineralization, nitrification, denitrification, and immobilization, making these changes difficult to predict. However, the highly significant correlations between nitrate change and both initial nitrate level and soil depth (negative relationships) in both models suggests that high fall nitrate levels and low soil depths have the best chance of resulting in lower nitrate differences. Low nitrate levels following broadleaves have the best chance of resulting in higher nitrate gains due to lower potential for nitrate loss and broadleaves’ lower C:N ratios than cereals.

Several recommendations will result from this project. First, changes between sites and years were large enough that sampling late fall or later is recommended to best capture growing season N availability. Secondly, higher overwinter credits should be given following broadleaves than following small grains or fallow. Thirdly, if November nitrate levels are very high, soil depth is less than 2 feet, and precipitation is above average, a second sampling in spring is recommended because there is a higher likelihood of overwinter nitrate losses. Recommendations 1 and 3 will be most problematic for winter wheat growers who apply their N at or near the time of seeding.

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