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Validating topdressed K fertilizer recommendations in an alfalfa-corn rotation

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Summary
We completed two years of on-farm research on alfalfa response to potash application in the last year of forage production. There was no alfalfa yield response to potash. Forage quality in 2008 at 5 farms also showed no response, except for NDF digestibility, but the improvement in NDFD would not affect milk production in total mixed rations. Forage quality analysis from 2009 is being completed. A French student intern helped develop a rapid plant K extraction procedure in summer 2009. Corn grain and silage yield in 2009 did not respond to previous potash treatments or to fertilizer N, confirming that alfalfa provided sufficient N to the first corn crop. Corn yield was increased, however, by addition of fertilizer K in spring. Five remaining sites will be in the corn phase in 2010. We expanded the corn phase of the AFREC-funded research with new funds from the Minnesota Corn Research and Promotion Council. This allowed us to attract a graduate student, who is working directly with the cooperating farmers, and will enhance the outputs of this AFREC project by including K removal in alfalfa, determining the potential ethanol yield from corn grain, cobs, and stover, and measuring residual soil inorganic N after corn harvest.

Introduction

Alfalfa is the fourth most widely grown crop in Minnesota, after corn, soybean, and wheat. Although alfalfa acreage is 20% smaller than wheat acreage, dry alfalfa hay production alone (excluding haylage) nearly equals wheat in value. Benefits of including this short-lived perennial legume in crop rotations are well known, but often are not given sufficient credit. These include improved water quality, less soil erosion, enhanced soil tilth and carbon storage, greatly reduced fertilizer N need for subsequent crops, interrupted life cycles of insect and disease organisms that reduce row crop yield, and high profitability without supplemental program support. However, statewide alfalfa yields have been stagnant at about 3 tons/acre, much lower than alfalfa's yield potential. Many top alfalfa producers regularly harvest 5 tons/acre, and yields of 6 to 7 tons/acre are common in the University of Minnesota alfalfa variety testing program, which uses high levels of soil fertility and pest control.

Soil fertility affects both yield and quality of alfalfa. Nutrient removal can be very high, because nearly all the above-ground portion of the crop is removed at each harvest. Alfalfa is stressed by multiple harvests, field traffic, winter conditions, poor drainage, and drought. Potassium plays a critical role in yield by moving sugars from shoots to roots, and then back again during regrowth. Furthermore, K availability is crucial for optimum stress tolerance, including winterhardiness when alfalfa is harvested frequently or when fall weather does not promote cold hardening. University of Wisconsin Extension recommends increasing K rates by 20% if stand life longer than three years is desired. On the other hand, K fertilizers are expensive and forage with excessive K concentration can cause problems as dry cow feed. Whether producing dairy-quality hay or biofuel feedstock, it is imperative that farmers apply the most economic rate to maximize profit. **From the point of view of alfalfa response (yield and quality), what K rate should be applied in the last growing season to provide the maximum marginal return?**

Potassium helps maintain alfalfa stands. It is clearly important for farmers to avoid untimely alfalfa stand loss, both from the point of view of alfalfa forage or biomass production, but also because it reduces the N benefit for the next crop of corn. Current University of Minnesota recommendations suggest that alfalfa provides 225 lb N/a to the next two corn crops when terminated stands had 4 or more alfalfa plants/ft^2, but only 40 lb N/a for 1 or fewer plants/ft^2. At $0.40/lb N, this represents a savings of $74/a over two years for the farmer who maintains 4 plants/ft^2 compared to1 plant/ft^2. Other states include a measurement of alfalfa shoot regrowth that is returned to the soil; we will measure regrowth in this research to determine whether University of Minnesota Extension N fertilizer recommendations can be refined. To our knowledge, there are no data on the effect of topdressed K on the alfalfa N credit. **Is the fertilizer N requirement for corn affected by K fertility during the last year of alfalfa?** Potassium fertilizer is recommended for corn on fields with suboptimal soil test K (STK). Some topdressed K on alfalfa may carry over to support corn yield the next year. **Are there direct effects of carryover K from alfalfa on the subsequent corn yield?**

As corn grain and cellulosic biomass production become more important in Minnesota, we need to know what minimum rates of fertilizer inputs will support maximum economic yields. **Considering that corn stover likely will become a significant source of cellulosic biofuel, do the same fertilizer N and K recommendations apply as for corn grain?** The N fertilizer credit and K carryover phases of our research will be applicable to corn grain for all purposes and to stover production for cellulosic biomass. Our results may apply to alfalfa managed for biofuel feedstock, but this would have to be tested directly in other research because the alfalfa biomass production system differs from a forage production system.

Goals and Objectives

The goal of this on-farm research is to determine optimal rates of K topdressing for the last production year of alfalfa, in terms of the response of alfalfa **and** the following first corn crop. Our objectives are to:

1. determine alfalfa yield, forage quality, and final plant population in response to topdressed K applied in spring of the last production year;
2. determine the fertilizer N requirement for corn after alfalfa that received different K rates;
3. determine the apparent fertilizer K carryover for corn when K is topdressed on alfalfa; and
4. calculate the net marginal economic returns for topdressing K on alfalfa during its last production year.

This research will yield the first system-level assessment of K response by alfalfa and the next crop of corn. Products will include several outreach activities and Internet-available educational materials, articles in the farm press, and peer-reviewed technical publications. Results will help corroborate current recommendations or may lead to modifications of K fertilizer recommendations for alfalfa and of N and K recommendations for corn grown after alfalfa.

Locations

We located 6 farms in 2008 and 5 in 2009 (Figure 1) that had soil test K lower than 120 ppm. This required collecting and analyzing topsoil samples from 15 prospective sites for 2008 and from 38 for 2009, in part because either the farmers or their advisors did not have an accurate understanding of the soil test K levels in these fields. Each alfalfa stand was in the third or later year of production. One site selected in 2008 was dropped from the data analysis after intensive soil sampling indicated high variability in soil test K that was missed earlier.

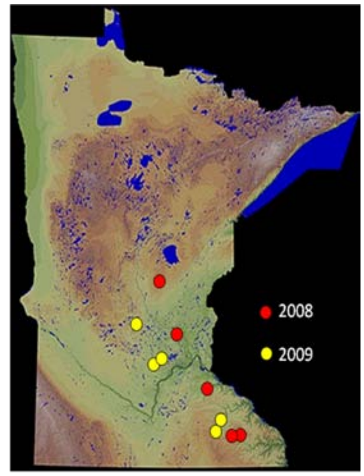

Figure 1. *Location of on-farm research trials to measure alfalfa response to topdressed potash.*

Site	Year	County	Initial STK	Soil pH	Annual rainfall
			ppm		in
1	2008	Olmstead	108	6.4	-1.1
2	2008	Olmstead	110	6.2	-8.9
3*	2008	Dakota	98	6.6	-4.2
4	2008	Wright	111	5.8	-9.1
5	2008	Morrison	89	6.9	-1.1
6	2009	Dodge	101	7.3	-0.7
7	2009	Dodge	95	6.6	1.3
8	2009	Carver	85	7.2	0.2
9	2009	Carver	79	7.7	1.3
10	2009	Stearns	92	6.3	-4.5

Soil textures ranged from sandy loam to clay loam in texture. Only one site was irrigated (Site 3). Initial soil test K averaged over each site ranged from 79 to 111 ppm K (see table). Soil test K varied within each site, but over all main plots, only 11 of the 173 had soil test K concentrations above 120 ppm (Figure 2). Topsoil pH was lower than optimum (6.5) at 4 sites. Farmers were notified that liming would be desired before the next alfalfa crop.

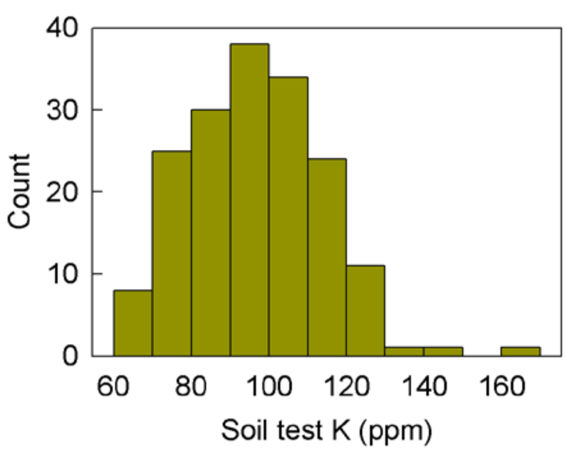

Figure 2. *Histogram of initial soil test K data from 10 on-farm sites in Minnesota*

Two sites received about 9 inches less rainfall than normal and two others received about 4 inches less, although one of those was the irrigated site.

Methods for the last-year alfalfa phase

The potassium rate treatments were laid out as main plots 45 by 60 feet in size and replicated 3 or 4 times in a randomized complete block design on each farm. Each plot was sampled for topsoil K by compositing 6 to 8 cores (0.75 inch diameter by 6 inches in depth). Samples were dried in a forced air oven at 95 F and sent to a certified commercial soil testing laboratory for analysis. Based on late fall or early spring topsoil tests taken from the proposed area, we fertilized each field with additional phosphate based on University of Minnesota recommendations. Potassium chloride was broadcast-applied (Figure 3) at 0, 20, 50, 100, or 200 lb K_2O/acre in early spring (3 sites) or after the first harvest (7 sites).

***Figure 3** Applying broadcast potash treatments to alfalfa after the first harvest.*

***Figure 4.** Regrowth samples taken within 1-m² quadrat.*

Each year, alfalfa forage samples were taken by hand clipping two 1 m^2 plots in each main plot (Figure 4) before the farmer harvested the crop, which occurred 3 or 4 times after K application. Plant samples were dried at 140 F, weighed, and pulverized. Subsamples from 2008 were analyzed for quality using NIRS, and a subset of samples was analyzed with wet chemistry techniques by a commercial laboratory to calibrate the NIRS equation to our samples. Relative Feed Quality (RFQ) and Relative Feed Value (RFV) were calculated using standard equations. Forage quality analysis for samples from 2009 has not been completed at the time of this report, although samples have been run through the NIRS and a subset has been sent for analysis by wet chemistry.

Using a method developed and tested by a French student intern during summer 2009, we are amplifying the proposed research project by measuring K uptake in alfalfa forage. Extracts are being analyzed by atomic emission spectroscopy and results will be reported next year.

Results for the last-year alfalfa phase

Yields differed among farms at every harvest, which was expected because the farmers used different harvest schedules. The more frequent the harvest, the less dry matter can accumulate. However, alfalfa yield was not improved by topdressed potash in these 10 site-years of research. This was the case whether K was applied during regrowth in early spring or after the first harvest (Figure 5) or whether alfalfa was irrigated or not.

There also were no differences in overall forage quality due to K application. For example, RFQ averaged 200 (range 197 to 203) across all potash rates, farms, and harvests.

The only quality parameter that showed a response to K fertilization in 2008 was neutral detergent fiber digestibility (NDFD), which increased by 3 points, from an average of 44.7% to 47.7%, as potash application increased from 0 to 200 lb/acre. Although small increases in this fiber characteristic can improve dry matter intake, it is doubtful that a change of this magnitude in a single component of the feed would improve herd performance with a mixed ration.

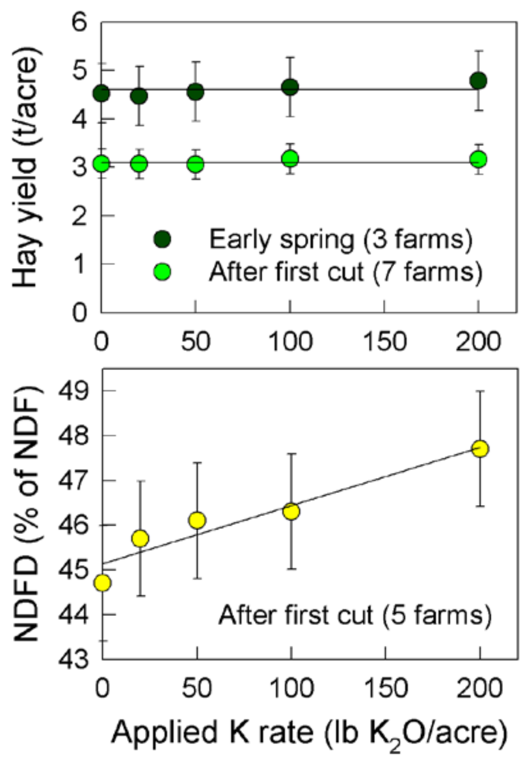

***Figure 5.** Total forage yield and Neutral Detergent Fiber Digestibility of alfalfa on 5 Minnesota farms in 2008.*

Figure 6. *Digging plants to determine population.*

Alfalfa plant populations (Figure 6) were adequate at all locations to support high alfalfa yields (4.1 to 9.2 plants/ft^2). Plant populations at the end of the season were not affected by the soil test K level in spring or by the applied potash. We expected that stands would decline on lower-testing soils, but other factors may have been important, such as leniency of previous fall harvests, soil pH, and stress tolerance of the alfalfa cultivars. These and other factors will be evaluated by the answers to farm management questionnaires that were distributed to the cooperators this winter.

Was the lack of response due to poor fertilizer recovery by the alfalfa? We will be able to answer this question after all plant tissue samples have been analyzed for K. At this point, we do not think so. Plants often can absorb K in amounts that exceed their need, a process called "luxury consumption." Excess K uptake results in forage with high K concentrations, which is especially problematic for fresh cows because it increases the risk of milk fever. The other concern with luxury consumption is that the fertilized crop will leave less K for the following crop, reducing the ultimate fertilizer ***use*** efficiency (improved yield per unit of nutrient applied) in the crop rotation.

At 4 of the 3 farms, little regrowth was incorporated in fall. At another, we were not able to obtain height measurements. The remaining 6 farms there was a variable realationship between growth height and dry mass (Figure 7). This suggests that regrowth height may not be a reliable predictor of N supply, which is directly related to yield, but we will need to complete sample analysis for N concentration to verify that idea. Regrowth height greater than 8 inches is expected to provide an additional 40 lb N/acre in Wisconsin. As data on corn N uptake and residual soil nitrate are collected and analyzed from the 2010 season, we will be able to evaluate that recommendation.

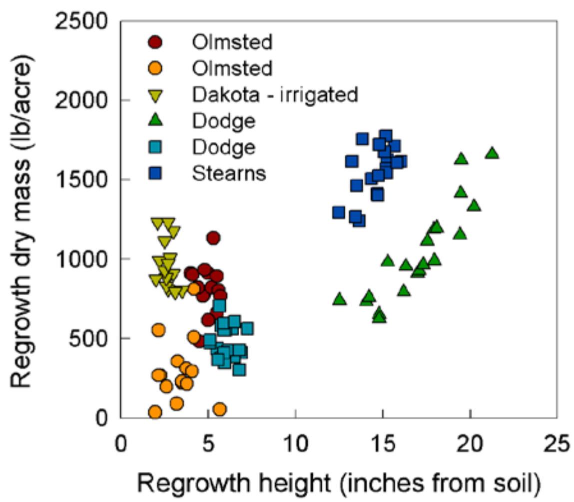

Figure 7. *Scatter plot of regrowth height and dry mass in late autumn. Height was measured from the soil surface; dry mass was for fresh herbage above the stubble height.*

Methods for the first-year corn phase

After the end of the 2008 growing season, farmers terminated the alfalfa by tillage with equipment and timing of their choice. Each main plot (K treatment) was subdivided into 6 subplots 10 to 15 feet wide by 30 feet long. After corn planting in the spring of 2009, we applied one of 5 N rates (0, 20, 40, 80, 160 lb N/acre) as ammonium nitrate to each subplot. An additional subplot received 80 lb N and 80 lb K_2O/acre to determine corn response to the variable soil test K levels established the previous year. We also sampled topsoil for soil test K in the 80 N and 80 N + 80 K_2O plots.

Plots were sampled for corn grain, cob, and stover yield either at a growth stage appropriate for silage or for grain, depending on the farmer's harvest time for the entire field (Figure 8). Each was determined on about 10 feet of row harvested by hand. After the ears were dried at 140 F, they were shelled, and grain and cob dry mass were determined. Stover was cut an average of 8 inches above the soil surface, the entire mass was weighed, coarsely chopped, and a subsample was collected, weighed, dried, and weighed again. Dry mass of stover was calculated using the wet mass of the entire sample and the moisture content of the subsample. All plant parts were pulverized and are being analyzed by NIRS and Dumas combustion for N and C.

Figure 8. *Harvesting corn ears (grain and cobs) and stover, and deep soil coring after crop harvest to determine residual soil nitrate.*

After the farmers completed harvest, we took three deep soil cores per subplot with a hydraulic probe. Cores were divided into one-foot increments (0 to 1, 1 to 2, 2 to 3, and 3 to 4 feet deep), mixed according to depth increment within each plot, dried at 95 F, and pulverized. We will determine nitrate and ammonium in the solution on a flow injection analyzer after samples are extracted with 2 *M* KCl following standard protocols. Additional cores were taken in the same increments to determine dry bulk density of the soil, which is used with the concentrations to calculate the amount of inorganic N per acre.

Results for the first-year corn phase

Corn grain yields were generally excellent in 2009, averaging well above 200 bu/acre. Below normal air temperatures may have reduced water stress on the crop and may also have reduced photosynthate losses due to respiration.

There was no yield response of corn grain, cob, or stover to K fertilizer rates applied to alfalfa. In contrast, it appears that 80 lb K_2O/acre applied after planting improved corn stover and total yield in some previous K treatments. We are still trying to separate the influences of site characteristics to discern what influenced this effect. It does not appear to be a simple function of previous K rate. In any case, because there was no main effect of K applied to alfalfa on the response of first-year corn, we analyzed corn response to N averaged over previous K rates.

Spring fertilizer N application rates did not affect corn grain, cob, or stover yields at the five farms in 2009 (Figure 9). An example of corn grain yields is shown for 4 of the 5 farms (one omitted for clarity). Therefore, the optimum fertilizer N rate in all cases would be zero. This is expected based on current University of Minnesota recommendations for preceding alfalfa stands with at least 4 plants/ft^2. Stover dry matter yields averaged 3.7 tons/acre and cob dry matter yields averaged 740 lb/acre. We report cob and stover separately, because cobs are being considered a potential source of cellulosic biomass that would be easy to harvest and presumably without causing declines in soil organic C. Potential ethanol yield from each fraction is pending completion and validation of an NIRS prediction equation.

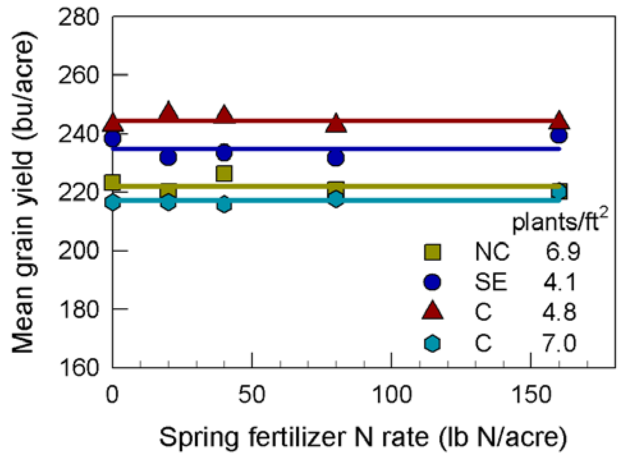

Figure 9. *Grain yield of the first corn crop after alfalfa did not respond to fertilizer N.*

Work plans for 2010

We plan to combine the estimates of K removal in alfalfa with changes in soil test K to evaluate the apparent fate of the fertilizer K during the alfalfa phase. After completing this analysis and the statistical analysis of forage quality over the 10 site-years, we will compile all the information collected in the alfalfa phase of this research to produce an Extension bulletin and a technical article for a peer-reviewed journal this spring. Included in future reports to AFREC will be plot history and management of the alfalfa crops (cultivar, fertilization, etc.), once all cooperating farmers have returned the questionnaires they received this winter.

We will apply N after corn planting on the remaining 5 AFREC farms and to corn on the 6 MCRPC farms (Figure 9) and will measure yield, N and K content, and potential ethanol yield of corn grain, cob, and stover, and residual soil nitrate to the 4 foot depth. If we find that fertilizer N response of first-year corn is affected by time of primary tillage of the alfalfa and/or the amount of regrowth that is incorporated, we will develop a prediction equation or protocol to estimate fertilizer N requirement that can be used by private and public crop advisors. If the protocol calls the current University of Minnesota guidelines into question, we will work with the

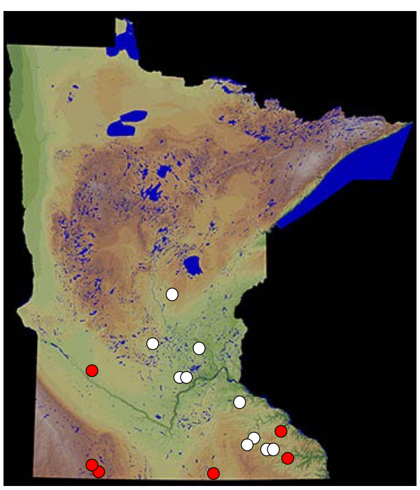

Figure 9. *Location of MCGA research sites (red dots) and AFREC research sites (white dots). Treatments in the MCGA research are 1) whether regrowth remains in the field, and 2) time of primary tillage to terminate the stand.*

Extension faculty to develop an improved version. We intend to use data from the MCRPC sites (red dots in the map) to generate the protocol, and data from the AFREC sites (white dots in the map) to provide an independent test of protocol predictive capacity. The final protocol will incorporate all data from the two research projects.

As occurred in 2009, we plan to publish applied articles in the farm press as the data analysis is completed and interpreted. We have begun planning summer field days at two AFREC sites and 3 MCRPC sites. These are being organized with local and regional Extension educators and we will invite the farmer cooperators to participate in the talks. The final report will be submitted in early 2011.

Presentations and articles

Coulter, J.A., M.P. Russelle, C.C. Sheaffer, and D.E. Kaiser. 2010. On-farm validation of alfalfa N credits to corn. p. 3. *In* K. Martinson et al. (ed.) Forage quarterly. Vol. 4, Issue 1. Available at www.extension.umn.edu/forages/pdfs/february_2010_fq_umeft.pdf (posted 1 Feb. 2010). Univ. of Minnesota, St. Paul.

Yost, M.A., M.P. Russelle, J.A. Coulter, C.C. Sheaffer, and D.E. Kaiser. 2010. Validating topdressed K fertilizer recommendations in an alfalfa-corn rotation. Nutrients in Our Environment Conference, Mankato, MN. poster presentation 18 Feb. 2010.

Russelle, M., J. Coulter, C. Sheaffer, and D. Kaiser. 2010. Should you topdress potash on last-year alfalfa? Forage Focus. March issue, pages 11 and 14.

In addition, each cooperating farmer receives annual summaries of data from his farm and copies of all publications and reports to AFREC.

Acknowledgments

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