PROJECT NO: BJKU10, BDK113

TITLE: Managing soil acidity and aluminum toxicity in northern Idaho

PERSONNEL: Dr. Kurtis Schroeder, Cropping Systems Agronomist
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JUSTIFICATION: Soil pH has been on the decline in northern Idaho for several decades, primarily due to the use of ammonium-based nitrogen fertilizers. This coupled with the parent soils in many regions of northern Idaho being forest-derived, which means they have a lower starting pH and lower buffering capacity, makes them more susceptible to changes in pH. Acidification of soils in northern Idaho and eastern Washington was well documented during the 1980's by Dr. Mahler at the University of Idaho. Recently, there has been renewed interest in this topic and since a significant proportion of farmland in northern Idaho is forest-derived, there is a potential for long-term declines in crop production and soil quality. Reports from growers in northern Idaho suggest that critical thresholds of free aluminum may be present in some fields. As soils become more acidic, the availability of many plant nutrients declines. Little information is available in northern Idaho to relate the nitrogen use efficiency of currently grown soft white winter wheat varieties to soil pH. Solutions for acid soils and aluminum toxicity include growing aluminum-tolerant crops, planting aluminum-tolerant wheat varieties and mitigation by application of calcium carbonate. The first two strategies are short-term solutions and may not be adequate for some growers. Ultimately, calcium carbonate applications will be needed to ameliorate the soil acidity, reduce the quantity of free aluminum ions in the soils, and improve soil microbial activity related to nitrogen cycling. Similar to the nitrogen fixing bacteria being impacted by pH, soil pH can also impact plant pathogens. An example is *Cephalosporium gramineum*, the causal agent of Cephalosporium stripe, being favored by acid soils. Less is known about other plant pathogens in wheat production. An added benefit of soil liming may be a reduction in disease.

HYPOTHESIS AND OBJECTIVES: The working hypotheses are that application of calcium carbonate, regardless of source, will increase soil pH and thereby yield. Secondly, the application of lime will improve the microbial activity in the soil, providing the plants with greater quantities of plant available nitrogen. Third, lime will decrease the severity and/or incidence of root and crown diseases. The goals are to examine the benefits of calcium carbonate application to improve soil pH and improve the sustainability of wheat production and yield. The specific objectives of the project are:

1) Continue to monitor winter wheat and spring pea plots that had three different commercial liming products applied in the fall of 2013.
2) Evaluate the impact of calcium carbonate application on nitrogen use efficiency in soft white winter wheat.
3) Examine the impact of soil pH on cereal pathogens, focusing on root and crown diseases.
4) Complete a regional survey in northern Idaho to access soil pH, total cation exchange capacity (CEC) and percentage of non-acid cations in the exchange.

5) Based on multi-year trial results, the profitability of liming products and rates for different regions and crops by computing the net present value for each scenario will be assessed.
6) Begin to examine higher rates of lime application that are comparable to the recommended rates based on lime requirement tests.

PROCEDURES:

1. *Crop response to calcium carbonate application.* Field trials were established in the fall of 2013 at Potlatch, ID; Winchester, ID; and Pullman, WA. Products included Moses Lake sugar lime (Cascade Agronomics), ground limestone (Pioneer Enterprises), and NuCal liquid lime (Columbia River Carbonates) each applied at 500, 1000 and 2000 lbs $CaCO_3$/A. A combination of 500 lbs/A NuCal and 1500 lbs/A ground limestone was included along with a non-limed control. At each of the three locations, two trials containing all of the above treatments were established. In the fall of 2014, each plot was split, planting Madsen (aluminum tolerant) in one half and Eltan (aluminum sensitive) in the second half, and seeding spring pea into the plots that were winter wheat in 2014. This same rotation will be maintained for the 2015/2016 crop season. In mid to late May, samples will be collected from each plot to a depth of 30 cm to monitor changes in the soil pH. Samples will be collected from 0-7.5 cm, 7.5-15 cm, 15-22.5 and 22.5-30 cm. Plots will be evaluated to assess plant damage due to acid soil and/or aluminum toxicity. At the end of the growing season, each plot will be harvested. Yield information will be used to generate an economic analysis of the lime application over the course of the study.

   In the fall of 2016, additional liming studies will be established at a minimum of five locations in northern Idaho to evaluate higher rates of lime based on the lime requirement tests. Many soils that have been surveyed over the past couple of years could require up to 4 to 5 tons of calcium carbonate per acre to return the soil to a pH of 6 in the upper 12 inches. Treatments will consist of 0, 1000, 2000 and a fourth rate based on a lime requirement test. Either sugar beet lime or ground limestone will be used at each location as the source of calcium carbonate. The plots will consist of four replications of each treatment and will be seeded to an aluminum sensitive variety of winter wheat. Data to be collected over the growing season will be the same as explained for the ongoing liming study outlined above.
2. *Fertilizer management in acid soils.* A trial was established at the Parker Farm in a field with a pH of 4.1 to 4.3. In this trial there were two nitrogen levels: either no nitrogen applied at planting or the full recommended rate based on soil testing. Four varieties of wheat were seeded with and without NuCal lime at about 16,000 lb/A. At harvest, plant tissue, grain and soils will be sampled to estimate the quantity of nitrogen in each to determine the fate of the applied nitrogen. In addition, total grain yield, test weights and grain protein will be determined from each plot.
3. *Impact of soil pH on root and crown diseases.* The impact of soil pH on the incidence and severity of root and crown diseases will be examined under greenhouse conditions. Soils will be collected from various sites on the Parker Farm in Moscow, ID that have soil pH from 4.0 to 6.0. Calcium carbonate will be added to portions of these soils to increase pH and soils will be inoculated with *Fusarium culmorum*, *F. pseudograminearum*, *Rhizoctonia solani*, and *R. oryzae*. After 3 to 4 four weeks, plants will be destructively harvested; disease incidence and severity scored; and first leaf length, plant height and dry plant weights recorded.
4. *Acid soil survey.* Soil samples will be collected throughout northern Idaho in the summer of 2015 to determine soil pH, non-acid base saturation and cation exchange capacity. In addition to soil pH, the percentage of non-acid base saturation can influence whether aluminum can be

accumulated by plants in a quantity that will cause toxicity. This data will be used to generate a series of maps using GIS to describe the distribution of soils throughout northern Idaho and to identify areas that are of risk of yield reductions due to low pH and aluminum toxicity.

5. *Assessing profitability of lime applications.* Detailed costs of production will be needed for each site in order to determine costs and returns for each scenario. Since the positive effects of lime application extend over a long timeframe, we will account for the stream of costs and benefits over time by estimating the net present value of each treatment. Various theoretical scenarios will also be developed to determine potential returns to the investment using preliminary data generated from the above experiments.

DURATION: This project is in the 3rd year of a 3 year project. Beyond the 2015/2016 growing season, additional soil samples may be collected from select plots to continue monitoring the soil chemistry at these sites. The new liming studies being initiating in the fall of 2016 are expected to continue for at minimum of 3 years beyond the other objectives of this project.

COOPERATON: This is a cooperative project with Dr. David Huggins, soil scientist with the USDA-ARS in Pullman, WA who is conducting similar liming source studies in Washington, but with an emphasis on direct seeding. Research plots will be conducted on University of Idaho research farms in Moscow and in cooperation with three local growers in Potlatch, ID; Winchester, ID; and Pullman, WA.

ANTICIPATED BENEFITS/EXPECTED OUTCOMES/INFORMATION TRANSFER: Results of this study will provide information on the potential benefit and strategies for liming in northern Idaho. The benefits of liming include the potential for improved yields, greater plant available nitrogen, reduced plant disease, and increased profitability over time. This information will allow growers to make informed decisions about the need to apply lime, allow them to identify which products will work best for their operation and need, and which will provide the greatest economic return. The results of this study will be shared at field days and winter cereal schools, and incorporated into regional Extension crop budgets published on the University of Idaho Extension website. In addition, at least two extension articles are anticipated from this work within the next year along with at least two peer-reviewed research publications.

LITERATURE REVIEW: Acidification of soils in northern Idaho was well documented during the 1980's by Dr. Mahler at the University of Idaho. As part of his research, the critical soil pH levels for pea, lentil, barley and wheat were determined, varying between a pH of 5.2 to 5.6 (Mahler and McDole 1987). Recently, there has been a renewed interest in this topic due to continued acidification and the discovery of associated acute aluminum toxicity in some areas of Spokane Co. in eastern Washington (Koenig et al. 2011). Recent research into the use of liming did not demonstrate an improvement in yield (Brown et al. 2008). However, the soils examined in this particular study were in soils historically covered by grass vegetation and have a high non-acid base saturation, preventing high quantities of aluminum from impacting plant health. However, under acidic conditions, independent of the base saturation of cations, nutrient availability is still impacted. Under historically forested soils, Mahler's research demonstrated an advantage to lime application to improve yields (Mahler and McDole 1985). Very little information exists on the impact of pH on Rhizoctonia root rot, *Pythium* spp. are known to be favored by slightly acidic conditions (5.0-5.5), and information on the impact of pH on Fusarium crown rot is mostly limited to studies examining ammonium versus nitrate forms of fertilizer, although Fusarium wilt diseases on other host crops are known to be favored by acidic conditions.

Brown, T.T., Koenig, R.T., Huggins, D.R., Harsh, J.B., and Rossi, R.E. 2008. Lime effects on soil acidity, crop yield and aluminum chemistry in direct-seeded cropping systems. Soil Science Society of America Journal 72:634-640.

Koenig, R., Schroeder, K., Carter, A., Pumphrey, M., Paulitz, T., Campbell, K., and Huggins, D. 2011. Soil acidity and aluminum toxicity in the Palouse region of the Pacific Northwest. Washington State University, Extension Bulletin FS050E.

Mahler, R.L., and McDole, R.E. 1985. The influence of lime and phosphorus on crop production in northern Idaho. Communications in Soil Science and Plant Analysis 16:485-499.

Mahler, R.L., and McDole, R.E. 1987. Effect of soil pH on crop yield in northern Idaho. Agronomy Journal 79:751-755.

IDAHO WHEAT COMMISSION - BUDGET FORM

Allocated by	Idaho Wheat Commission	during FY 2015	$	20,288
Allocated by	Idaho Wheat Commission	during FY 2016	$	20,288

REQUESTED FY 2016 SUPPORT:

	Salary	Temporary Help	Fringe	Travel	OE	Graduate Tuition/Fees	TOTALS
Idaho Wheat Commission	$ -	$ 9,600	$ 1,561	$ 3,500	$ 9,500	$ -	$ 24,161

OTHER RESOURCES (not considered cost sharing or match):

TOTAL OTHER RESOURCES $ 46,450

TOTAL PROJECT ESTIMATE FOR FY 2017:	$ 24,161	$ 46,450	$ 70,611
	(Requested)	*(Other)*	*(Total)*

BREAKDOWN FOR MULTIPLE SUB-BUDGETS:

	Schroeder	*Painter*	*Finkelnburg*	*(PI name)*
Salary	$ -	$ -	$ -	$ -
Temporary Help	$ 6,000	$ 3,600	$ -	$ -
Fringe Benefits	$ 150	$ 1,411	$ -	$ -
Travel	$ 1,500	$ 1,000	$ 1,000	$ -
Operating Expenses	$ 7,500	$ -	$ 2,000	$ -
Graduate Student Tuition/Fees	$ -	$ -	$ -	$ -
TOTALS	$ 15,150	$ 6,011	$ 3,000	$ -

Total Sub-budgets $ 24,161

10.7.2015 - Version

ANNUAL REPORT

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ACCOMPLISHMENTS:

Four separate projects were conducted to assess the impact of soil pH on and liming on wheat production. These included field trials to assess liming products and rates, evaluation of the impact of liming on nitrogen use efficiency, continuation of a soil pH survey and greenhouse studies to assess the impact of soil pH on soilborne plant pathogens.

For the first of the studies, three plots were established in the fall of 2013 that had calcium carbonate applied at rates of 500, 1000 or 2000 lbs/A in the form of sugar beet lime (Moses Lake), ground limestone or fluid lime (NuCal). These plots were established at Winchester and Potlatch, ID as well as Pullman, WA on fields with soil pH below 5.0 in the top 6 inches. Winter wheat varieties Madsen and Eltan were seeded into the plots in the fall of 2014 and spring pea (Banner) was seeded into adjacent plots in the spring of 2015. In late May, soil samples were collected at four depth increments (0-3, 3-6, 6-9 and 9-12 inches) from all 88 plots at each of the three locations. These samples will be sent to Best Test Laboratories (Moses Lake, WA) by January 2016 for soil analysis. The results of these tests will include information on macro and micronutrients, soil pH, cation exchange capacity, base saturation and free aluminum concentration.

Plant height, grain yield and test weight were collected from all three locations, but there was not a significant difference in either varieties of winter wheat. However, at both Potlatch and Pullman, the non-limed plots had the lowest yield for both Madsen and Eltan, and the 2000 lb/A rates of lime generally had the highest yields. At Potlatch, most lime treatments increased the yield of Madsen by a minimum of 7 bu/A. The spring peas at Pullman were lost due to an aerial application of herbicide on the surrounding winter wheat field. The yield data obtained from Potlatch and Winchester was not very meaningful as average pea yields were only 47 and 43 lb/A, respectively. Due to unseasonably high temperatures in June and early July, most of the blooms aborted at both locations. Based on soil tests, there is still free aluminum in these soils despite lime application. The soil pH measured in 2014 showed only a small increase in soil pH, even with the 2000 lb/A rates. It may be necessary to add greater quantities of lime to see a significant yield response. Regardless, the soil analysis are providing useful data on changes in soil pH and soil chemistry that should result in improved soil health.

Two additional field studies were established at the Plant Science farm east of Moscow to examine the impact of lime application on nitrogen uptake by plants. The first trial consisted of plots that were limed (16,000 lb/A) or non-limed with calcium carbonate (NuCal fluid lime), five

Winter wheat yield at lime rate and source studies for 2015.

	Winter Wheat Yield (bu/A)					
Treatments	Potlatch (Madsen)	Potlatch (Eltan)	Pullman (Madsen)	Pullman (Eltan)	Winchester (Madsen)	Winchester (Eltan)
No lime	71.2	60.5	93.3	90.7	69.8	58.1
Sugar beet 500 lb	87.5	75.3	96.6	95.3	66.2	59.9
Sugar beet 1000 lb	83.2	65.6	95.5	94.5	65.4	56.5
Sugar beet 2000 lb	85.7	77.7	102.7	98.8	66.9	57.7
Ground lime 500 lb	72.9	60.6	96.5	99.8	62.8	52.7
Ground lime 1000 lb	78.3	66.6	101. 7	96.6	69.8	57.6
Ground lime 2000 lb	83.5	69.7	95.0	97.3	67.5	59.7
NuCal 500 lb	83.1	75.4	94.1	97.1	67.1	55.5
NuCal 1000 lb	84.7	66.9	96.7	94.6	63.2	53.8
NuCal 2000 lb	81.4	69.3	102.0	101.8	68.9	56.9
NuCal 400 + Ground 1600 lb	83.2	63.3	96.3	92.1	67.6	59.3
Average	81.3	68.2	97.3	96.2	66.8	57.1
LSD (0.05)	ns	ns	ns	ns	ns	ns
P-value	0.5959	0.5980	0.9836	0.6706	0.3795	0.8411
CV (%)	13.8	18.9	12.7	7.4	6.6	10.9

rates of fertilizer applied at planting (50, 75, 100, 125 and 150 lb/A), and four varieties of winter wheat with varying tolerance to aluminum (Brundage 96, Eltan, Madsen and Stephens). A second trial also included limed and non-limed plots, the same four wheat varieties, but uniform nitrogen application at planting. In the second trial, plant tissue and soil samples were collected at harvest to measure nitrogen levels in the tissue and residue nitrogen in the soil. For the first trial, there was very little response to liming and the overall yield between limed and non-limed plots was not significantly different. Although the mid-season biomass measurements showed a significant response to liming, it did not translate into improved yield. There was also very little response to increasing nitrogen rates. This plot was located in a different part of the Plant Science farm where the pH is in the high 4s versus 4.2, where it was located in 2014. It is possible that there was insufficient free aluminum to cause a significant yield response. There were also problems with fertilizer delivery when seeding this plot, so the highest nitrogen rates may be lower than the target rate. However, the second study that was initiated last fall with uniform nitrogen applied at planting resulted in a significant response to lime application for both with the mid-season measurements and yield. Tissue and soil samples are still being processed, so we are unable to make a correlation with nitrogen uptake by the plants and yield at this time.

For the regional soil survey in northern Idaho, approximately 100 additional samples were collected during May of 2015. Soil analyses are currently be completed on these samples. The data will be used to help identify which soils are more susceptible to showing signs of aluminum toxicity and associated declines in plant health and yield. A greenhouse project is also underway to examine the impact of soil pH on *Fusarium culmorum, Rhizoctonia solani* AG-8 and *R. oryzae*, all common soilborne pathogens in northern Idaho. Samples were collected from the Plant Science farm and amended with calcium carbonate to bring the soil pH to 5, 6 and 7. Based on the results of these experiments, similar studies may be established in the field in 2016. Work has begun on the economic analysis of lime application. In addition to analyzing the data from these trials, projections may be generated to estimate the potential long-term benefit of lime application.

This research was featured at the Plant Science Field Day at Parker Farm, Moscow and was presented as a poster at the ASA-CSSA-SSSA meeting in Minneapolis, MN.

Summary of results from nitrogen use efficiency studies at Plant Science farm.

Variety	Lime	Yield (bu/A)	Test Weight (lb/bu)	Plant Height (inches)	Wet Shoot Weight (g)	Dry Shoot Weight (g)
Brundage 96	Limed	69.3	54.0	29.8	311.0	109.0
Brundage 96	No Lime	45.9	57.1	26.6	77.6	25.7
Eltan	Limed	23.2	58.1	25.8	47.7	15.0
Eltan	No Lime	0.9	---	21.8	1.0	0.1
Madsen	Limed	71.0	55.0	31.6	198.6	84.9
Madsen	No Lime	51.0	57.3	31.0	96.8	31.3
Stephens	Limed	43.5	56.9	28.6	122.1	51.8
Stephens	No Lime	21.0	57.4	25.4	27.6	8.8

Treatment	Yield (bu/A)	Test Weight (lb/bu)	Plant Height (inches)	Wet Shoot Weight (g)	Dry Shoot Weight (g)
Limed	51.8 a	56.0	29.0	169.9 a	65.2 a
No Lime	29.7 b	57.3	26.2	49.3 b	16.5 b
LSD (0.05)	3.7	ns	1.1	38.9	11.6
P-value	<0.0001	0.1105	<0.0001	<0.0001	<0.0001
CV (%)	14.1	5.8	6.1	53.3	43.7

PROJECTIONS:

The lime source and rate studies at Winchester, Potlatch and Pullman were reseeded with winter wheat in October. We will continue to monitor the soil chemistry during the summer of 2016. We have seen only modest improvements in yield and the soil pH has risen only slightly in the upper 6 inches of soil, so it is very likely that higher rates of lime will be required. Based on this, we are planning to initiate new study sites in the fall of 2016 to focus on applying higher rates of calcium carbonate in line with recommended lime requirements for each site. The study to examine nitrogen use efficiency and its relation to soil pH was also reseeded. As in 2014, higher rates of calcium carbonate were applied to the site to achieve the lime requirement as determined by soil testing. We intend to evaluate the coverage of our soil survey and may collect a few more samples from strategic areas in north Idaho in 2016. Greenhouse work will continue to examine the impact of soil pH on root and crown pathogens.

PUBLICATIONS:

Paulitz, T., and Schroeder, K. 2015. Acid soils: how do they interact with root diseases? Washington State University (http//smallgrains.wsu.edu/soil-and-water resources/soil-acidification-in-the-inland-northwest/) (in press)

Schroeder, K. L., Finkelnburg, D., and Huggins, D. R. 2015. Wheat and pea response to lime source and rate in acidified soils of northern Idaho. ASA-CSSA-SSSA annual meeting, Nov. 15-18, Minneapolis, MN. (abstract)

McFarland, C., Huggins, D., Koenig, R., Carpenter-Boggs, L., Blackburn, J., Schroeder, K., Brown, T., Carter, P., and Kahl, K. 2015. Determining lime requirements using buffer tests in eastern Washington and northern Idaho. ASA-CSSA-SSSA annual meeting, Nov. 15-18, Minneapolis, MN. (abstract)

McFarland, C., Huggins, D. R., Carpenter-Boggs, L., Koenig, R., Blackburn, J., **Schroeder, K.**, and Paulitz, T. How surface-applied lime products affect soil fertility. Pp 24-25. In: *2015 Dryland Field Day Abstracts: Highlights of Research Progress*. Dept. of Crop and Soil Sciences Technical Report 15-1, Washington State University, Pullman.

McFarland, C., Kahl, K., Huggins, D., Carpenter-Boggs, L., Koenig, R., Blackburn, J., **Schroeder, K.**, and Paulitz, T. 2015. How much lime to apply? Pp. 23. In: *2015 Dryland Field Day Abstracts: Highlights of Research Progress*. Dept. of Crop and Soil Sciences Technical Report 15-1, Washington State University, Pullman.