ANNUAL REPORT

Grant Code: AP6320

Title: Exploring the feasibility of using high lime rates on crop performance in northern Idaho and identifying aluminum-tolerant wheat

Personnel: Dr. Kurtis L. Schroeder, Associate Professor of Cropping Systems Agronomy

Address: Plant Sciences Department, University of Idaho, 875 Perimeter Drive MS 2333, Moscow, ID 83844-2333; 208-885-5020; kschroeder@uidaho.edu

Abstract:
Soil pH has been declining steadily in northern Idaho for decades. The primary cause of this decline can be attributed to the consistent use of ammonium-based nitrogen fertilizers. One strategy to mitigate the negative impacts of soil acidity and aluminum toxicity is liming. However, the concept of liming is new to the region and infrastructure for large scale liming is not present. Locally sourced ground limestone is one of the most economical liming material available, thus it was chosen for this study. Four locations near Potlatch and Tensed, ID were established in the fall of 2016 by applying 0, 1, 2 or 3 ton/A of ground limestone and incorporating to a depth of approximately 4 to 6 in. Crops have been sequentially grown at these locations for the past 6 years, monitoring crop performance and changes in soil chemistry. Soil samples are collected each May to a depth of 12 in. Lime application has reduced the quantity of soluble aluminum in the upper 3 in by 79 to 96% and by 18 to 47% in the 3 to 6 in depth. Rotations differed at each location, but included winter wheat, spring wheat, spring barley, spring canola, lentil and chickpea. There was a significant and incremental increase in yield with increasing lime rate for winter and spring wheat. All lime treatments significantly improved winter and spring wheat, spring barley, spring canola and chickpea yields. Over the course of 6 years, there was an average increase in profit of \$129, \$146, and \$191 per acre 1, 2 and 3 ton/A rates of lime, respectively compared to the no lime control. Management of soil acidity and aluminum toxicity is a new concept for growers in the region, and this data supports expanding liming within the region.

Background/Objectives:
Soil pH has been on the decline in northern Idaho for decades. A recent survey revealed that soils have continued to decline in pH, with most northern Idaho fields having a pH of 5.2 or lower (76%) in the upper 6 inches. About 34% of the fields sampled had a pH below 5. While low soil pH can influence many factors including fertilizer availability, herbicide breakdown (longer residual), disease suppression, and the abundance of nitrifying and nitrogen fixing bacteria, one of the most significant impacts is the increase in soluble aluminum. Soluble aluminum is toxic to plants and at high enough quantities will result in substantial root damage, leading to reduced plant growth and yield. While there are some short-term solutions for wheat production such as selecting aluminum-tolerant varieties or including aluminum-tolerant crops in rotation, the problems with the soils will only be solved by increasing the soil pH via liming. The objectives of this project were to 1) examine crop response and changes in soil chemistry at four locations limed with up to 3 tons/A in the fall of 2016, 2) determine the economic impact of applying high rates of lime in north Idaho,

and 3) evaluate current varieties and elite breeding lines of winter and spring wheat to identify aluminum-tolerant varieties.

Results/Accomplishments:

Four trial sites were continued during the 2022 growing season to continue assessing the impact of varying lime rates on aluminum toxicity and crop performance following the liming of these locations in 2016. This research continued to demonstrate the agronomic advantages of liming acidic soils in northern Idaho unlike previous work that was plagued by inconsistent crop responses due to site variability or use of lime quantities below 1 ton per acre. In the current study, sites selected for study had a soil pH below 5 uniformly across the trial. Strip trial locations include two locations near Potlatch and two locations north of Tensed. In the fall of 2016 1, 2 or 3 tons calcium carbonate/A was applied in the form of ground limestone. During the 2021-2022 growing season, these sites included spring canola cv CP 955 RR (Potlatch #1), winter wheat cv UI/WSU Huffman (Potlatch #2 and Tensed #1), and spring wheat cv Seahawk (Tensed #2). Both UI-WSU Huffman and Seahawk are among the more tolerant wheat varieties and were intentionally chosen for that purpose and to demonstrate the impact of liming using a tolerant variety. All plots were seeded using a custom AgPro Conservation Plot Drill equipped with Bourgault paired-row openers on 12-inch spacing. All cereal crops were fertilized at planting following standard, recommended rates. Soil samples were collected in May from each plot, removing two composite subsamples per plot at 3-inch increments to a depth of 12 inches. All analyses were performed by Best Test Analytical Services (Moses Lake, WA). During the growing season, the plants were monitored for disease and plant height. At the end of the growing season, plots were harvested to determine grain yield, test weight and protein. In addition, two UAV flights were made of each location, with the first in late May and the second in late June.

Soil samples were collected from each plot at four locations in May of 2022 (5 years and 8 months post liming). A composite from all four locations and all six years of soil sampling is shown in Figure 1. Data for the 6 to 9 and 9 to 12 in depths is not shown as these do not differ between treatments. The average soil pH at the end of six years in the 6 to 9 in depth was 5.0 and at the 9 to 12 in depth was 5.5. Soil pH varied across years, but the trend between treatments remained throughout the study with significant and incremental increases in soil pH corresponding to increasing rates of lime. During the May 2022 soil sampling, it was determined that the quantity of soluble aluminum continues to be substantially reduced in the limed soils with a 79 to 96% reduction in the 0 to 3 in depth and an 18 to 47% reduction in the 3 to 6 in depth with the greatest reductions in soils from the 3 ton/A plots. Despite the reduction in soluble aluminum, there is still about 54 and 33 ppm at the 3 to 6 and 6 to 9 in depths of the 3 ton/A lime rate, respectively. Thus, deeper incorporation of lime and likely greater rates of lime would be required in some circumstances to eliminate the soluble aluminum that could result in aluminum toxicity.

The 2022 crop season had some challenges. An unusually cold and wet spring delayed the seeding of spring crops which significantly reduced the resulting yield for the spring wheat and spring canola crops (Table 1). The wet and cool spring also impacted the overall crop yield of winter wheat at the Potlatch#2 location. As observed in previous years, there was a substantial increase in crop yield in plots that were limed in 2016. Despite the low crop yield for spring canola, there was a 44 to 77% increase in yield in the limed plots. Likewise, the yield of spring wheat was increased by 9 to 15% while the yield of winter wheat was increased by 15 to 46% with liming. In all cases, the no lime control resulted in the lowest yield increase with the 2 or 3 ton/A rate giving the highest yield.

Figure 1. Soil pH at 0 to 3 in (A) and 3 to 6 in (B) from four field locations in Potlatch and Tensed from 2017 (Year 1) to 2022 (Year 6) following the application of lime in 2016.

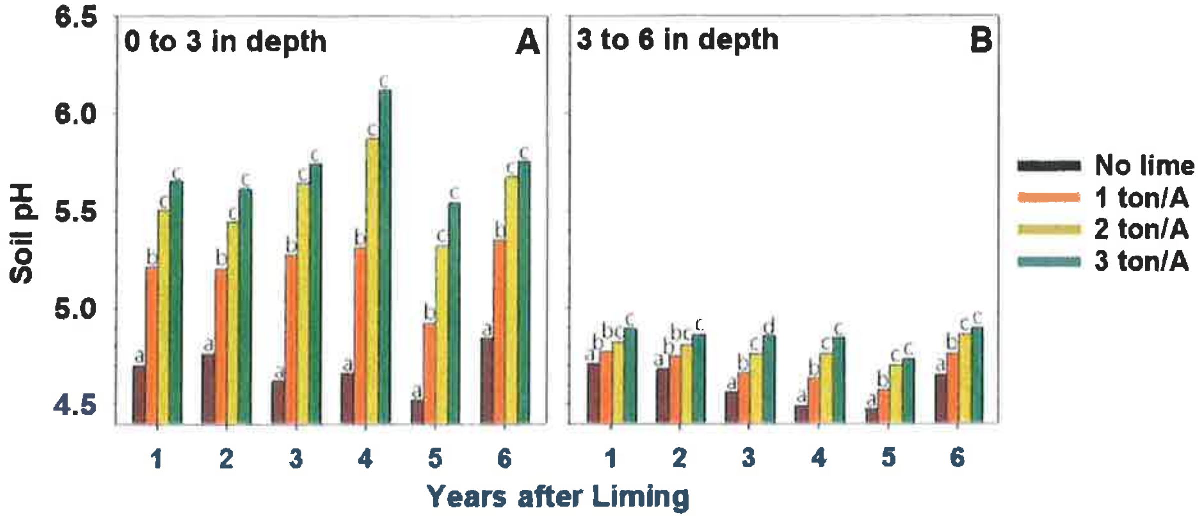

Table 1. Increase in seed yield following application of ground limestone, 2022.

Lime (ton/A)	Seed Yield			
	Potlatch#1 S. Canola	Potlatch#2 W. Wheat	Tensed#1 W. Wheat	Tensed#2 S. Wheat
	-----bu/A-----	------------lb/A------------		----bu/A----
0	498 c	39 c	80 b	34 b
1	718 b	48 b	92 a	37 ab
2	880 a	51 b	96 a	38 b
3	870 a	57 c	97 a	39 b
	Percent Increase in Yield			
1	44	23	15	9
2	77	31	20	12
3	75	46	21	15

During the duration of this study between 2017 and 2022, there were data collected on yield response to lime application for six crops grown in northern Idaho with an emphasis on winter wheat (Table 2). There were increases in yield for nearly all lime rates and crops with the largest increases occurring with the 3 ton/A rate of lime. For winter wheat, there were 11 site-years of data collected and an average increase in yield of 10 bu/A following the application of 3 ton/A of lime. Similarly, there was a 6 bu/A increase in spring wheat (3 site-years), 1,440 lb/A increase in spring barley (1 site-year), 157 lb/A increase in spring canola (3 site-years), 284 lb/A increase in lentil (2 site-years), and 719 lb/A increase in chickpea (1 site-year) with the 3 ton/A rate. Aside from aluminum sensitive varieties of wheat, barley is one of the most sensitive crops to low pH and aluminum toxicity and hence the large increase in yield with lime application.

Table 2. Average yield by crop for all trials conducted between 2017 and 2022 on sites limed in 2016.

Lime Rate (ton/A)	Winter Wheat (bu/A) (11 site-years)	Spring Wheat (bu/A) (3 site-years)	Spring Barley (lb/A) (1 site-year)	Spring Canola (lb/A) (3 site-years)	Lentil (lb/A) (2 site-years)	Chickpea (lb/A) (1 site-year)
0	62 c	35 b	2,784 b	1,068 b	842 b	2,079 b
1	68 b	37 b	3,840 a	1,235 a	1,043 a	2,502 a
2	70 ab	38 ab	4,224 a	1,196 a	1,078 a	2,666 a
3	72 a	41 a	4,224 a	1,225 a	1,126 a	2,797 a

Means followed by the same letter are not significantly different using Fisher's LSD (0.05).

Using the data generated from this study, an economic analysis was conducted to determine evaluate the economic feasibility of annualized lime applications in 2022. The original cost of the ground limestone applied in 2016 was $74 per ton which included the cost of the product and transportation plus $13 per acre for application. The annualized cost of lime application assuming a 10 (1 ton/A), 15 (2 ton/A) or 20 (3 ton/A) year time frame for efficacy was $12 (1 ton/A), $17 (2 ton/A) and $20 per acre (3 ton/A). The farm gate value of the crops for each year (average of Aug to Nov prices, USDA-NASS) were used. The values in Table 2 represent the total increased return over 6 years after subtracting the annualized lime cost. In all cases, there was a positive return with the highest rates of return for the 3 ton/A rate at Potlatch#1, Tensed#1 and Tensed#2. The rate of return was similar for all lime rates at Potlatch#2. We originally suggested annualizing the cost of the lime over 10, 15 or 20 years. However, the benefits of liming are likely to last longer than these timespans. At the current rate of progress, the cost of lime application will likely be recouped for all lime rates within 10 years with the exception of Tensed#2.

Table 2. Economic value of increased grain yield over 6 years in northern Idaho after accounting for annualized cost of lime application per acre.

Lime Rate (ton/A)	Potlatch #1	Potlatch #2	Tensed #1	Tensed #2
	$/acre			
1	$164	$203	$62	$89
2	$225	$193	$104	$61
3	$271	$188	$184	$120

*Annualized cost of lime application is $12 (1 ton/A), $17 (2 ton/A) and $20 (3 ton/A) assuming an efficacy of 10, 15 and 20 years for the 1, 2 and 3 ton/A rates, respectively.

**Commodity prices used in analysis are the farmgate value from USDA-NASS, average price from August to November for Idaho and Washington combined.

The values above represent an initial look into the economic impact of liming. Further analysis of this data will be required in collaboration with economists to develop guidelines for estimating cost and risk of liming along with potential gains. It is crucial to understand how this long-term investment figures into the economics of the farm operation. The positive gains in grain yield along with the improvements in soil health and economic analysis all point to high rates as being the best possible solution for management of soil acidity in northern Idaho when the soil pH is below 5. This data is vital not only for the grower, but also for use in convincing the landowner of the need for these treatments. Of the 2.1 million acres of cropland in northern Idaho, approximately 62% of growers operate land they own and rent, while an additional 15% farm only on rented land (2017 USDA Census of Agriculture).

The second major component of this project is to screen varieties of spring and winter wheat for tolerance to aluminum toxicity. While liming will solve the soil acidification and aluminum toxicity issue, use of tolerant varieties can provide an immediate tool for management of this aluminum toxicity. A total of 147 winter wheat entries and 44 spring wheat entries were tested. These include both released varieties and experimental lines from public and private sources. A field site at the University of Idaho Parker Plant Science Farm east of Moscow with a pH of about 4.2 to 4.4 in the upper 6 inches and greater than 300 ppm soluble aluminum was used for these evaluations. There was a wide range of crop response with rating ranging from 1 (healthy) to 5 (dead plants) in both the winter and spring wheat trials. Data from 2022 is currently in the process being analyzed and combined with data from previous years.

Outreach/Applications/Adoption:
Information about liming and this project in particular has been shared at several workshops and winter schools, in the annual "Dryland Field Day Abstracts" publication, and presented in professional meetings. Two extension publications are currently in the planning phases, one to update the liming guide for Idaho as well as incorporate economic data from this study and a second to provide a guide on variety selection for aluminum-tolerance in wheat. Many growers in the region are experimenting with lime application and several growers have made significant investments in lime following early initial successes.

Next Steps/Projections:
Understanding the long-term benefits of lime application on north Idaho cropping systems is important to maintaining the viability of crop production in the region. While most locations are being discontinued, the site designated Potlatch#2 will continue to be operated for at least another 4 to 9 years. In the near term, this site will be used to study the impact of liming on crop competition with weeds as well as to understand the impact of soil pH and liming on the prevalence of important weeds species. The site will also continue to be monitored for crop performance and changes in soil pH and soluble aluminum. There is also a plan to continue screening wheat varieties and breeding lines for tolerance to aluminum as part of the north Idaho variety testing program. It is important to obtain the crop response data to aluminum in new breeding material and varieties so growers in areas with low pH and aluminum toxicity can make an educated decision on the best varieties for their system.

Publications/Presentations/Popular Articles/News Releases/Variety Releases:
Presentation:
Schroeder, K. L. 2022. Management of aluminum toxicity in northern Idaho. ASA-CSSA-SSSA Annual Meeting, Nov. 6-9, Baltimore, MD.

News Releases:
Addressing soil acidity: liming studies focus on looming soil health challenge. August 2022 by

John O'Connell, College of Agriculture and Life Sciences, University of Idaho. https://www.uidaho.edu/extension/news/story/2022/liming-studies

Lime application study assesses looming soil threat. September 6, 2022 by John O'Connell, Idaho Farm Bureau Federation. https://www.idahofb.org/news-room/posts/lime-application-study-assesses-looming-soil-threat/

U of I lime application study assesses looming soil threat. September 13, 2022 by John O'Connell, Intermountain Farm & Ranch. https://www.postregister.com/farmandranch/crops/u-of-i-lime-application-study-assesses-looming-soil-threat/article_3448614c-3377-11ed-8361-d3dd7d4307cc.html