Grant Code: AP7076
Title: Liming for Improved Nutrient Utilization and Weed Management in Wheat
Personnel: Jared Spackman, Assistant Professor, UI Aberdeen; Albert Adjesiwor, Assistant Professor UI Kimberly; Jared Gibbons, Madison County; Tom Jacobsen, Fremont County, Joseph Sagers, Jefferson County; Kurt Schroeder, Associate Professor, Moscow
Address: Jared Spackman 1693 S. 2700 W. Aberdeen, ID 83210; (208) 312-2454; jspackman@uidaho.edu

Justification/Rationale: The optimal soil pH for most agronomic crops is 6.2 to 7.3 when nutrient availability is maximized. Most southern Idaho agricultural soils are neutral to alkaline (pH 7 to 8.5) but naturally slowly acidify due to precipitation. Agricultural production accelerates acidification when ammonium-containing fertilizers are applied and as cations are removed at harvest[3]. Because soil pH change is gradual, yield reductions are often not observed until a soil pH threshold is reached. The critical threshold for sugar beets, barley, potatoes, and wheat are 6.0, 5.8, 5.5, and 5.4, respectively. Below these thresholds, root growth is inhibited negatively impacting nutrient and water uptake. While most southern Idaho soils are above these thresholds, soil acidity is becoming increasingly problematic from Ashton to Driggs, as well as other pockets across southern Idaho. Sugar beet lime is a readily available amendment, but the current University of Idaho and soil testing lab liming recommendations are based on other Midwest and Pacific Northwest states' recommendations that do not reflect southern Idaho soils' physical, chemical, and climatic properties.
In addition to improving nutrient availability and crop growth, scientific experiments have shown that lime applications can reduce weed seed germination and vigor and make crops more competitive. Liming acidic soils in Idaho could provide additional benefits of improving wheat competitiveness against weeds, reducing weed pressure, decreasing the overall impact of weeds on wheat yield, and reducing the number of weed seeds in the soil. Weed seeds in the soil remain the major source of weed infestation in crops. Thus, the best indication of the "next" weed problem is the composition of weed seeds in the soil. We are proposing a multi-disciplinary study that evaluates the effect of liming on nutrient availability, crop growth, weed density, and weed seed composition in the soil.

Objectives:
Hypothesis: Liming will improve soil nutrient availability, crop growth, and reduce weed pressure on agronomic crops.
Objective 1: Monitor how liming with precipitated calcium carbonate (sugar beet lime) modifies soil nutrient availability, plant nutrient uptake, and grain quality and yield over time.
Objective 2: Monitor how liming with precipitated calcium carbonate (sugar beet lime) modifies soil pH and exchangeable aluminum (a plant toxin) throughout the soil profile over time.
Objective 3: Evaluate weed species vigor when grown with wheat in a greenhouse under differing soil pH regimes.

Methods/Plan of Work: Four on-farm field experiments were established in Ashton (3) and Swan Valley (1) in the fall of 2021. Four replications of four sugar beet lime rates were applied at 0, 2, 4, and 6 tons per acre using Valley Ag's spreader to 50 x 100' plots. In 2022, the individual field sites were planted to wheat or barley, and in 2023 were planted to potatoes, barley, or canola. In 2024, the field sites will be planted with wheat or another rotational crop (

seed potatoes, barley, or canola). The plots will be managed according to the grower practices. Soil samples will be collected at the 0-2, 2-4, 4-6, 6-8, and 8-12" depths in the fall of 2023. These samples will be analyzed for soil pH, electrical conductivity, and free lime (when soil pH>7). Additional soil samples will be collected at 0-6" depths and analyzed for extractable aluminum (a source of soil acidity and root toxicity). At maturity, yield, yield components (test weight, grain protein), aboveground biomass, weed biomass, and weed density will be measured from within each plot. The aboveground biomass will be analyzed for complete nutrient analysis.

Lime requirement recommendations for Idaho soils are being conducted by collecting ten gallons of acidic soils (pH<6) from the 0-6" depth in Ashton, Driggs, Soda Springs, Grace, Moscow, Potlach, and other sites identified by agronomists and soil testing labs. A 90-day lime incubation will be initiated by adding calcium carbonate lime to each soil at rates of 0, 0.5, 1, 2, 4, 6, 8, and 10 tons per acre. Soil pH, electrical conductivity, free carbonate, and nitrate and ammonium content will be measured at the beginning and end of the incubation. The non-limed soils will be evaluated for lime requirement using the Sikora buffer, the modified Mehlich buffer, single addition calcium hydroxide, and sequential addition of calcium hydroxide methods.

The modified lime incubation soils will be subdivided into 3 or 4 pots each and co-planted with wheat and red root pigweed, wild oat, Kochia, and/or corn spurry. Seedling emergence and vigor will be assessed to determine if these noxious weed species are affected by soil pH. Additional weed species may also be assessed.

Duration: Four years (2021, 2022, 2023, 2024) Year 4 of 4

Cooperation/Complementation: The last national push to conduct liming research was in the 1970s and 1980s. Interest in liming research has been renewed in the last decade, especially in the western states. Lime incubation studies or field trials were recently conducted in the Palouse region, Montana, Washington, and Oregon due to increasing occurrences of soil acidification.

This study supports the research and trial and error testing done by Valley Wide Ag in Ashton over the last 20 years. The IWC study is a collaborative effort to provide research-based lime requirement recommendations to agronomists and the farmers they work with.
Dr. Spackman's lab is working with a national research group (Fertilizer Research Support Tool https://soiltestfrst.org/lime/) to reevaluate liming recommendations and practices. Drs. Spackman and Schroeder joined this research team in 2022. Dr. Spackman has submitted acidic soils from Ashton and Soda Springs for inclusion in a national lime incubation study.
Dr. Spackman's lab is working with Dr. Dave Tarkalson at USDA ARS in Kimberly and Amalgamated Sugar on ways to utilize precipitated calcium carbonate (spent sugar beet lime) as an agronomic amendment in both acidic and alkaline soils. Through this relationship, Dr. Spackman will help convert some of Dr. Tarkalson's research articles into Extension bulletins.

Anticipated Benefits/Expected Outcomes: We anticipate that this study will generate two peer-reviewed journal articles and two Extension bulletins. Both the on-farm and the incubation studies will contribute data to Dr. Adjesiwor's database of herbicide-resistant weeds and weed seed bank density across southern Idaho. Because Idaho's lime guidelines were developed using research from other Pacific Northwest states' datasets, this lime recommendation study will be the only dataset to our knowledge that is specific to the lime requirements of southern Idaho soils. The data from this study will help growers know how long a single lime application lasts in southern Idaho irrigated conditions and what rate is most effective.

Transfer of Information/Technology: One graduate student used the previously generated data from this study in her thesis. The results were presented at the Tri-Societies meetings in 2022 and 2023 and the Western Nutrient Management Conference in 2023. This information will also be shared at the 2024 Cereal School and field days. The raw dataset will be published in a publicly available data repository to ensure the longevity of the dataset and its availability for future research applications. This project will be used to inform growers and crop advisors about the potential benefits of liming for a competitive advantage over weed pressure, improved crop health, and nutrient availability and uptake.

Literature Review:

Soil acidification is an increasingly common problem for Idaho wheat producers. Formerly neutral to slightly alkaline agricultural soils in Montana, Idaho, Oregon, and Washington have acidified following repeated applications of ammonium-containing fertilizers, cation leaching with irrigation water, and cation removal with harvest[2,3]. Additionally, sandy soils acidify more rapidly than clayey soils due to less organic matter and cation exchange capacity. Acidic soils reduce soil nutrient availability to crops and increase aluminum and manganese solubility which reduces crop growth by killing the root tips[3]. Lime is required to neutralize soil acidity and includes a variety of sources including limestone, sugar beet lime, and wood ash among others[6]. Sugar beet lime is a readily available source in southern Idaho and is commonly used on acidic soils in Ashton and other southern Idaho fields. In a Montana study, 2.5 tons ac^{-1} of sugar beet lime was required to raise soil pH from 4.7 to 6.0 in the top 4 inches of the soil profile[2]. Most of the pH change occurred in the first year following tillage.

In addition to improving crop growth and nutrient availability, liming acidic soils increases the competitiveness of the crop against weeds[4,5]. Healthy crops effectively compete with weeds for water and nutrient resources reducing weed density and the number of weed seeds produced annually. This is especially important for managing herbicide-resistant weeds. A recent study demonstrated that lime application to acidic soil increased tiller number in wheat and the overall competitiveness of wheat against rigid ryegrass[1]. This reduced rigid ryegrass growth and weed seed production. In the Ashton area, a local agronomist often observes reduced barnyard grass and corn spurry pressure following liming (Personal communication with Bryan Miller, 2020).

References:

1. Borger CPD, Azam G, Gazey C, van Burgel A, Scanlan CA (2020) Ameliorating soil acidity–reduced growth of rigid ryegrass (Lolium rigidum) in wheat. Weed Sci. 68: 426–433. https://doi.org/10.1017/wsc.2020.38
2. Engel, R., C. Jones, and R. Wallander. 2020. Soil acidification: Remediation with sugar beet lime. Montana State University–Extension. https://landresources.montana.edu/fertilizerfacts/html/FF80.html
3. Hart, J.M., D.M. Sullivan, N.P. Anderson et al. (2013). Soil acidity in Oregon: Understanding and using concepts for crop production. Oregon State Extension EM 9061. https://catalog.extension.oregonstate.edu/em9061
4. Lemerle D, Verbeek B, Coombes N (1995) Losses in grain yield of winter crops from Lolium rigidum competition depend on crop species, cultivar and season. Weed Res 35:503–509 https://doi.org/10.1111/j.1365-3180.1995.tb01648.x

5. Li Y, Cui S, Chang SX, Zhang Q (2019) Liming effects on soil pH and crop yield depend on lime material type, application method and rate, and crop species: a global meta-analysis. J Soil Sediment 19:1393–1406 https://link.springer.com/article/10.1007/s11368-018-2120-2
6. Mahler, RL, and RE McDole (1994). Liming materials. University of Idaho, Cooperative Extension Service, Agricultural Experiment Station, College of Agriculture. https://drive.google.com/file/d/1tZ5ujnwvNBlJ_C3TGAPShYJTK5Wz3p6h/view

FY2025
COMMODITY COMMISSION BUDGET
Principal Investigator: *Jared Spackman*

Allocated by Idaho Wheat Commission *(Commission/Organization)*	during FY2023	$	33,247
Allocated by Idaho Wheat Commission *(Commission/Organization)*	during FY2024	$	29,415

REQUESTED SUPPORT Budget Categories	*Awarded for FY2024*	*Requested for FY2025*
(10) Salary *(staff, post-docs, et NOTE: Faculty salary/fringe NOT allowed*	$ 10,904	$ 7,378
(12) Temporary Help/IH	$ 1,800	$ -
(11) Fringe Benefits	$ 5,336	$ 3,047
(20) Travel	$ 5,396	$ 4,352
(30) Other Expenses	$ 5,979	$ 7,696
(40) Capital Outlay >$5k	$ -	$ -
(45) Capital Outlay <$5k	$ -	$ -
(70) Graduate Student Tuition/Fees	$ -	$ -
TOTALS	$ 29,415	$ 22,473

TOTAL BUDGET REQUESTED FOR FY2025:	$ 22,473

BREAKDOWN FOR MULTIPLE INDEXES:

Budget Categories	*Spackman*	*(Insert Co-PI Name)*	*(Insert Co-PI Name)*	*(Insert Co-PI Name)*
(10) Salary *(staff, post-docs, et*	$ 7,378	$ -	$ -	$ -
(12) Temporary Help	$ -	$ -	$ -	$ -
(11) Fringe Benefits	$ 3,047	$ -	$ -	$ -
(20) Travel	$ 4,352	$ -	$ -	$ -
(30) Other Expenses	$ 7,696	$ -	$ -	$ -
(40) Capital Outlay >$5k	$ -	$ -	$ -	$ -
(45) Capital Outlay <$5k	$ -	$ -	$ -	$ -
(70) Graduate Student Tuition/Fees	$ -	$ -	$ -	$ -
TOTALS	$ 22,473	$ -	$ -	$ -
			Total Sub-budgets	$ 22,473

ANNUAL REPORT

Grant Code: AP7076
Title: Liming for Improved Nutrient Utilization and Weed Management in Wheat
Personnel: Jared Spackman, Assistant Professor, UI Aberdeen; Albert Adjesiwor, Assistant Professor UI Kimberly; Jared Gibbons, Madison County; Tom Jacobsen, Fremont County, Joseph Sagers, Jefferson County; Kurt Schroeder, Associate Professor, Moscow; Jacob Bevan, Research Technician; Kaone Mookodi, MS Graduate Student; Sean Maupin, Ashton Farmer Collaborator; Alan Baum, Ashton Farmer Collaborator; Nathan Scafe, Ashton Farmer Collaborator; Clark Hamilton, Swan Valley Farmer Collaborator; North Fremont High School FFA; Grant Wilkerson, BYUI student; Rachel Ritchie, BYUI Student.
Address: Jared Spackman 1693 S. 2700 W. Aberdeen, ID 83210; (208) 312-2454; jspackman@uidaho.edu
Accomplishments: Three on-farm field experiments were established in the fall of 2021 in Ashton and one at Swan Valley. Four replications of four sugar beet lime rates were applied at rates of 0, 2, 4, and 6 tons per acre on 50'x100' plots. Other than liming, the plots were managed according to the grower practices. During the 2022 growing season, irrigated spring wheat was grown at the Ashton sites and dryland barley was grown at the Swan Valley location. During the 2023 growing season, seed potatoes were grown at the Maupin field, barley at the Baum and Scafe fields, and dryland canola at the Swan Valley field. At crop maturity, yield and yield components were measured near the center of each plot. For potatoes, we worked with the North Fremont FFA potato judging team to hand harvest two 10' rows of potatoes. Total potato yield was measured and sorted into different market classes. For barley, a 5x5' section of field was hand-harvested, threshed, and the grain will be measured for test weight, plumps and thins, grain protein concentration, and nutrient content of the straw and grain components. For canola, a 5x5' section of the field was hand-harvested, threshed, and the grain will be measured for yield and oil content using NIR. Then the grain and stover will analyzed for total nutrient content. We scouted the fields for weed pressure, but other than a few wild oat escapes scattered throughout the barley fields, there did not appear to be an affect of liming on weed pressure or presence in the fields. Soil samples were collected at the 0-2, 2-4, 4-6, 6-8, and 8-12" depths in the spring and after grain harvest in 2022, and after harvest in 2023. These samples were dried and ground and are in the process of being analyzed for soil pH (1:1 soil: water, 1:2 soil: water, 1:1 soil:0.01 M calcium chloride), electrical conductivity, and free lime. Additional soil samples were collected at 0-6 and 6-12" depths and are awaiting analysis by Brookside Laboratories for extractable aluminum (a source of soil acidity and root toxicity).

My graduate student, Kaone Mookodi, conducted an incubated lime requirement study in 2022 by collecting 10 gallons of acidic soils from 16 field sites in southern (10) and northern Idaho (6) from Ashton, Swan Valley, Soda Springs, Moscow, and Potlatch. The soils were dried, ground, homogenized, and then subdivided into 32 containers and treated with 0, 0.5, 1, 2, 4, 6, 8, and 10 tons per acre of calcium carbonate (lime). Water was added to each pot to bring the soil moisture content to 80% and then the pots were incubated for 90 days. The soils were dried, ground, and analyzed for soil pH, electrical conductivity, free carbonate, nitrate and ammonium content, and lime requirement using the Sikora buffer, the modified Mehlich buffer, single addition calcium hydroxide, and Woodruff buffer methods. At the end of the incubation, each pot was subdivided into 3 or 4 smaller pots and planted to either wild oats, Kochia, common lambsquarters, or redroot pigweed seeds. Germination and seedling vigor were assessed for five weeks at the Kimberly R&E Center. We did not see a significant difference in germination or seedling vigor in any of the weed species in response to soil pH. Unfortunately, Ms. Mookodi

did not save the soils for further analysis. So, in the fall of 2023, we collected an additional 10 acidic soils from Power, Fremont, Caribou, and Madison counties, and two BYUI students are in the process of preparing for a second incubation study. After conducting the lime incubation study, these soils will be co-planted to barley or wheat with corn spurry, barnyard grass, wild oats, kochia, common lambsquarters, and redroot pigweed. Corn spurry and barnyard grass are considered by many growers to be indicator plants of pending soil acidity problems. By co-planting barley or wheat with the various weed species, we will be able to determine if small grain response to soil acidity and interspecies competition plays a greater role in weed vigor than just growing the weed alone.

Ms. Mookodi successfully wrote up her MS thesis and defended it in the summer of 2023. She has now moved on to Washington State University where she is conducting additional research on biochar and its potential to buffer soil pH and to reduce acidification over time.

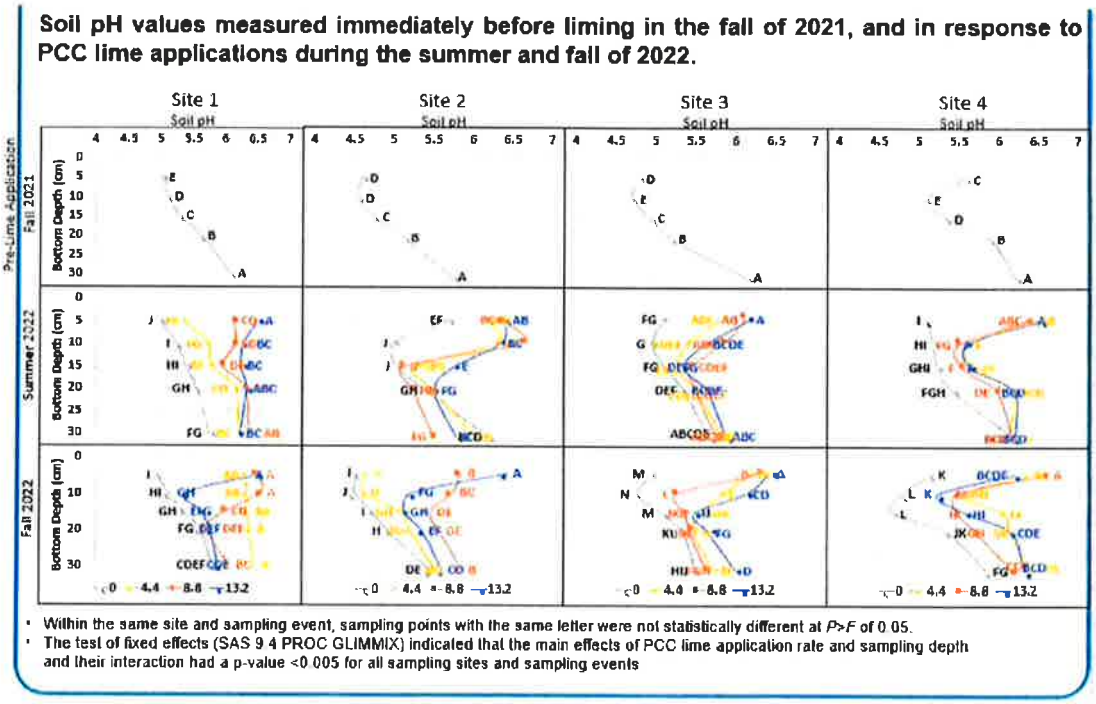

Figure 1: Soil pH changes by depth before and in the year following lime application. Pre-liming, soil pH followed a pattern of decreasing from the 0-2" depth to the 2-4" and 4-6" depths and increasing in the 6-8" and 8-12" depths. Historically, these soils were alkaline but over 100 years of farming, applying nitrogen fertilizers, and withdrawing base cations at harvest, the surface soil pH has declined while the deeper depths have greater soil pH values. Calcium carbonate deposits can still be found at deeper depths in these soils. At all sites, the soil pH was greater than the critical soil pH threshold of 5.2 for wheat and barley, and <5.0 for potato within the top 20 cm of the soil profile. We did not measure any differences in crop yields between treatments that may indicate that the crop roots were able to grow through the acidic topsoil into the more alkaline subsoils and successfully extract nutrients and water. PCC lime additions had the greatest modification on soil pH within the top 15 cm of the soil profile. It is typically

assumed that liming products are immobile in the soil profile. Hence, tillage is required to intimately mix the lime with the soil to amend the soil pH. The Ashton sites (sites 1, 2, and 3) are under conventional tillage whereas Swan Valley (Site 4) is under continuous no-till. Despite the lack of tillage, we observed that soil pH increased at all sampling depths by the fall of 2022 at Site 4 indicating that the PCC lime may gradually move with soil water.

In addition to the lime incubation study funded by the IWC, Dr. Spackman conducted an additional lime incubation study with undergraduate students at BYUI. These students evaluated precipitated calcium carbonate, calcium hydroxide, and calcium carbonate as liming agents and determined how long it takes for these lime products to neutralize acidic soils. They are also examining the impact of soil moisture at the time of lime application on how readily soil pH is neutralized.

Projections: We are in the process of editing Ms. Mookodi's chapters from her thesis to convert them into journal articles and Extension bulletins. In September 2022, Dr. Spackman and Tom Jacobsen had an informal meeting with several small grain growers in Ashton and Soda Springs to talk about liming principles, nutrient management, and the current status of the IWC-funded liming study. These growers expressed interest in conducting additional lime research studies and are now participating in 5 additional field sites in Lamont and Soda Springs funded by Western SARE and the Idaho Barley Commission. Based on things we learned from the IWC study, we decided to use longer plots (450x50' plots) with three subsampling points within each plot. We will also use a plot combine to harvest the field sites to get a more accurate estimate of yield. We are also exploring the potential of using electrical conductivity mapping to help create prescription lime maps.

Dr. Spackman's lab is working with a national research group (Fertilizer Research Support Tool https://soiltestfrst.org/lime/) to reevaluate liming recommendations and practices. Drs. Spackman and Schroeder joined this research team in 2022. Dr. Spackman has submitted acidic soils from Ashton and Soda Springs for inclusion in a national lime incubation study. The submitted soils include soils from the current IWC liming study sites.

Dr. Spackman's lab is working with Dr. Dave Tarkalson at USDA ARS in Kimberly and Amalgamated Sugar on ways to utilize precipitated calcium carbonate (spent sugar beet lime) as an agronomic amendment in both acidic and alkaline soils. Through this relationship, Dr. Spackman is converting some of Dr. Tarkalson's research articles into Extension bulletins.

Publications:

1) Mookodi, K.L. 2023. Liming for Improved Nutrient Utilization and Weed Management. Aug 2023. https://www.lib.uidaho.edu/digital/etd/items/mookodi_idaho_0089n_12704.html.
2) Mookodi, K., J.A. Spackman, A. Adjesiwor. First-year evaluation of precipitated calcium carbonate as a lime amendment in Eastern Idaho. Plant Sciences Departmental Seminar. Kimberly, ID. 24 Feb. 2023. (Zoom 17 attendees; 35 minutes)
3) Spackman, J.A., A. Adjesiwor, J. Bevan, J. Sagers, and T. Jacobsen. 2023. Precipitated Calcium Carbonate as a Lime Amendment in Southern Idaho Soils. ASA-CSSA-SSSA Annual Meetings. St. Louis, MO. 29 Oct. – 1 Nov. 2023.
4) Spackman, J.A., A. Adjesiwor, T. Jacobsen, and J. Sagers. 2023. Precipitated Calcium Carbonate as a Lime Amendment. 2023 Western Alfalfa and Forage Symposium: Soil Fertility and Health Workshop. Reno, NV. 12 Dec. 2023.
5) T. Jacobsen, J.A. Spackman, A. Adjesiwor, Mookodi, K., J. Sagers, K. Schroeder, and J. Bevan. 2023. First-Year Evaluation of Precipitated Calcium Carbonate as a Lime Amendment in Eastern Idaho. University of Idaho Annual Extension Conference. Sun Valley, ID. 11 – 12 Apr. 2023.
6) Mookodi, K., J.A. Spackman, A. Adjesiwor, J. Sagers, T. Jacobsen, K. Schroeder, and J. Bevan. 2023. First-Year Evaluation of Precipitated Calcium Carbonate as a Lime Amendment in Eastern Idaho. Western Nutrient Management Conference. Reno, NV. 8 – 10 Mar., 2023.