SOIL ACIDIFICATION OF CULTIVATED FIELDS IN SEMIARID MONTANA: ADAPTATION AND CHALLENGES TO REMEDIATION

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ABSTRACT

Historically, soil acidification was not a problem in Montana because the parent material of most cultivated soils exhibited a neutral to an alkaline reaction. However, fertilizer ammonium-N use (including urea) by farmers has grown tremendously in recent decades contributing to leading to a downward trend in soil pH and with incidences of soil acidity/Al toxicity now beginning to appear. Here we summarize the results from on-farm sugar beet lime trials to remediate soil acidity; seed-placed P fertilizer applications to mitigate crop Al toxicity aluminum toxicity; growth; and define the relationship between soil pH and cumulative fertilizer-N inputs, in order, to better understand the legacy effects of fertilizer-N on soil pH. On-farm sugar beet lime strip-trials (15 to 25 ac) have demonstrated this product is effective at raising soil pH within one year if incorporated with tillage after application. Pulse crops, particularly lentil (*Lens culinaris*) and yellow pea (*Lathyrus aphaca*) were observed to exhibit greater early-season biomass or seed yield in response to sugar beet lime applications. Small-plot replicated fertilizer trials have shown that seed-placed P can significantly increase the yield of durum wheat (*Triticum durum*) under acidic soil conditions (pH 4.4), and even when soil P levels test very high (50 ppm Olsen-P). Long-term cropping systems studies have revealed that soil pH falls about 0.044 units for every 100 lb/ac of N input. Hence, once pH is corrected with lime the impacts will likely last for a prolonged time (>20 yr).

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INTRODUCTION

Historically, soil acidity related production problems have been virtually unknown in Montana because the parent material of most cultivated soils exhibited a neutral to an alkaline reaction. Over the past 40 years, Montana has experienced tremendous growth in fertilizer-N use (**Fig. 1**) such that N consumption is now 300% of the levels used in 1985. Fertilizer-N inputs are most frequently applied as urea, 46-0-0 (86% of all N) and often as a broadcast application to the soil surface. Coupled with this has been a no-till revolution among dryland farmers that began in the early 1990s due to the popularity of direct-seeding equipment, and then later with the introduction of low-cost glyphosate following the expiration of Monsanto's patent (2000). Because of these factors, plus nitrification of ammonium-based N fertilizer (including urea) results in acidification, it is not surprising that soil pH of surface layers has fallen. In 2011, dryland growers in central Montana approached County Extension and the Montana Agricultural Experiment Station faculty members with concerns about declining crop performance and stand-establishment in fields under long-term cultivation. Insect, disease, and plant nutrient deficiencies were all considered and eliminated as causal factors. Ultimately, soil test results revealed pH levels < 5 (some as low as pH 4.0), KCl-extractable aluminum concentrations >25 ppm, and crop roots with classic aluminum toxicity symptoms. Since this initial discovery, Montana farmers have become more aware of soil acidification and concerned/interested in its impact on crop production as well as remediation In 2016, at the bequest of farmers we initiated a study to investigate the efficacy of liming practices, fertilizer management, and cultivar selection on soil acidity management and remediation. Our presentation (and this manuscript) will highlight the results obtained from research and demonstration trials. Our objectives were i) to evaluate the efficacy of sugar beet lime applications to remediate soil acidity problems in on-farm trials; ii) determine if seed-placed P fertilizer applications would mitigate aluminum toxicity and improved crop growth; and iii) define the relationship between soil pH and cumulative fertilizer-N inputs at a long-term cropping system study field site, so as to better understand the legacy effects of fertilizer-N on soil pH.

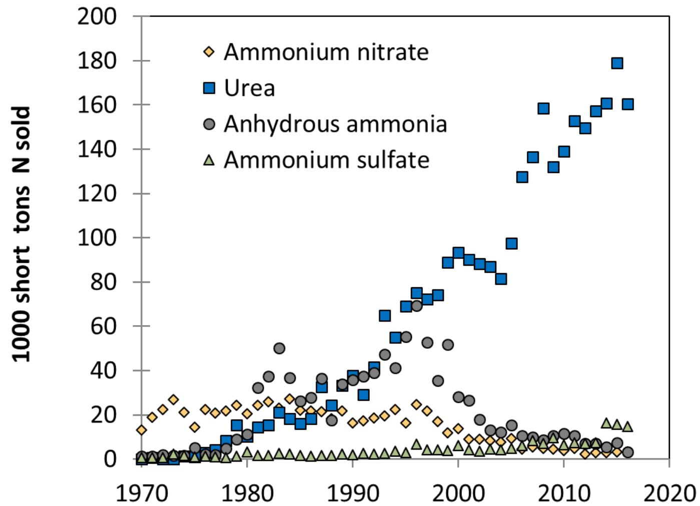


Figure 1. Historical fertilizer-N use in Montana for the most common N sources (1970 –2017).

MATERIALS AND METHODS

Sugar beet lime strip-trials

We conducted on-farm sugar beet lime strip-trials at three locations in Chouteau County, northwest of Big Sandy, south of Fort Benton and north of Geraldine. The Fort Benton and Geraldine trials were under a continuous crop management program and the Big Sandy trial was under a fallow-crop system. Each trial consisted of eight strips with three sugar beet lime rates, i.e., 0, 1, 2- and 4-ton material/ac at Big Sandy and Geraldine, and 0, 2, 4, and 6-ton material/ac at Fort Benton. The 0 and 4 ton/ac rates were replicated three times in a randomized complete block design. The sugar beet lime was transported from the Western Sugar Cooperative in Billings to the field locations. Beet lime was applied to each field site in the fall of 2017 using a Stolzfus wet lime applicator and incorporated with tillage at Fort Benton and Geraldine, but not Big Sandy (left on surface). Chemical analysis of the beet lime indicated it contained 30% moisture and 55% $CaCO_{3e}$ (wet-weight basis). Individual strips had a long and narrow configuration to incorporate natural variances in terrain and/or background soil pH that occurred across the field sites (**Fig. 2**). In 2018, the Big Sandy, Fort Benton and Geraldine locations were seeded by cooperating farmers to safflower, lentils and durum, respectively. In 2019, the Fort Benton and Geraldine the field sites were seeded to spring wheat and yellow pea, respectively, and the Big Sandy site was in fallow. The dominant soil series at Big Sandy was a Telstad loam and Bearpaw-Vida clay at Fort Benton and Geraldine. Soil pH (0-4”) at Big Sandy, Fort Benton and Geraldine prior to lime application averaged 4.87, 4.6, and 4.8, respectively, but exhibited considerable variance across the field locations. Five soil cores (0-8") were collected at georeferenced locations in the fall 2017 (prior to beet lime application), 2018 (1-yr post, and 2019 (2-yr post), and composited by depth increments of 0-2", 2-4", 4-6" and 6-8".

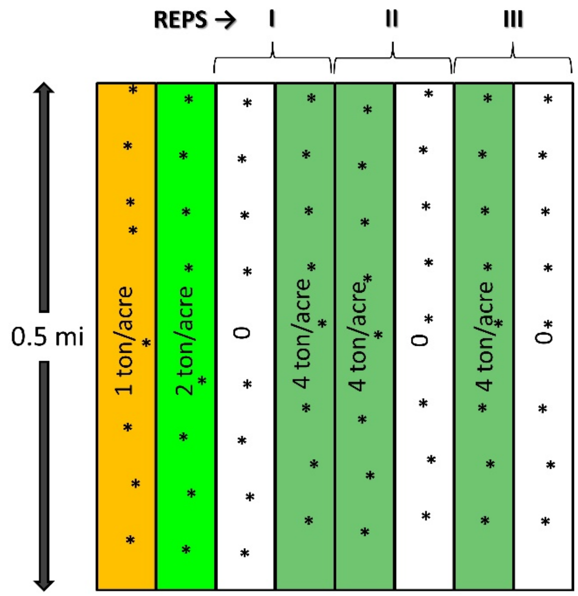


Figure 2. On-farm sugar beet lime strip-trial plot design at Big Sandy and Geraldine farm sites. Plot plan at Fort Benton was similar except strips were 0.28-mile-long and a 6-ton/ac rate replaced the 1-ton/ac rate. Individual plots were 60' feet wide. Soil cores were collected at geo-referenced locations (*) along a transect that ran parallel to the length of each plot (precise locations not identified in the figure).

Seed-placed P fertilizer trials

We conducted a replicated small-plot P fertilizer trial with durum wheat in 2018 and 2019 at a farm on the Highwood Bench, south of Fort Benton Montana. The soil was a Gerber silty clay with pH 4.4. The study was a factorial of five P fertilizer rates of 0, 15, 30, 60 and 90 lb P_2O_5/ac and two Ag-lime treatments (0, 5 ton/ac). The Aglime was purchased from Montana Limestone Company, broadcast applied in the fall of 2017 with a Stolzfus wet-lime applicator, and incorporated with tillage (6" depth). Treatments were replicated three times in a split-block design with lime main-plot and P rate sub-plots. Plots were five rows or 5' wide and 20'in length.

Soil pH at the MSU-GGRS long-term cropping system trial

The MSU-Greenhouse Gas Research Study consists of eight-crop management systems (including fallow-wheat, continuous wheat, and diversified wheat-based systems with pulse and oilseed crops) managed under two fertilizer-N input levels. The field study was initiated west of Bozeman at the MSU Post Farm in Fall 2002. The soil is an Amsterdam silt loam. This study was initiated principally to determine the impact of cropping systems on soil organic C in Montana. However, it also provided a controlled study where cumulative fertilizer-N inputs varied greatly among the 16 treatments (20 to 2050 lb N/ac) over a 14-yr time-window (2002-2016). In 2016, soil cores (0-4" depth) were collected from all plots and analyzed for pH to quantify the long-term impact of cumulative fertilizer N inputs on surface soil pH.

RESULTS AND DISCUSSION

Sugar beet lime strip-trials

We found sugar beet lime applications (applied Fall 2017) at Fort Benton and Geraldine raised soil pH (0-4") over a 1-year and 2-year time window according to the curvilinear relationship of **Fig. 3.** The dominant soil series at both field sites was Bearpaw-Vida clay loam, and so it was not surprising then the pH change with lime was similar at the two locations. Overall, the relationships demonstrated beet lime was effective at ameliorating soil acidity, and that most of the pH changes occurred during the 1st year if the lime material was incorporated with tillage. Sugar beet lime requirements necessary to raise soil pH by 1.3 units to a target pH of 6 was approximately 2.5 tons/ac, or 2750 lb $CaCO_3$/ac. This application rate equates to a $100/ac investment for transport and field application with tillage incorporation†**.** While this is a considerable cost input, we believe the costs are modest when viewed over a long-term time horizon (e.g., 20 years - discussed below).

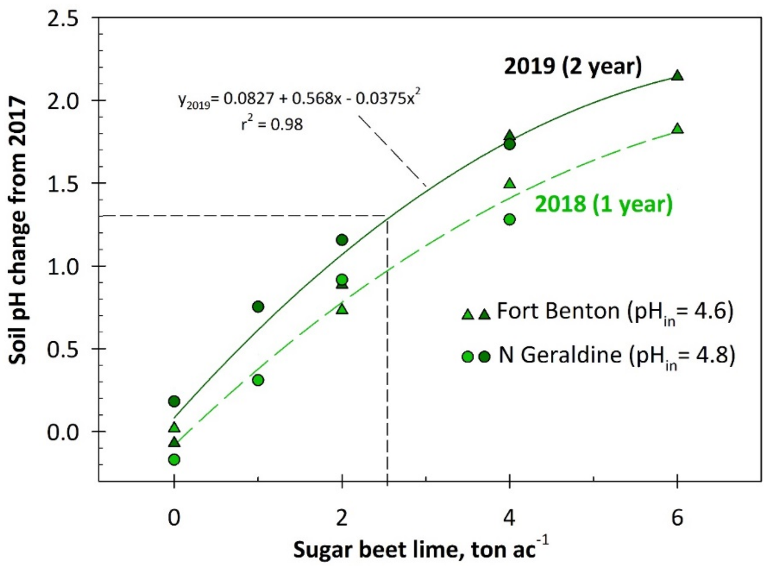


Figure 3. Soil pH change from 2017 at 1-year (2018) and 2-year (2019) post-application of sugar beet lime.

Soil pH depth-profile relationships at the 4 ton/ac beet lime application rate revealed that pH was affected in the 0-2" and 2-4" depth layers at Geraldine and Fort Benton trial, and only the 0-2" layer at Big Sandy (**Fig. 4**). This response was not surprising as sugar beet lime was incorporated with tillage at Geraldine and Fort Benton, while at Big Sandy it was left on the soil surface without incorporation. These results demonstrated for the benefit of area farmers that beet lime does not wash into the soil if left on the surface, and that incorporation will be necessary to correct soil acidity to eliminate pH stratification in Montana's semiarid climate.

† Sugar beet lime transport cost to the farm was estimated at $35/ ton, and field application plus tillage was estimated at $12/ac.

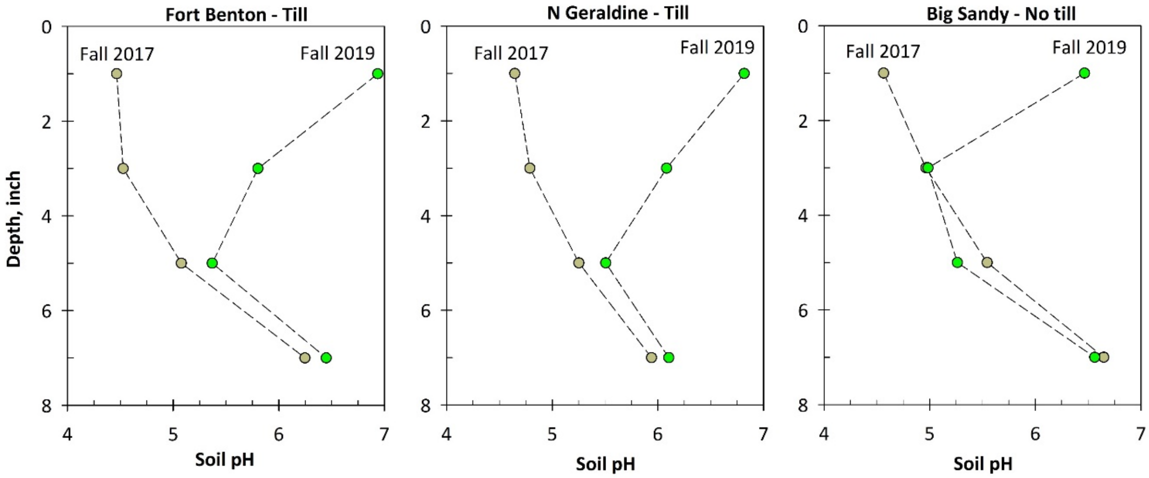
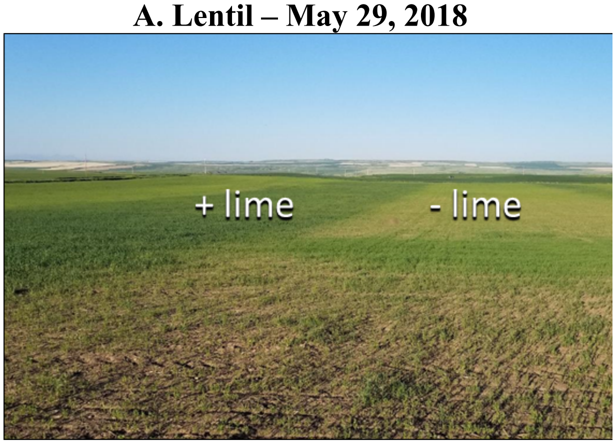


Figure 4. Soil pH depth-profile in fall 2017 and 2019, or before and after sugar beet lime application (4 tons/ac) at Fort Benton (till), N Geraldine (till), and Big Sandy (no-till).

Significant grain yield responses to sugar beet lime at our strip-trial locations were not been observed for durum, spring wheat and safflower in 2018 and 2019. However, we have found visually obvious differences in lentil and yellow pea growth to beet lime applications. In 2018, lentil top growth was greener, and biomass was 50% greater in areas receiving lime compared to the non-limed area at Fort Benton (**Fig. 5A**). Similarly, in 2019 we observed yellow pea growth at Geraldine was more robust where lime was applied (**Fig. 5B),** seed yields were significantly impoved relative to areas/strip without lime (-lime = 23.3 bu/ac vs. +lime =30.0 bu/ac). The benefit of liming was believed to result from improved rhizobia activity, nodulation, and N-nutrition of these pulse crops.

A. Lentil – May 29, 2018 **B. Yellow pea – June 19, 2019**



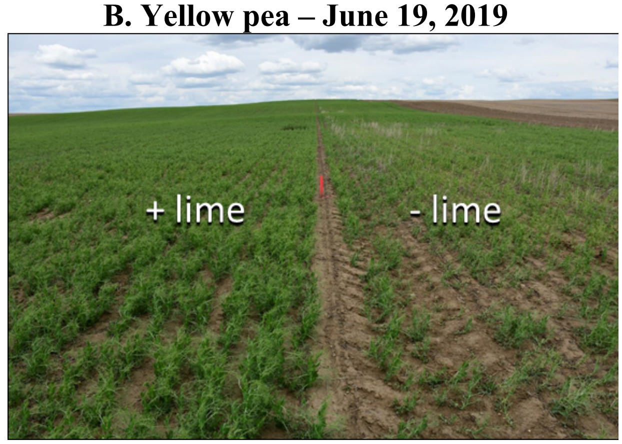


Figure 5. Visual differences in lentil and yellow pea growth were apparent from the sugar beet lime applications at Fort Benton (left) and Geraldine (right) sites.

Seed-placed P fertilizer trials

In 2018, we observed a large growth response to P fertilization in durum where the soil pH was not amended with Aglime application (**Fig. 5)**. Grain yield was affected by the interaction of lime and P fertilizer (**Fig. 6**). Briefly, seed-placed P fertilizer mitigated Al toxicity symptoms and improved grain yield 20 bu/ac over unfertilized controls where lime was not applied. Conversely, durum was unresponsive to P fertilizer where lime was applied to correct soil acidity. In 2019, a similar response by durum to P fertilizer was evident early in the growing season at the Highwood Bench field site. However, two hailstorm events during the growing season reduced yield by approximately 50% and the mitigated the response to P fertilizer. Our results indicate that seed-placed P fertilizer provides a method for mitigating Al toxicity at field sites with acidic soils, and occurs even at sites with very high soil P levels. Reports from Kansas winter wheat trials, some dating back to the 1990s, have shown a similar response. Utilization of high rates of seed-placed P to mitigate Al toxicity should be viewed as a short-term approach to manage acidic soils. In Montana, this strategy might best be applicable where a farmer is renting land under a short-term lease agreement (e.g., 5-years).

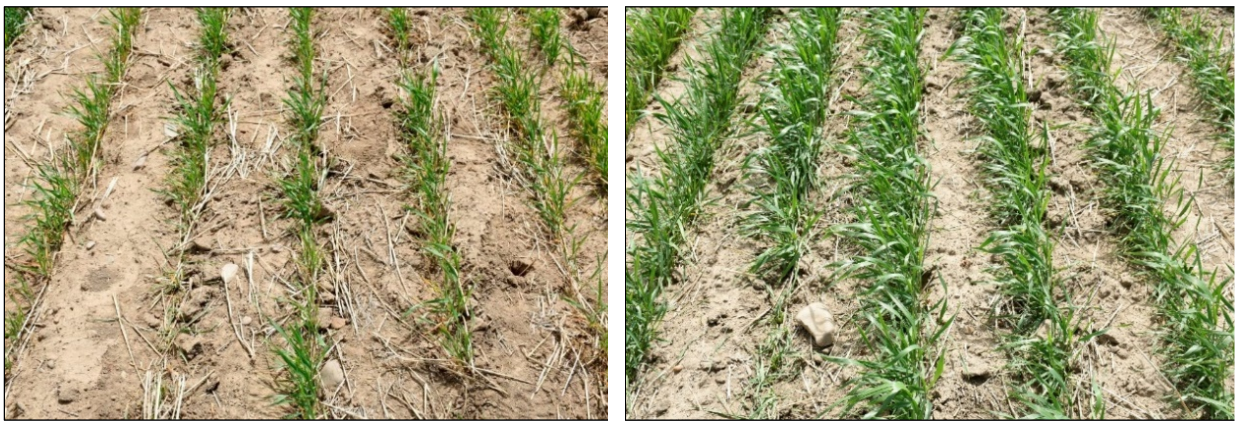


Figure 6. Seed-placed P (right) resulted in more vegetative growth and higher durum yields than 0 P, control areas (left) at our field site on the Highwood Bench and where soil pH was not remediated with lime.

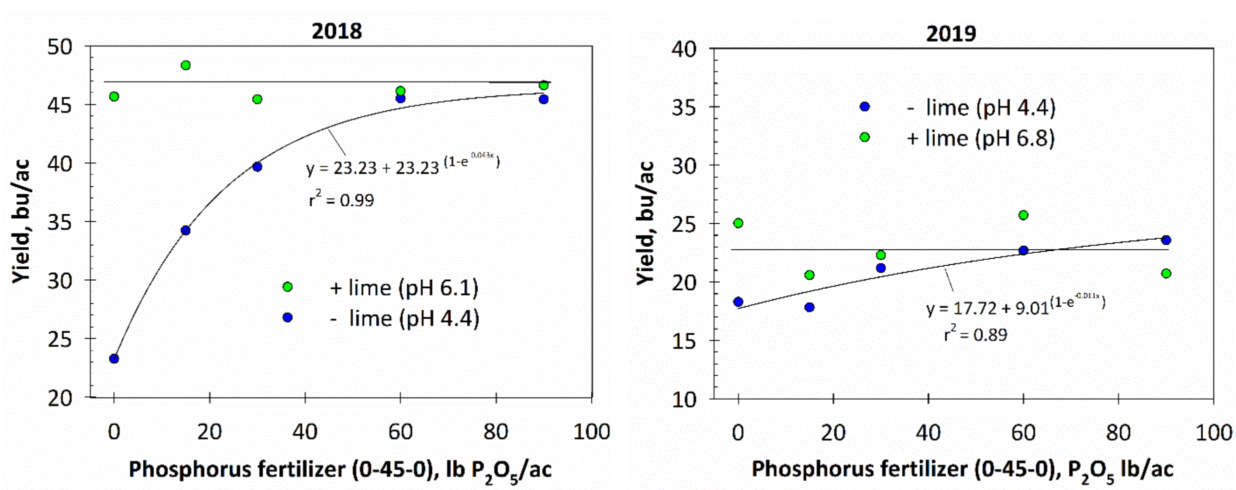


Figure 7. Durum grain yield on the Highwood Bench was improved with P fertilizer under acid soil conditions (-lime) but was not affected where soil acidity was mitigated with lime applications. Olsen soil P level = 50 ppm in 2018 and 83 ppm in 2019 (very high).

Soil pH at the MSU-GGRS long-term cropping system trial

Soil pH vs. cumulative fertilizer-N input relations (**Fig. 8)** demonstrated that soil pH was directly related to fertilizer-N for eight cropping system x two fertilizer-N level treatments. The slope of the lines indicates that soil pH fell 0.044 for every 100 lb N/ac input, which equates to a drop of 1 pH unit over 23-year at this level of fertilizer-N. These results are significant as they provide an index of the buffering capacity of Montana soils. Our on-farm investigations with sugar beet lime revealed that 2.5 tons of sugar beet lime material were required to remediate soil pH 4.6 to 4.8 to a target pH of 6. The estimated cost of this remediation is approximately $100/ac. If we assume soil acidity-Al toxicity problems do not develop until pH < 5, then a similar soil would require 2300 lb/ac of cumulative fertilizer-N inputs before a production problem might be expected. Although, fertilizer-N inputs and soil buffering capacity vary among farms these results add credibility to our belief that lime remediation of acidic soils in Montana's climate will have a prolonged impact on land productivity (>20 years).

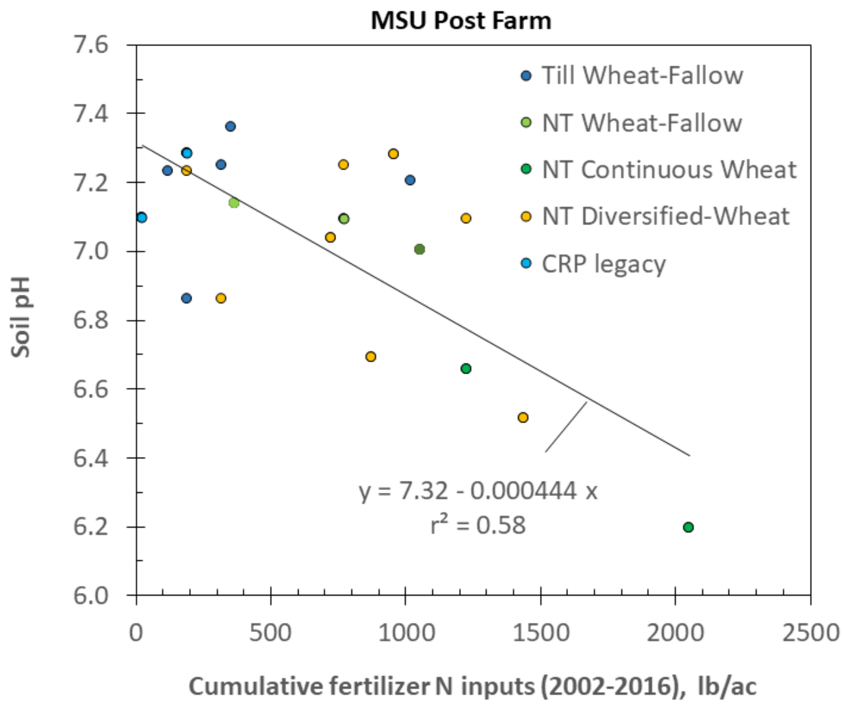


Figure 8. Soil pH vs. cumulative fertilizer N inputs over 14 years at the MSU-Greenhouse Gas Research Study location near Bozeman, Montana.