# EFFECTS OF LIME AND MICRONUTRIENT AMENDMENTS FOR ACIDIC SOILS OF THE INLAND PACIFIC NORTHWEST

Rachel A. Wieme[1], Lynne A. Carpenter-Boggs[1], Stephen Van Vleet[2], Paul G. Carter[3]
[1]Washington State University, Crop and Soil Sciences Department, Pullman, WA
[2]Washington State University Extension, Agriculture and Natural Resources, Colfax, WA
[3]Washington State University Extension, Agriculture and Natural Resources, Dayton, WA

## ABSTRACT

The soil pH of agricultural land in the Inland Northwest has reached critical levels, leaving tens of thousands of acres of previous prairie soil at pH <5.0 and unable to grow low pH and aluminum-sensitive crops. Some farmers in the region are beginning to use lime application to neutralize soil acidity. However, pH changes and liming can also change soil micronutrient availability to crops, and demand by crops. Therefore research to understand the interactions of soil amendments is imperative. This study assessed soil quality, crop yield, and economics of liming and micronutrient treatment for 6 years after application in the Palouse region of eastern Washington State. Plots were established in 2014 in a minimum tillage system with initial soil pH averaging 4.9 in the surface 0-3 in, 4.66 at 3-6 in, and 5.48 in the subsurface 6-12 in. Liquid lime was applied at 2000 lb $CaCO_3$/acre in September 2014 and micronutrients (B, Cu, Zn, Cl) were added September 2015 as a full factorial design to create four treatments: Lime + Micronutrients (LM), Lime Only (L), Micronutrients Only (M), and Control (C). Average soil pH at the surface 0-3 in was significantly higher in L and LM than M and C in 2015-2020. Crop yields increased in the order of LM > M ≥ L = C. Only combined LM significantly increased yield over the control for all crops: peas (2016) 26.0%, hard red winter wheat (2017) 6.7%, soft white winter wheat (2019) 15.2%, and spring barley (2020) 10.4%. Micronutrient levels in barley grain were higher in M and LM. These results support taking a more holistic approach to managing soil nutrients when addressing soil acidification.

## INTRODUCTION

Declining soil pH, or soil acidification, is a growing concern in agricultural systems throughout the world. The Palouse region of the Inland Northwest (includes eastern Washington, northeast Oregon, and northwest Idaho) is one such area where the agriculturally driven decline of soil pH is an increasingly limiting factor to crop production (Mahler et al., 2016; McFarland et al., 2015). Acidifying practices like the repeated use of nitrogen fertilizers, intensive tillage practices, and removing large amounts of crop biomass from fields have driven soil pH from the near-neutral levels of the native soil to current levels that are at or below the thresholds for the region's major crops, including winter and spring cereals (pH 5.2 – 5.4), oilseeds (5.5) and grain legumes such as peas, chickpeas, and lentils (5.4 – 5.6) (Mahler and McDole, 1987). Soil pH is often referred to as a "master variable", because it affects numerous other processes in soil and indicators of soil quality, such as nutrient availability, aluminum toxicity, soil biotic populations and activity, and fate of herbicides, all of which are contributing to the production limitations on acidifying Palouse soils (McFarland et al., 2015; Brown et al., 2008).

Lime application is a commonly used tool to counter low soil pH, increase base saturation and nutrient availability, and reduce aluminum toxicity for some agricultural soils (Thompson et al., 2016). However, adoption of liming in the Inland Northwest has been very low for many reasons. Geologically, the region has few sources of liming materials; transportation and source development increase the cost of lime in the region. Growers do not already own the needed equipment and, due to additional soil health deficits, liming alone does not always lead to crop yield increases (Godsey et al., 2007; Brown et al., 2008). There can be difficulty getting liming materials to reach acidified layers quickly in no-till systems (Tao et al., 2018), and buffering capacity of soils throughout the region vary (McFarland et al. 2020). Additionally, acidification and liming can both cause changes in short- or long-term availability of plant nutrients and leave these valuable elements vulnerable to permanent loss from the soil. Liming without attention to micronutrient nutrition may not improve crop yield or overall soil functioning and can even exacerbate micronutrient deficiency, despite neutralizing pH (Fageria et al., 2012).

This research aimed to quantify long-term soil and crop response to lime and micronutrient applications in a minimal-tillage cropping system in the Palouse, to further our understanding of tools to combat soil acidification problems in this region.

## MATERIALS AND METHODS

The research site was located on a commercial farm in Walla Walla county, Washington, with silt loam soil and annual precipitation averaging 19 inches. Randomized plots 10 ft x 100 ft of lime (L) versus control (C) were established in September 2014. Lime treatment was 2000 lb of ultra-micronized liquid CaCO3, applied using an ultra terrain vehicle equipped with a boom buster spray nozzle. No tillage was conducted immediately following the lime application; peas and chickpeas were seeded the following spring.

Soil was sampled from all plots in the spring 2015 with hand probes; samples were divided into 0-3 in, 3-6 in, and 6-12 in layers for analysis. Soil sampling continued in this manner from select plots each spring thereafter.

Table 1. Micronutrients applied in September 2015

| **Element** | **Rate** (lb/acre) | **Cost** ($/acre) |
|---|---|---|
| Boron | 1.1 | 11.00 |
| Copper | 0.79 | 19.80 |
| Zinc | 1.13 | 18.00 |
| Chloride | 16 | 8.50 |
| Potassium* | 21.5 | |

*Potassium Chloride (KCl) was carrier solution for the other nutrients

New treatments were added after harvest 2015 based on concurrent research and observations in the region regarding interactions with lime and micronutrient applications. Soil tests from 2015 confirmed deficiencies of micronutrients at the study site; boron (B) averaged 0.11 ppm (<0.2 ppm is considered "very low" and 1-3 lb B/acre additions are recommended), zinc (Zn) average 0.41 ppm (the recommended level is >1.5 ppm), and copper (Cu) averaged 1.1 ppm recommended level can be ≥1.4) (Horneck et al., 2011). Therefore, micronutrients were added across half of lime and control treatments resulting in a factorial design with treatments of: Lime + Micronutrients (LM), Lime Only (L), Micronutrients Only (M), and Control (no lime and no micronutrients, C). The micronutrient solution was added to the soil surface in September 2015 at the rates indicated in Table 1; no tillage was performed immediately after application and peas were planted the following spring.

Each year from 2016, crops were seeded and fertilized according to the farmer practices within this minimal tillage system. The crops and harvest years were as follows: peas in 2016, hard red winter wheat (HRWW) in 2017, soft white winter wheat (SWWW) in 2019, and spring barley in 2020 (spring peas were grown in 2018 but harvest data was not collected). Crop yields were determined by weighing grain harvested from a center strip within the plots; nutrient levels in barley grain (2020) were determined by Best Test Analytical Services.

## RESULTS AND DISCUSSION

Initial soil pH ranged 4.7 – 5.2 in the surface 0-3 in, 4.5 – 4.8 at 3-6 in, and 5.4 – 5.6 at 6-12 in. This stratification, with lowest pH located in the seeding zone is common for no- and low-till systems in the region, as this is where fertilizers are routinely injected (Brown et al., 2008; Tao et al., 2018). Lime application significantly raised the pH in the surface 0-3 in layer, up to an average of 5.6 at the first sampling, 6 months after application. The pH of the surface layer for limed treatments was higher again at the 2016 sampling (average 6.13) and remained significantly higher than the control through 2020 (Figure 1). Soil below 3 in showed no change in pH over the 6 years of sampling in any treatments. This is consistent with other studies in no-till systems and the relatively low rate of lime application (Godsey et al., 2017). Brown et al. (2008) increased pH for the 0-2, 2-4 and 4-6 in depth in a Palouse soil two years after surface applying lime, but application rate was much higher at 5800 lb CCE/acre. We observed a slight increase in control pH over time (0-3 in), which was likely due to drift from seeding (across the 10ft width of plots). Correlated with the increase in pH, there was also a decrease in exchangeable aluminum in the surface layer (0-3 in) of limed plots; the difference was significant from 2015-2017 (Figure 4).

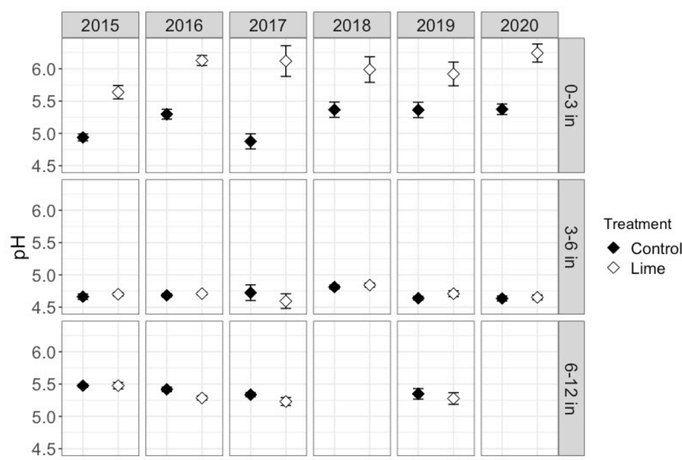


Figure 1. Soil pH at three depths (0-3 in, 3-6 in, 6-12 in) over six years. Error bars indicated standard error of the mean.

There was no yield difference between L and C plots in 2015 peas and chickpeas. Yield differences were observed after micronutrient treatments were added. In 2016 peas and 2019 SWWW, M and LM produced significantly higher yields over C (Figure 2). In 2017 and 2020, only LM produced significantly higher yields over C. LM consistently produced the largest yield, and it was the only treatment to significantly outyield control plots every year. Treatment M often produced higher yields than treatment L, though they were always statistically similar. The largest yield responses were observed in peas in 2016; LM yielded 26% higher than C, L yielded 10% higher than C, and M yielded 18% higher than C (Table 2). Legumes are known to be more sensitive to low soil pH and aluminum toxicity; research also indicates micronutrients can help alleviate Al toxicity in peas (Rahman et al., 2018; Yu et al., 2000).

Table 2. Mean crop yields for each treatment, with percent increase over the control. HRWW=Hard red winter wheat; SWWW=soft white winter wheat. Means with the same letter within a year are not statistically different at $p \leq 0.05$ as determined by Tukey HSD tests.

| Treatment | 2016 Pea Yield | | 2017 HRWW Yield | | 2019 SWWW Yield | | 2020 Barley Yield | |
|---|---|---|---|---|---|---|---|---|
| | lb/acre | % over C | bu/acre | % over C | bu/acre | % over C | bu/acre | % over C |
| Control | 1625±43 a | | 122±2 a | | 111±2 a | | 119±3 a | |
| Micronutrients | 1909±74 bc | 18% | 126±2 ab | 3.4% | 122±3 bc | 9.8% | 123±4 ab | 3.3% |
| Lime | 1789±66 ab | 10% | 125±1 ab | 2.5% | 116±2 ab | 4.5% | 125±3 ab | 5.4% |
| Lime+Micronutrients | 2045±45 c | 26% | 130±1 ab | 6.7% | 128±2 c | 15% | 131±3 b | 10% |

Six harvests after a single lime application and five harvests after micronutrient application, the LM treatment is still producing significant increases in crop yield as observed in the barley harvest from 2020. Despite only a small increase in crop yield from lime only treatments, there is visual evidence of improved crop growth in limed plots in early spring and greater biomass throughout the growing season (Figure 3). It is possible that the pH neutralization in the surface layer allows for better growth and root development for young plants, but crops still encounter nutrient limitations and therefore yields are still limited in L treatments. No differences were observed in HRWW protein in 2017 nor barley crude protein levels in 2020.

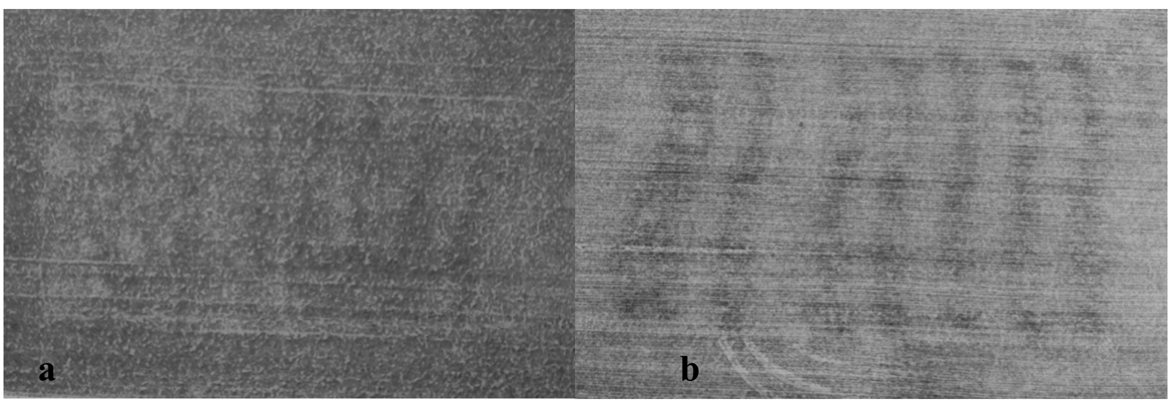


Figure 3. Photographs taken with a drone of (a) peas growing in June 2018 (no harvest data) and (b) barley growing in May 2020 show crop growth improvement along the length of plots limed in 2014, compared to unlimed plots.

The crop yield results from this study are consistent with other fields that received similar treatments; Carter and Wegner (2017) reported no differences in yields after the first year in only limed versus unlimed plots, but the following year micronutrient and lime+micronutrient treatments resulted in 16% and 18% yield increases in soft white spring wheat respectively, and 5.5% and 6.5% increases in soft white winter wheat. Brown et al. (2008) also had no treatment effects on crop yields for 3 years from a one-time surface or subsurface lime application when it was applied with regular N fertilization or N plus S fertilization.

Micronutrient applications were also apparent in subsequent soil tests and crop harvests. Boron significantly increased in 0-3 in and 3-6 in layers for M and LM, and LM was higher than M most years (Figure 4). Zinc followed similar patterns; it was significantly higher for 0-3 in soil that received micronutrients for 2016, 2017, and 2019, and highest in LM. Copper also increased in the 0-3 in surface layer for plots with micronutrient treatments (M and LM) (Figure 4). Even with the micronutrient additions, soils in this study area remained in the "low" category of 0.2-0.5 ppm for boron and under the "sufficient" category for zinc (Horneck et al., 2011), so this field may still benefit from future micronutrient additions. Zinc and copper were also significantly higher in barley grain (2020) from treatments with micronutrients.

Potassium chloride was used as a carrier for application of the other micronutrients, but we do not think potassium (K) drove the observed yield increases. Soils in the Palouse generally contain more than adequate levels of potassium (>250 ppm), especially those that retain residue. This soil averaged 800 ppm K in the surface layer, 541 ppm at 3-6 in and, 538 ppm at 6-12 in, and soil K did not change with treatment or time. While chloride can provide some benefit to wheat through reduced disease severity (Koenig, 2005; Horneck et al., 2011), soil chloride levels were not affected by micronutrient treatments in this study.

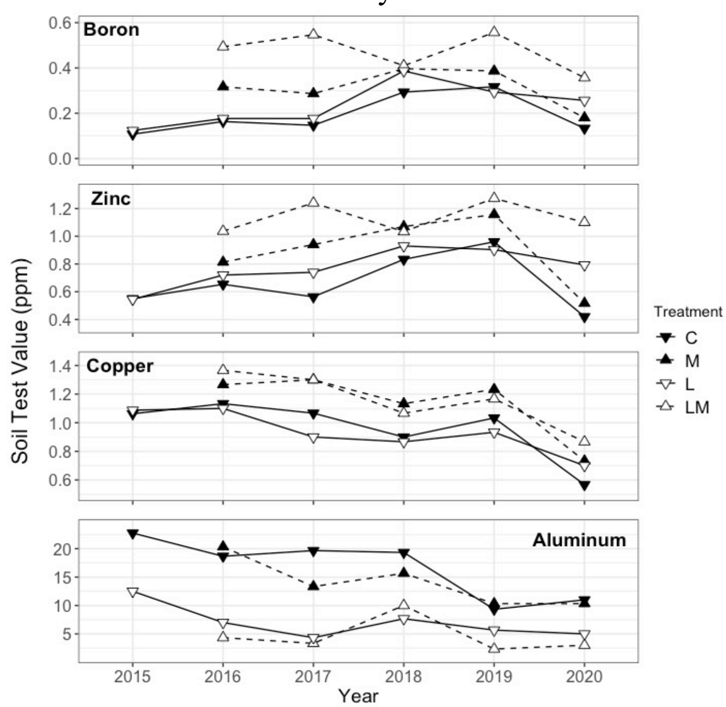


Figure 4. Available aluminum and select micronutrients in 0-3" soil. Dashed lines are treatments receiving micronutrients; white symbols are treatments receiving lime.

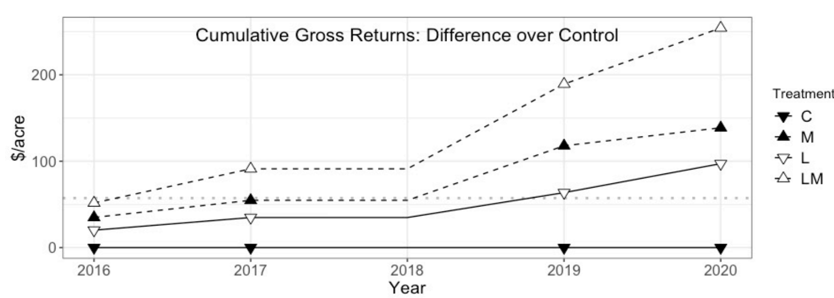


Figure 5. Cumulative gross returns over the control treatment, using actual crop prices each year. Dotted line represents the input cost of micronutrients.

Based on crop prices for the years of this study, the micronutrients had nearly paid for themselves by the 2nd harvest after application (yield boosts 2016-2017 resulted in an extra

$55/acre gross; total cost of micronutrients was $57.3/acre); after 4 harvests micronutrients had supplied a net extra $81.4/acre (Figure 5). The LM treatments have accumulated an extra $254/acre, which does not yet cover the cost of this rate of ultra-micronized lime ($415/acre) plus micronutrients (note this data is missing a year of pea harvest; the 2016 pea harvest from LM grossed an extra $52/acre). Using other type of lime may decrease cost, but may also affect the benefits to soil and yield. More research on the long-term economic balances from more studies - including micronutrients and various rates and sources of lime – are needed.

## REFERENCES


Brown, T.T., R.T. Koenig, D.R. Huggins, J.B. Harsh, R.E. Rossi. 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. doi:10.2136/sssaj2007.0061

Carter, P.G. and G. Wegner. 2017. Amending acidic soils for sustainable wheat production. Proceedings from the Western Nutrient Management Conference.

Fageria, N.K., V.C. Baligar, and R.B. Clark. 2002. Micronutrients in crop production. Advances in Agronomy, 77:185-268. doi:10.1016/S0065-2113(02)77015-6.

Godsey, C.B., G.M. Pierzynski, D.B. Mengel, and R.E. Lamond. 2007. Management of soil acidity in no-till production systems through surface application of lime. Agronomy Journal, 99:764-772. doi:10.2134/agronj2006.0078.

Horneck, D.A., D.M. Sullivan, J.S. Owen, and J.M. Hart. 2011. Soil test interpretation guide. Oregon State University Extension. EC1478.

Koenig, R. T. 2005. Dryland winter wheat eastern Washington nutrient management guide. Washington State University Extension. EB1987E.

Mahler, R.L., and R.E. McDole 1987. The relationship of soil pH and crop yields in Northern Idaho. University of Idaho College of Agriculture, Cooperative Extension Service. Current Information Series No. 811.

Mahler, R.L., S. Wilson, B. Safii, and W. Price. 2016. Long-term trends of nitrogen and phosphorus use and soil pH change in northern Idaho and eastern Washington. Communications in Soil Science and Plant Analysis, 47:414-424.

McFarland, C., S. Shiwakoti, L. Carpenter-Boggs, K. Schroeder, T. Brown, D.R. Huggins. 2020. Evaluating buffer methods for determining lime requirement on acidified agricultural soils of the Palouse. Soil Science Society of America Journal, 84:1769-1781.

McFarland, C.R., D.R. Huggins, and R.T. Koenig. 2015. Soil pH and implications for management: an introduction. Washington State University Extension. FS170E.

Rahman, M.A, S-H. Lee, H.C. Ji, A.H. Kabir, C.S. Jones, and K-W. Lee. 2018. Importance of mineral nutrition for mitigating aluminum toxicity in plants on acidic soils: current status and opportunities. Int J. Molecular Sciences, 19(10):3073.

Tao, H., W.L. Pan, P. Carter, K. Wang. 2019. Addition of lignin to lime materials for expedited pH increase and improved vertical mobility of lime in no-till soils. Soil Use and Management, 35:314-322. doi:10.1111/sum.12483

Thompson, W., C. McFarland, T. Brown, and D. Huggins. 2016. Agricultural Lime and Liming, Part1: Introduction to Agricultural Lime and Liming. Washington State University Extension, FS212E.

Yu, M., R. Shen, H. Xio, M. Xu, H. Wang, H. Wang, Q. Zeng, and J. Bian. 2009. Boron alleviates aluminum toxicity in pea (Pisum sativum). Plant and Soil, 314:87.