

# WHEAT STRAW PULPING BY-PRODUCT MIXED WITH LIME MAY ADDRESS SOIL ACIDIFICATION IN NO-TILL FIELDS



## Abstract

Soil acidification has become a growing concern for dryland crop production in the Pacific Northwest (PNW). Many no-till (NT) soils have stratified soil pH in the fertilizer application zone due to repeated nitrogen (N) fertilizer applications. The practice of liming to correct low soil pH is less effective for stratified soil acidity in no-till systems because lime is relatively insoluble. Consequently, without tillage, the vertical movement of surface-applied lime to the most acid-affected depths (generally 4–12 inches) can take many years. We conducted a greenhouse study to determine whether mixing lime materials with lignin-containing black liquor, a by-product from the pulp industry, offers a viable solution for soil acidity in no-till systems. Results indicate that the lime-black liquor mixture can expedite downward movement of lime and correct stratified soil pH in a short period of time. At 42 days after liming, the super fine micro lime-black liquor mixture increased soil pH from the soil surface to a depth of 6 inches. After 147 days, this finer mixture increased soil pH in the 10–12 inches depth, and the coarser agricultural lime-black liquor mixture increased soil pH from the surface to a depth of 10 inches.

## Introduction

### *Stratified Soil pH in No-Till Soils*

In the Pacific Northwest (PNW), native soil pH was near neutral but has continuously declined since nitrogen (N) fertilizer production began around 1960 (Koenig et al. 2011; Paulitz and Schroeder 2017). Soil acidification changes soil chemistry, fertility, and biological properties which, in turn, can have major negative effects on crop production.

In no-till (NT) crop production systems in the dryland farming areas of the PNW, deep-banding N fertilizers to a depth of two to four inches from the soil surface is a common practice. As a result, the soil at this depth acidifies more quickly and severely than in other depths of the soil profile. Our previous survey found that 97% of 73 NT wheat fields in Columbia County, Washington (WA) (Figure 1) were acidified, with an average soil pH of less than 5.2 and less than 5.0 at soil depths of 0–3 and 3–6 inches, respectively (Figure 2).

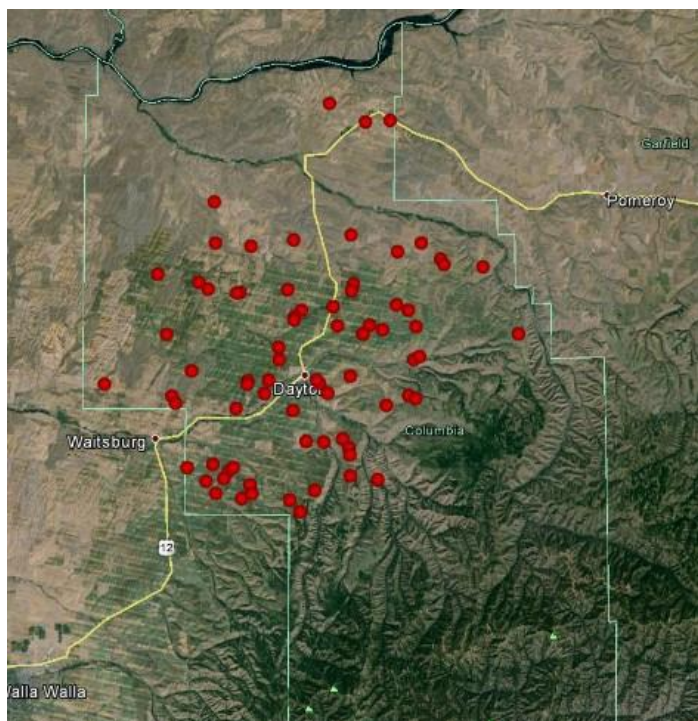


Figure 1. Locations of 76 no-till fields and adjacent native soils sampled for the soil pH survey in Columbia County, WA, in 2013.

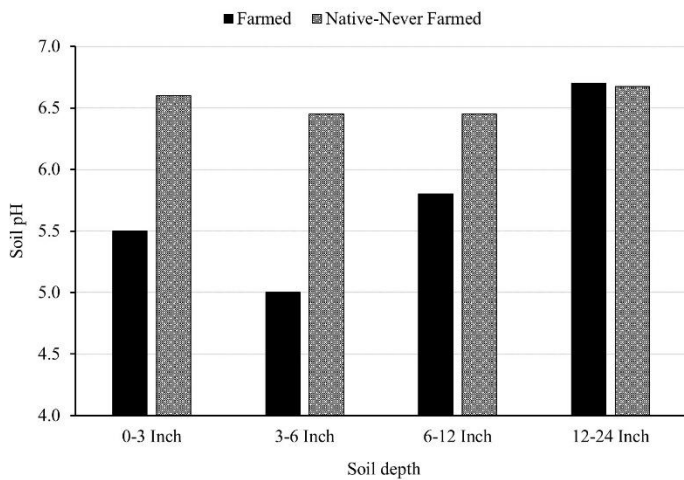


Figure 2. Average soil pH values at 3-inch increments of 24-inch soil profiles, sampled in 76 no-till farmed fields and adjacent native soils (never farmed) in Columbia County, WA. Samples were collected in 2013.

## Low Soil pH Affects Nutrient Availability and Causes Aluminum Toxicity

In general, with the exception of iron, the availability of crop essential nutrients decreases as soil pH decreases. Decreases in soil pH also reduces base saturation (BS), which is the percentage of a soil's cation exchange capacity (CEC) occupied by base cations, such as calcium (Ca), magnesium (Mg), and potassium (K). In most soils, aluminum (Al) becomes soluble when soil pH is less than 5.5. And, soluble Al increases exponentially as soil pH further decreases. This soluble Al can then take the place of other cations on the soil's cation exchange sites, reducing BS, and in turn, significantly reducing nutrient availability. Therefore, crop yield losses can occur due to this Al toxicity (Schroder et al. 2011).

Figure 3 shows how soil pH affects soil test Al (i.e., exchangeable Al, which is mostly Al absorbed on the cation exchange sites) and BS, based on the soils we studied. When soil pH was higher than 5.5, we found no soluble Al in the soils. When soil pH decreased below 5.5, we began to see the concentration of soluble Al increase rapidly. In contrast, BS decreased dramatically as pH decreased. The BS dropped below 70% when soil pH was 5.9.

## Challenges with Liming No-Till Soils and a Proposed Strategy

Liming is a common practice to increase soil pH. This practice neutralizes soil pH most effectively when lime material is thoroughly mixed with soils using tillage because common materials—limestone ( $\text{CaCO}_3$ ), quick lime ( $\text{CaO}$ ), and hydrolyzed lime ( $\text{Ca(OH)}_2$ )—are water insoluble. In NT systems, correcting soil pH by liming takes much longer. For

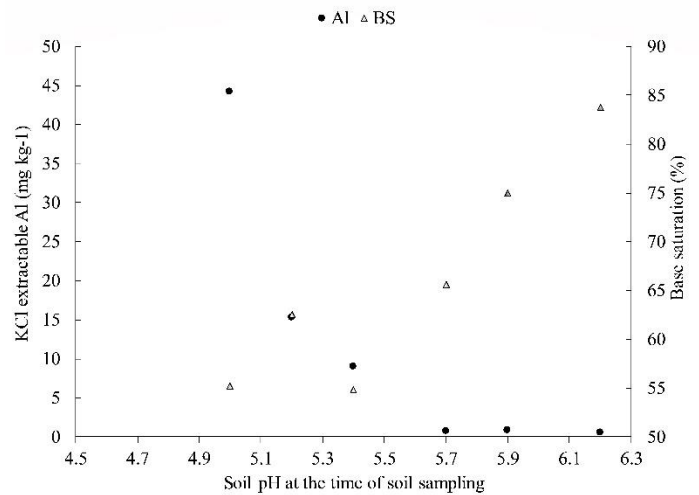


Figure 3. The relationships between soil pH, KCl extractable aluminum (Al), and base saturation (BS) of the soils used in this study.

example, previous NT studies have shown that many years of surface-applied lime are necessary to correct soil pH in the top 0–2 inches or to observe pH changes in deeper acidified zones (Conyers et al. 2003; Godsey et al. 2007).

A by-product from the paper pulp industry may offer a solution for efficiently correcting soil acidity in NT systems. Prospects for utilizing wheat straw for producing cellulose pulp for papermaking has been recognized in the PNW for 20 years, based on a collaborative University of Washington-Washington State University research project. Black liquor is a by-product of this paper pulp process and is rich in micro- and macronutrients and lignin. Previous studies have shown that application of black liquor can replenish soil nutrients and organic matter and increase soil pH, microbial activity, and soil aggregation (Xiao et al. 2006, 2007, 2008). In addition, the high pH and the acid- and alkaline-soluble organic matter in black liquor might be capable of mobilizing surface-applied lime by creating a colloid effect in soils.

## Objective

For this study, we conducted a greenhouse incubation study with undisturbed soil columns. Our objective was to investigate whether mixing black liquor with lime materials can result in faster pH changes in the deep soil profiles of NT silt loam soils.

## Materials and Methods

### Soil Sampling and Experimental Materials

Soil samples used for this soil-column incubation study were collected from a long-term, wheat-fallow NT field on a commercial farm in Dayton, Washington. The average annual rainfall at this site is 19 inches. The soil in the field is a silt loam. On April 13th, 2016, we collected 36 intact soil cores, measuring 6 inches in diameter by 12 inches in depth, from the soil surface.

The effectiveness of liming is greatly affected by the fineness of the lime materials. The finer the material, the faster pH can be neutralized for a greater amount of soil. In this study, we compared two commonly used lime materials with differing fineness, micro lime (ML) and agricultural lime (AL). ML is the finer of the two materials; 99%, 89%, 82%, and 80% passed a 40, 60, 100, and 200 mesh, respectively. AL is coarser; 67%, 60%, 59%, and 58% passed a 40, 60, 100, and 200 mesh, respectively. The lime score (Thompson et al. 2016) was 92 and 66 for ML and AL, respectively.

We obtained the black liquor by-product from Sustainable Fiber Technologies in Dayton, Washington, a company that performs small-batch, wheat straw pulp production testing. The black liquor had a pH of 12 and contained 15% solids by weight.

## Experimental Design, Soil pH Measurements, and Statistical Analysis

A greenhouse soil-column incubation experiment was initiated on May 13th, 2016 at Washington State University (Figure 4). We used a completely randomized design with four treatments and a control, replicated four times. The treatments included agricultural lime (AL), micro lime (ML), agricultural lime mixed with black liquor (AL-L), and micro lime mixed with black liquor (ML-L). We used a lime:black-liquor mixture ratio of 70:30, based on weight. The rate of all lime treatments (not including black liquor) was 4 ton/acre, which was the approximate lime requirement based on the Mehlich buffer test for increasing soil pH from 5.0 to 6.0 (McFarland 2016). Each pot of soil was irrigated with a total of 2.4 gallon water during the first 6 weeks of the incubation period, which is equivalent to the historical average annual rainfall in Dayton. We measured the pH of the soil columns at 2-inch increments for a total of six depth measurements: 0–2, 2–4, 4–6, 6–8, 8–10, and 10–12 inches at 42 and 147 days after liming.

## Results and Discussion

In general, the changes in soil pH differed among lime material treatments, soil depths, and the two sampling dates. Increases in soil pH values varied among the different soil depths at both 42 days and 147 days post-liming. For each lime treatment, soil pH increases were the greatest in the top 0–2 inch soil layer.

pH values in the 0–2, 2–4, and 4–6 inch soil depths of the ML- and AL-treated soils increased less compared with soils treated with the black liquor mixtures (ML-L and AL-L). Compared to soils treated with AL-L, soils treated with ML-L showed significantly greater pH values in the 0–2, 2–4, and 4–6 inch soil depths (Figure 5). Soil pH increased to 7.4, 7.0, and 6.2 in the 0–2, 2–4 and 4–6 inch layers, respectively, of the ML-L-treated soils compared to 5.3, 5.2, and 4.8 in the untreated soils. These



Figure 4. The greenhouse incubation study was established on May 13th, 2016. Photo taken May 13th, 2016 by H. Tao.

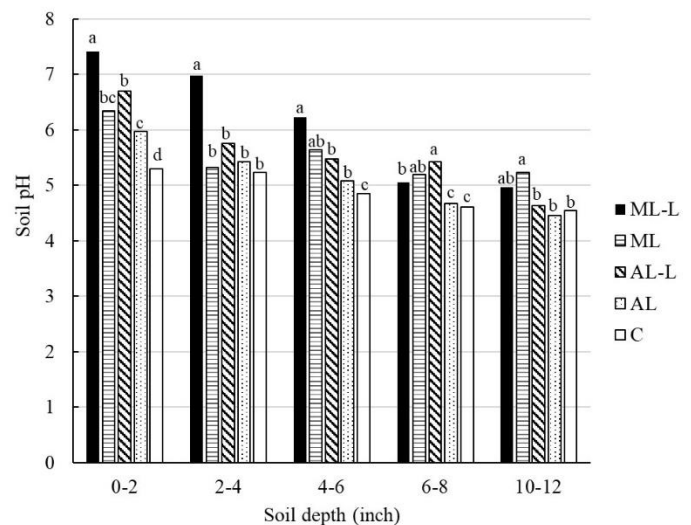


Figure 5. Soil pH (soil:water = 1:1) measured at 42 days after lime treatments. AL-L = agricultural lime mixed with black liquor; ML-L = fine micro lime mixed with black liquor; ML = fine micro lime; AL = agricultural lime; C = untreated control. Columns of pH values labeled with different letters are significantly different from each other within the same soil depth at  $\alpha = 0.1$  confidence level. Note: we did not measure soil pH for the 8–10 inch soil depth layer.

pH increases in the ML-L-treated soils were much higher than the increases in soils treated with AL-L, ML, and AL.

At 147 days post-liming, soils treated with AL-L showed greater pH values in all measured soil depths between 0–10 inches, compared to the ML-L-treated soils. This finding suggests that the downward movement of AL-L was slower than that of ML-L, allowing time for chemical reactions to occur before the AL-L moved deeper. Soil pH values declined at all depths between 0–10 inches of the ML-L-treated soils measured at 147 days compared to measurements at 42 days. This finding is likely due to some of the ML moving deeper than ten inches and to gradual release of exchangeable acidity in the 0–10 inch depth during this period of time (Figure 6).

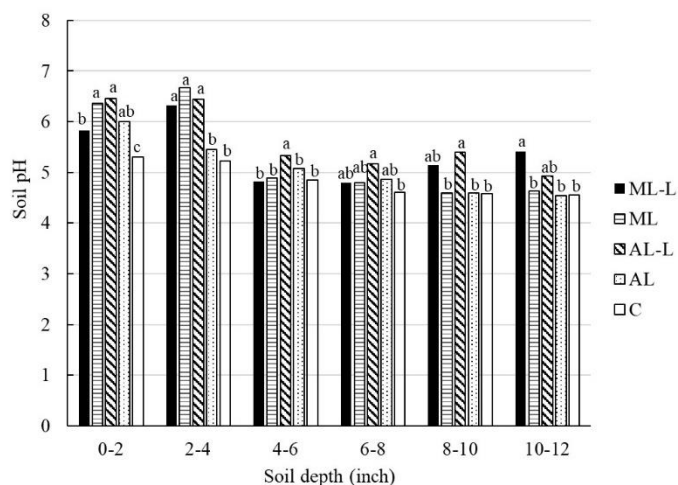


Figure 6. Soil pH (soil:water = 1:1) measured at 147 days after lime treatments. AL-L = agricultural lime mixed with black liquor; ML-L = fine micro lime mixed with black liquor; ML = fine micro lime; AL = agricultural lime; C = untreated control. Columns of pH values labeled with different letters are significantly different from each other within the same soil depth at  $\alpha = 0.1$  confidence level.

At 147 days, ML-L was the only treatment that resulted in a pH increase in the 10–12 inch depth. In the ML-L treated soils, the mean soil pH was significantly higher in the 10–12 inch soil layer on day 147 compared with the mean pH on day 42 (5.41 on day 147 vs. 4.96 on day 42) (Figure 5 and Figure 6). This result provides further evidence that black liquor mixed with lime can facilitate downward movement and that finer lime-black liquor mixtures are more conducive for vertical movement and increasing subsoil pH. Because the 10–12 inch layer was the deepest in our experiment, we are unsure if downward movement of the ML-L would have continued out of the fertilizer application zone.

For NT fields where the acidified layers are still within fertilizer application zones, movement of lime material into the acidified zones but no deeper is optimal. In the surveyed 76 NT fields in Columbia County, natural subsoil had a near neutral pH on

average, and N-induced acidification had yet to affect the greater than 12-inch subsoil (Figure 2). At 147 days, we found the highest soil pH values in the soil layers nearest to the surface with the AL-L treatment; thus, AL-L may be a better choice than ML-L. In regions that are experiencing extremely acidified soil, particularly where low soil pH occurs beyond the 12-inch depth, ML-L may be a better choice.

## Logistics of Field-Scale Application of Lime Material-Black Liquor Mixtures

Black liquor is locally available in Washington. For example, Columbia Pulp is currently under construction in Starbuck, WA (Figure 7). When completed, this straw pulp mill will be the largest in the world and is projected to generate 160,000 tons of black liquor at 50% solids per year (W. McKean, personal communication). The application of black liquor will not only increase liming efficiency but also return substantial amounts of organic matter to the soil. This latter benefit is especially important for fields from which straw is harvested. The foreseeable issue for field application of black liquor is sodium in the black liquor. We recommend monitoring sodium concentration in the soil when applying black liquor. In addition, not all black liquor produced will be available for agricultural use. The pulp industry has developed other markets for black liquor, for example, road dust control and industrial chemical use.

Different soil conditions and precipitation patterns may strongly influence chemical reactions and the vertical movement of lime materials mixed with black liquor. Further research is needed to investigate whether this practice can produce similar benefits under different farm field and climate conditions. However, the results of this field study can provide a viable strategy for correcting below soil surface pH in NT systems.



Figure 7. Pulp mill processing plant under construction near Starbuck, WA (left). Wheat straw bales stored near the construction site (right). Photos taken April 3, 2018 by W. Pan.

## Conclusions

In this greenhouse soil-column incubation study, we found that mixing lime materials with black liquor may be a solution to resolve a long-standing issue with stratified soil acidity in no-till

cropping systems. Mixing lime materials with black liquor increased the effectiveness and accelerated the downward movement of lime, regardless of the fineness of lime materials. Subsoil pH started to increase at 147 days after surface-applied lime-black liquor mixture, much faster than using lime material alone, based on our experimental results and those previously reported.

Xiao, C., R. Stevens, M. Fauci, R. Bolton, M. Lewis, W.T. McKean, D.F. Bezdicek, and W.L. Pan. 2007. Soil Microbial Activity, Aggregation and Nutrient Responses to Straw Pulping Liquor in Corn. *Biology and Fertility of Soils* 43(6): 709–719.

## References

Conyers, M.K., D.P. Heenan, W.J. McGhie, and G.P. Poile. 2003. Amelioration of Acidity with Time by Limestone under Contrasting Tillage. *Soil and Tillage Research* 72: 85–94.

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.

Koenig, R., K. Schroeder, A. Carter, M. Pumphrey, T. Paulitz, K. Campbell, and D. Huggins. 2011. [Soil Acidity and Aluminum Toxicity in the Palouse Region of the Pacific Northwest](#). *Washington State University Extension Publication* FS050E. Washington State University.

McFarland, C.R. 2016. Liming No-Till Soils and Determining Lime Requirement in the Palouse Region. MS Thesis. Washington State University.

McKean, W. n.d.

Paulitz, T., and K. Schroeder. 2017. [Acid Soils: How Do They Interact with Root Diseases?](#) *Washington State University Extension Publication* FS195E. Washington State University.

Schroder, J.L., H. Zhang, K. Girma, W.R. Raun, C.J. Penn, and M.E. Payton. 2011. Soil Acidification from Long-Term Use of Nitrogen Fertilizers on Winter Wheat. *Soil Science Society of America Journal* 75: 957–964.

Thompson, W.H., C. McFarland, T. Brown, and D.R. Huggins. 2016. [Agricultural Lime and Liming, Part 3: Aglime Product Selection and Comparison Calculator User Guide](#). Soil Acidification Series. *Washington State University Extension Publication* FS213E. Washington State University.

Xiao, C., M. Fauci, D.F. Bezdicek, W.T. McKean, and W.L. Pan. 2006. Soil Microbial Responses to Potassium-Based Black Liquor from Straw Pulping. *Soil Science Society of America Journal* 70: 72–77.

Xiao, C., M. Fauci, D.F. Bezdicek, W.T. McKean, and W.L. Pan. 2008. Soil Aggregation and Microbial Responses to Straw Pulping Byproducts. *Soil Science Society of America Journal* 72: 1471–1477.

By  
Haiying Tao, Assistant Professor, Department of Crop and Soil Sciences  
William L. Pan, Professor, Department of Crop and Soil Sciences  
Paul Carter, Associate Professor and Director of Columbia County Extension,  
Washington State University



**TB63E**



Copyright © Washington State University

WSU Extension publications contain material written and produced for public distribution. Alternate formats of our educational materials are available upon request for persons with disabilities. Please contact Washington State University Extension for more information.

Issued by Washington State University Extension and the US Department of Agriculture in furtherance of the Acts of May 8 and June 30, 1914. Extension programs and policies are consistent with federal and state laws and regulations on nondiscrimination regarding race, sex, religion, age, color, creed, and national or ethnic origin; physical, mental, or sensory disability; marital status or sexual orientation; and status as a Vietnam-era or disabled veteran. Evidence of noncompliance may be reported through your local WSU Extension office. Trade names have been used to simplify information; no endorsement is intended. Published November 2019.