OPVC FINAL PROJECT REPORT: 2016 **PROJECT YEAR:** 2 of 2

1. COVER PAGE

Project title: Increasing liming efficiency on processed vegetable farms (2016)

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OTHER FUNDING SOURCES
Ashgrove Cement Co. ($1,000)

Total Project Request
Year 1: $13,236 Year 2: $5,002 **Total: $18,238**

2. EXECUTIVE SUMMARY

Several new powdered limestone products that are more finely ground (smaller particle size distribution) than products historically used have become commercially available. A major factor influencing the effectiveness of a liming material is its particle size distribution, with smaller particles reacting more quickly. Because lime efficiency estimates for various particle size fractions were established in the 1950's, there is a need to evaluate current guidelines to determine if they adequately predict liming efficiency for these new products. The objective of this study was to assess the reactivity of commercially available powdered lime products (both calcitic and dolomitic) and various particle size fractions over a year with the goal of evaluating current OSU lime guidelines.

The products evaluated included two produced from Ashgrove Cement Company (Ashgrove Ag Lime and Ashgrove Ground Dolomite) and two finely-ground limes produced by Columbia River Carbonates (Microna Ag H2O and Microna Ag Lime sold under the trade name Access lime). Of these products, Ashgrove Ag lime is the most widely utilized in the Willamette Valley. The following particle size fractions (US mesh) of calcitic limestone were also evaluated: 10-20, 20-40, 40-60, 60-100, and 100-200. The performance (ability to increase soil pH or exchangeable Ca (X-Ca)) of the lime products and particle size fractions were evaluated in field and laboratory studies.

Initially the dolomitic lime was the least reactive product (this is due to the low solubility of magnesium carbonate relative to calcium carbonate), but was equal in performance to other products at 12 months. Although the Microna products were generally more reactive than the Ashgrove Ag lime at 1 month, from 3 months on there were little or no differences in pH or X-Ca between products. In our study, there was no observed increase in lime performance for particles <20 mesh (i.e., all particles <20 mesh performed equally) measured at 12 months.

3A. BACKGROUND

Agricultural liming materials vary in their ability to neutralize soil acidity. A major factor that influences the effectiveness of a liming material is its particle size distribution. As particles get smaller, surface area increases and the lime reacts more quickly. Oregon Department of Agriculture uses a Lime Score as a marketing standard to estimate the acid neutralizing potential of a liming material, which is used to determine a liming material's application rate. The Lime Score is calculated based on lime moisture content, calcium carbonate equivalence, and estimated reactivity of various particle size fractions 1 to 3 years after addition to soil (called the *fineness factor;* Hart, 1998). For example, particles passing a no. 40 sieve (400 µm) are considered to be 100% effective while those passing a no. 20 (814 µm) but retained on a no. 40 sieve are considered to be 60% effective. The guidelines for estimating the fineness factor were established by OSU in 1955.

In 2012 a new very fine powdered product, Microna Ag Lime (produced by Columbia River Carbonates in Woodland, WA and sold by Wilco under the name Access lime), entered the marketplace. This product has 100% of lime particles passing a no. 100 sieve (149 µm) and ~90% passing a no. 200 sieve. Although the particles are small with a higher surface area, based on the way Oregon's lime score is calculated, Access lime has the same lime score as other agricultural lime products (i.e., should have the same reactivity over a year's time). Despite the same lime score, the manufacturer claims that up to half the rate is needed to achieve the same results compared to other aglimes with a larger particle size distribution. If true, farmers could potentially reduce costs by using Access lime compared to the predominant aglime used in the Willamette Valley, Ashgrove Ag lime (savings vary depending on bulk discounting and distance from distribution centers).

Although Access lime may be more reactive, there is the potential that the lime will not be able to maintain the soil pH over the long term (1+ years) if applied at a lower rate as specified by the manufacturer. This may occur because the lime has more completely reacted, leaving little additional lime to buffer pH change (i.e., larger particles sizes that continue to react over a longer period of time. As a result, the Access lime may have to be applied more frequently, negating any price savings over the long term.

There is also the possibility that Oregon's *fineness factor* estimates (Hart, 1998) underestimate reactivity and that CRC's claims may be valid even over the long term. Oregon's *fineness factor* calculations are likely based on the research of Meyer and Volk (1952). In their research, they observed that particles that passed a 40 mesh sieve, but did not pass a 50 mesh sieve were as effective as particles that passed a 100-mesh sieve in neutralizing soil acidity at 12 to 18 months after lime incorporation into soil. However, more recent research has challenged their finding. Scott et al. (1992) observed that particles passing a no. 60 sieve but retained on a no. 200 sieve did not completely dissolve over a 3-yr field trial. They estimated that the efficiency of various particle size fractions passing a no. 60 sieve but retained on a no. 200 sieve was between 47 to 73% compared to particles passing a 200 mesh sieve.

3B. OBJECTIVES

1. Determine if Oregon's guidelines for estimating lime efficiency (reactivity) for specified particle size fractions are adequate for predicting performance of finely ground powdered calcitic and dolomitic lime products. This will be accomplished by:
    a. Evaluating the short- (<6 months) and long-term (1 year) influence on soil pH of commercially available liming products and various particle size fractions.

3C. SIGNIFICANT FINDINGS

On-farm, large scale field study

- There was no difference in soil pH between the liming products Microna Ag lime (Access) and Ashgrove Ag lime at any sampling date (0, 1, 3, 6, and 12 months) for the low rate (1.4 t/a).
- At the high rate (2.8 t/a), there were no differences at 1 and 3 months. There was a statistically significant difference in soil pH between the products at 6 months (6.6 for Ashgrove vs. 6.7 for Microna) and 9 months (7.0 for Ashgrove vs. 6.8 for Microna) however, the absolute differences were slight.

Research-farm field study

- The soil responded linearly to increasing additions of Ashgrove Ag lime from 0.5 to 2.5 ton/acre lime.
- Even by 6 months, unreacted lime was visible in some soil samples.
- The solution grade product, Microna Ag H2O was the most reactive product and achieved the highest pH and X-Ca one month after application. This product was used as a benchmark (i.e., assumed 100% reactivity) to assess relative reactivity of other materials and particle size fractions. But after 1 month, there were little or no differences in performance among calcitic lime products.

- Ashgrove dolomite was the least reactive product from 1 to 6 months, but by 12 months, it had an equivalent performance compared to the calcitic products.
- There was no statistical difference in performance between Microna Ag Lime and Ashgrove Ag over 12 months. Since both products had the same lime score, OSU's methods for calculating lime efficiency appear adequate.

Research-farm pot incubation study

- When the lime products were added to sieved soil, thoroughly incorporated, and incubated in pots under field conditions with growing crops, the lime more completely reacted and higher pH was achieved relative to the field study, indicating that degree of mixing and fineness of seed bed is just as or more important than the lime product used.
- At 1 month, both Microna products performed better than the Ashgrove Ag lime, but from 3 months on, there were no differences among products.
- At 12 months, particles <20 mesh (841 μm) all performed the same (i.e., pH and X-Ca not statistically different).
- OSU's methods for estimating lime efficiency using a fineness factor were adequate for estimating lime performance.

Laboratory incubation

- CO2-C is released when the calcium and magnesium carbonate (CO3) in lime products react with soil acidity. Based on change in pH and CO2-C evolution from three soils (reported as the % of total CO3-C added to soil) at 31 days, the Microna Ag lime was more reactive compared to Ashgrove Ag lime. This difference in short-term reactivity is consistent with the results of the other studies previously discussed above.

Assessing lime reactivity using a citric acid reactivity test

- The citric acid reactivity test is a direct measurement of lime reactivity and could be used as an alternative to the fineness factor estimates used to estimate reactivity, which is indirect. Although results suggest that this test may have merit, there is no compelling reason to adopt the test for the following reasons:
    1. Extensive field research would be needed to create a model relating lime performance to lime score, and there is currently no significant benefit in changing current methods, which appear to adequately predict lime reactivity.
    2. After 1 month, there was no difference in performance between lime products even though they had very different citric acid reactivity values, indicating that the test may only be appropriate for predicting short-term reactivity.

3D. METHODS

Lime and soil characteristics

The characteristics of each liming material used in this study are given in table 1 and 2. Soil characteristics are given in table 3. Lab analysis for the lime and the soil CEC was done by Brookside Laboratories Inc. (New Bremen, OH). As stated by the manufacturer, each lime product tested had an Oregon Lime Score of 97 or greater except for the Ashgrove Ag Lime with a lime score of 95.

Table 1. Lime characteristics

Product	CCE[4]	Ca	Ca as CaCO3	Mg	Mg as MgCO3	OR lime score	Citric acid reactivity value[6]
	% of pure CaCO3	---------------- % ----------------					
Ashgrove Ag Lime	98	39.8	99.5	0.2	0.6	95	28
Ashgrove Flourlime	98	40.1	100.1	0.2	0.6	98	NA
Ashgrove Dolomite	100	24.6	61.4	9.7	33.6	98	NA
Microna Ag lime[2]	98	38.9	97.1	0.5	1.6	97	55
Microna Ag H20	98	39.4	98.3	0.4	1.4	97	76
10-20 mesh[1]	96	38.2	95.5	0.5	1.6	29[5]	8
20-40 mesh[1]	96	39.8	99.3	0.3	1.0	58[5]	13
40-60 mesh[1]	96	40.1	100.1	0.2	0.8	96[5]	16
60-100 mesh[1]	96	40.4	100.8	0.3	0.9	96[5]	18
100-200 mesh[1]	96	40.0	100.0	0.4	1.5	96[5]	26
Reagent grade CaCO3	100	NA	NA	NA	NA	100	88

1- This material was provided by Columbia River Carbonates (CRC), the manufacturer of the Microna lime products; 2- sold under the name Access lime; 4- calcium carbonate equivalence; 5- calculated using OSU Fertilizer Guide FG 52 6- see methods below for "Citric acid reactivity test"

Table 2. Particle size distribution

Sieve (US mesh)	8	20	60	100	200	325	Vol. weighted mean particle diameter[2]
Micro meter	2360	841	250	149	74	44	
Product	----------- wt % passing[1] -------------				volume % passing[2]		Micro meter
Ashgrove Ag Lime	100	100	97	91	54	40	65
Ashgrove Flourlime	100	100	98	93	NA	NA	NA
Ashgrove Dolomite	100	99	94	85	37	24	103
Microna Ag lime	100	100	100	100	94	76	25
Microna Ag H20	100	100	100	100	99	98	11

1- measured by Brookside Lab, Inc.; 2- measured by a Malvern Mastersizer Hydro 2000G particle size analyzer

Table 3. Soil Characteristics

Site	pH (1:2)	SMP buffer pH	Clay[2] %	Texture	CEC[3] cmol/kg
VF[1] EF	5.9	6.5	12	sandy loam	19.8
VF[1] A18	6.4	6.4	18	loam	21.6
On-farm	6.6	6.4	15	silt loam	20.3

1- OSU's Vegetable Research Farm; 2- particle size analysis measured by the hydrometer method; 3- CEC measured by displacement with ammonium acetate

Field evaluation of liming products in field trials

Research farm field trial (VF East Farm)

A replicated field trial was established at OSU's Vegetable Research Farm (VF EF). The treatments applied are given in Table 4. The rates given in Table 4 are given based on the theoretical neutralizing power of 100% pure calcium carbonate. Actual application rates were adjusted based on the calcium carbonate equivalence (CCE) of each material given in Table 1. The experiment was arranged in a randomized complete block design with 4 replicates. Each plot was 10' x 20'. Lime was hand spread early in the morning over 4 days (June 15-18). This was necessary to avoid wind transporting material into adjacent plots. On June 19, 2015, the lime was incorporated to a depth of 6" using a rotary hoe with an implement width of 8'. At the end of each plot, the rotary hoe was lifted and set back down so as to prevent lime movement between plots (Fig. 1). That same day, snap beans were planted (OSU 5630) and irrigated.

Table 4. Research farm field trial treatments and rates

Treatment	Rate (CCE[1] equivalent) ton/acre
Control	NA
Ashgrove Ag Lime 0.5x	0.5
Ashgrove Ag Lime 1x	1.0
Ashgrove Ag Lime 1.5x	1.5
Ashgrove Ag Lime 2x	2.0
Ashgrove Ag Lime 2.5x	2.5
Microna Ag lime 1x	1.0
Microna Ag lime 1x	2.0
Microna Ag H2O 1x	1.0
Microna Ag H2O 2x	2.0
Ashgrove dolomite 1x	1.0
Ashgrove dolomite 2x	2.0

1- Calcium carbonate equivalence

At 67 days after planting, the bean plants were clipped at the soil surface and removed from the field (i.e., no residue remained in the field). To avoid movement of lime with tillage, wheat cv. 'Kaseberg') was direct seeded into the field at a rate of 65 lbs/acre on October 9, 2015.

At each sampling date (1, 3, 6, and 12 months), the soil in the middle of each plot was sampled (6 samples composited) to a depth of 6", sieved, air dried, and analyzed for pH (1:2 soil to water) and exchangeable Ca (X-Ca) using the Mehlich III extraction. Only select samples were analyzed for X-Ca due to economic constraints.

On-farm field trial

An on-farm liming trial was established on a commercial farm that grows processing vegetables. The trial consisted of 2 lime products applied at 2 rates (1x=1.4 t/a and 2x= 2.8 t/a): 1) Ashgrove Ag lime 1x, 2) Ashgrove Ag lime 2x, 3) Microna Ag Lime 1x, and 4) Microna Ag Lime 2x. The lime was applied by a commercial applicator (March 10 and 12, 2015 for the Microna and Ashgrove limes, respectively) and the rate was verified using the weigh scale in the lime buggy. Each plot was 75' x 200' (1/3 of an acre) and each treatment was replicated 3 times.

The trial was set-up as a paired response (i.e., each replicate or block was not randomized). The lime was incorporated April 24 (~44 days after application) to a depth of ~8" (2 passes with a vibrashank, 2 with a perfecta, and 1 with a rototiller). Broccoli was transplanted on May 7. A total of 190 lb/acre of nitrogen was applied to grow the crop. In October, beds were created and garlic planted.

At 1, 3, 6, and 12 months after incorporation, the soil in the center of each plot was sampled (10 samples composited) to a depth of 6", sieved, air dried, and analyzed for pH (1:2 soil to water). This was done to minimize contamination from adjacent plots due to multiple tillage operations that could possibly have carried lime into edges of the plots.

Efficacy of liming products and discrete lime particle size fractions under field temperature and moisture conditions

It is assumed that the performance of a commercial liming material is the sum of the performance of each discrete particle size fraction. Long-term incubations were be conducted in pots in the field to evaluate reactivity of discrete lime product particle size fractions vs. "whole liming materials" (mixture of particle sizes). Because we are confident of the application rate to each pot, and because we are confident of uniform mixing of lime + soil in pots, these incubations have greater accuracy and precision in measuring differences in the efficacy of liming materials.

Soil from the VF East Farm (EF) field site was collected and sieved through a 4.75 mm screen. Treatments (Table 5) were applied to 15 lb field moist (~14 lbs oven dry) subsamples of soil at a rate of 2 ton/acre CCE equivalent (calculated based on 1.6 million lbs of soil per acre), thoroughly mixed, and then placed into #2 pots (1.6 gallons) on June 19, 2015. Each treatment had 4 replicates and the pots were buried at the edge of the field trial in a randomized complete block design so that the surface of soil in the pots was flush with the soil in the field (Fig. 2). Three bean seeds were sown in each pot, which was then thinned to 1 plant per pot. This was done so that we could evaluate lime performance under field conditions (i.e., wetting and drying, changes in soil temperatures, and influence of plant growth). After removing the bean plant at harvest, the soil was not disturbed (i.e., not mixed). On October 9, 2015, 3 wheat seeds were sown per pot.

At 1, 3, 6, and 12 months, two soil cores (0.75") were taken with a soil probe to the depth of the pot, air dried, and analyzed for pH (1:2 soil to water) and X-Ca.

Table 5. Pot incubation study lime treatments

Treatment
Control
10-20 mesh
20-40 mesh
40-60 mesh
60-100 mesh
100-200 mesh
Ashgrove Ag Lime
Ashgrove Flour lime
Ashgrove dolomite
Microna Ag lime
Microna Ag H2O

Laboratory evaluation of short-term lime reaction with soil acidity (via CO2 evolution measurement)

Carbon dioxide gas is evolved when lime reacts with soil acidity. Measuring CO_2 evolution with time after lime addition can be used to determine how fast lime reacts with soil acidity during the first weeks after application. Each liming material (Table 5) was mixed with 150 g of air-dried, sieved soil (2.8 mm) at a rate of 2 tons/acre CCE equivalence. We assumed a bulk density of 1.3 g/cm3 to calculate the lime rate to apply to each container. The soil + lime material mixtures were then placed into specimen cups with holes in the bottom. Each liming material treatment was replicated 3 times, and compared to a no-lime, soil only control. To bring the samples to field capacity, about ¼ of the required DI water was added to the surface, while the remaining ¾ was placed in the bottom of the Mason jar and the soil was wetted by capillary action. The jars were sealed immediately after adding each soil + lime product mixture.

Headspace air in each jar was collected via a syringe pushed through a rubber septum in the Mason jar lids. Carbon dioxide concentrations present in each jar were determined by injection into an ultrapure N_2 gas stream flowing through a Quibit CO_2 analyzer. After each sampling event, the jars were opened and fanned to remove CO_2 from the containers. The cumulative quantity of CO_2-C evolved during the first weeks after lime addition to soil serve as a direct measurement of lime reactivity in soil. Soil pH was measured at 31-d.

Figure 1. Lime incorporation using a power harrow. To prevent lime movement, the implement was lifted at the end of each plot and the n set back down.

Figure 2. Installing limed pots at the research farm.

Assessing lime reactivity using a citric acid reactivity test

Estimating lime reactivity based on an efficiency factor of various particle sizes is indirect and does not account for differences in lime minerology, degree of crystallinity, or surface conditions of the lime (rough with high surface area vs. smooth with smaller surface area). A direct measurement of reactivity can be measured through various tests that add a weak acid for a set time interval.

One common lime reactivity test that is used in Europe is the automatic titration of lime with citric acid (European Committee for Standardization method EN 16357:2013). For this test, 5 g of lime (10 g if particles >1mm or 18 mesh) is added to a 100 ml beaker and add 80 ml DI water. Using a Mettler Titration unit with a pH meter, citric acid (457.2 g/l) is metered into the beaker over 15 minutes, which is constantly stirred with a magnetic stir bar, to maintain a target pH of 4.5. To make sure that the unit is working correctly, a precipitated calcium carbonate (PCC) standard should consume 15 ml (+/- 0.5) of citric acid after 15 minutes. This method does not work well for dolomite and overestimates its reactivity. Each sample was run three times, and the average consumption of citric acid was recorded.

A citric acid reactivity value (R_{CA}) is calculated using the following equation:

$$R_{CA} = 100 \text{ x } V_{CA}/12 \text{ x } C_{CA}/457.17 \text{ x } 5/m_t \text{ x } 56/NV_{AR} \text{ x } (((4\text{-}1)^* \text{ MgO}/21) +1)$$

Where V_{CA}= average citric acid consumption at 15 minutes (ml), C_{CA}= concentration of citric acid (457.2 g/l), m_t= "as-is" (includes moisture) lime product added (g), NV_{AR}= lime neutralizing value “as-is”, and MgO = MgO content of “as-is” product to account for difference in dolomite reactivity. The lime neutralizing value (NV_{AR}) was calculated using the methods given by the European Committee for Standardization (method EN 12945:2014).

3E. RESULTS AND DISCUSSION

Field evaluation of liming products in field trials

Research farm field trial (VF East Farm)

The soil pH response to increasing rates of Ashgrove Ag Lime was linear at each sampling date except at 6 months (data not shown, $R^2 \geq 0.93$; control removed from analysis as research has shown that the pH increase from the addition of the first increment of lime step is higher than additional increments). The lime requirement (LR) of the soil based on the SMP buffer test and table 3 in OSU Extension publication EM9057 is estimated to be 3.4 t/a lime for 1-unit pH change (1 to 3 yrs after addition). Based on the slope of the graph at 1, 3, and 12 months, the LR was estimated to be 5.8, 4.2, and 2.9 t/a lime for 1-unit pH change, respectively. Based on this data, the SMP buffer test LR was adequate for predicating the LR at 1 year after addition.

Table 6. Soil pH for research farm field trial (VF EF). Different letters for each column (sampling date) indicate a statistical difference (LSD 0.05).

Treatment	1 month		3 month		6 month		12 month	
Control	5.7	f	5.7	g	6.1	d	5.9	e
Ashgrove Ag Lime 0.5x	6.2	de	6.4	ef	6.6	ab	6.2	ed
Ashgrove Ag Lime 1x	6.3	cde	6.5	ef	6.6	ab	6.3	dc
Ashgrove Ag Lime 1.5x	6.4	bcde	6.7	bcde	6.5	abc	6.6	bc
Ashgrove Ag Lime 2x	6.4	bcd	6.7	bcde	6.7	ab	6.6	bc
Ashgrove Ag Lime 2.5x	6.6	bc	6.9	abc	6.7	ab	6.9	a
Microna Access 1x	6.1	de	6.6	cdef	6.6	ab	6.6	bc
Microna Access 2x	6.2	cde	7.0	ab	6.8	ab	6.9	ab
Microna Ag H2O 1x	6.7	ab	6.8	abcd	6.7	ab	6.6	bc
Microna Ag H2O 2x	7.0	a	7.1	a	6.9	a	6.9	ab
Ashgrove dolomite 1x	6.0	ef	6.3	f	6.2	dc	6.4	dc
Ashgrove dolomite 2x	6.1	de	6.5	def	6.5	bc	6.7	ab
Pr>F	<0.001		<0.001		0.001		<0.001	
LSD (0.05)	0.4		0.36		0.34		0.31	

Table 7. Exchangeable calcium for research farm field trial (VF EF). Different letters for each column (sampling date) indicate a statistical difference (LSD 0.05).

	1 month		3 month		6 month	12 month	
Treatment	------------------------------ mg/kg ------------------------------						
1-Control	1817	d	1581	b	1726	1521	c
3- Ashgrove 1x	2209	bcd	2006	ab	1975	1778	bc
5- Ashgrove 2x	2619	ab	2395	a	1996	2082	ab
7- Access 1x	2103	cd	1826	b	1893	1852	bc
8- Access 2x	2273	bc	2376	a	2196	2424	a
9- Ag H2O 1x	2180	cd	1791	b	1934	2035	ab
10- Ag H2O 2x	2837	a	2303	a	2223	2092	ab
Pr>F	0.002		0.006		0.417	0.009	
LSD (0.05)	430		450		NS	416	

In the short-term (<3 months), Microna Ag H2O was the most reactive product, obtaining the highest pH and X-Ca (Tables 6 and 7). Microna Ag H2O, which is a solution grade product with a very small particle size (99% smaller than a 325 mesh sieve (44 microns)) and is not an economical product for use in vegetable production. This lime product was added so that we could evaluate effect of particle size on performance. After 6 months, Microna Ag H2O was not more effective than the other calcitic lime products tested.

Although the dolomitic lime had the same or higher Oregon lime score than the other products, it had a lower liming efficiency in the first 6 months compared to the calcitic lime product. This is due to a combination of coarser particle size than the other materials (Table 1) and the presence of $MgCO_3$, which is less soluble than $CaCO_3$ and reacts slower. But at 12 months, dolomite performance was equivalent to the calcitic limes.

For a given application rate, performance of Microna Ag lime was no different than Ashgrove Ag lime (as measured by change in pH or X-Ca) Tables 6, 7, and 8.

Table 8. Lime efficiency for the field trial (Field) and field pot incubation study (Pot). Efficiency is calculated as the change in pH of each treatment compared to the change in pH from the Microna Ag H2O product, which was assumed to be the most reactive due to its small particle size. Letters in each column that are different represent a statistical difference (LSD; p=0.05).

	Field	Pot	Field	Pot	Field	Pot	Field	Pot
Trt	1 month		3 month		6 month		12 month	
Ashgrove Ag Lime 1 t/a	62ab	NA	67bc	NA	82ab	NA	59dc	NA
Microna Access 1 t/a	40b	NA	79abc	NA	81ab	NA	98bc	NA
Ashgrove dolomite 1 t/a	34b	NA	52c	NA	23cd	NA	66dc	NA
Ashgrove Ag Lime 2 t/a	58a	86b	73ab	93a	78ab	98a	68bc	103
Microna Access 2 t/a	41ab	100a	90a	96a	88ab	95a	100ab	109
Ashgrove dolomite 2 t/a	32b	52c	58bc	69b	51cb	80b	81ab	107

On-farm field trial (On-farm)

Changes in soil pH following the application of Ashgrove Ag lime and Microna Ag lime (Access) are given in Fig. 3. No difference in pH between the Microna Ag lime and the Ashgrove Ag lime was observed over the entire 12 months after lime incorporation for the 1x rate. For the 2x rate, the Microna Ag lime was slightly higher than Ashgrove at 6 months, but lower at 12 months. However, absolute difference between these treatments were slight (≤0.2 pH units).

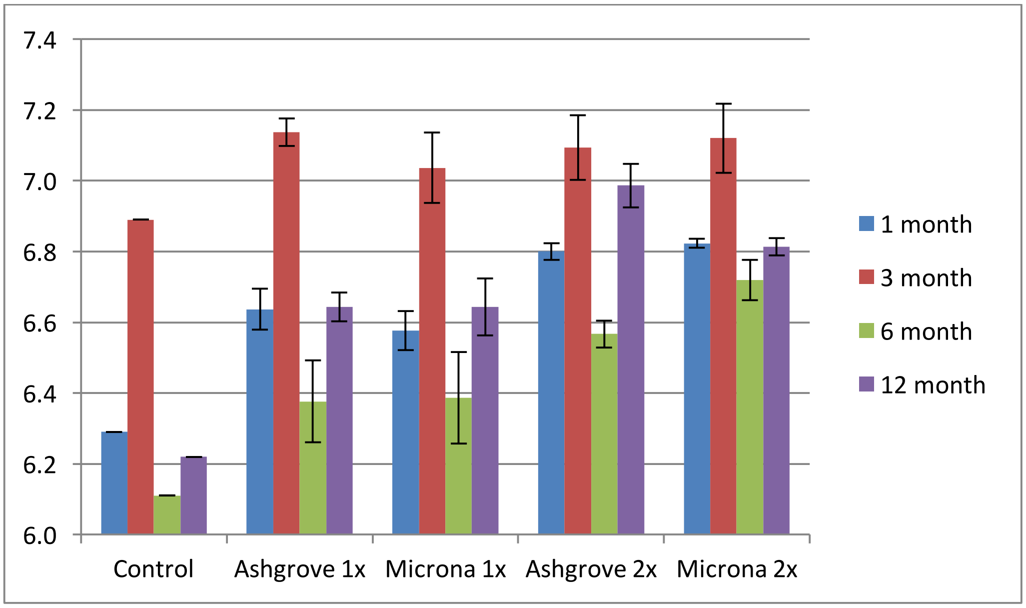

Figure 3. Soil pH (0-6") at on-farm trial for Ag lime products; 1x= 1.4 ton/acre and 2x= 2.8 ton/acre. Error bars represent the SE (n=3).

Efficacy of liming products and discrete lime particle size fractions under field temperature and moisture conditions

The pH and X-Ca for each in-field pot incubation treatment is given in Tables 9 and 10. Compared to the field study 2x rate (2 ton/acre, which is what was applied in the incubation pot study), the pH was much higher in the pot study. For example, at 3 months the pH of Ashgrove Ag lime was 6.7 in the field vs. 7.4 in the pot. Degree of mixing may explain this difference. In the pots we used sieved soil and thoroughly mixed the lime, which increased the contact between the soil and the lime. When the pots where sampled, there was no visible lime (for the powered lime products only) whereas in the field some samples had visible unreacted lime at 3-m. For the particle size fractions >100 mesh, individual lime particles were visible at 3-m. Also, in the field there were larger soil aggregates/clods, which likely created sites of lower pH inside the clods that the lime could not affect. When sampled, these lower pH sites may have caused the overall pH to be lower.

In this study, both Microna products were more reactive than Ashgrove Ag Lime at 1 month (Tables 8, 9, and 10). But from 3 months on, there were no differences.

Table 9. Soil pH for research farm in-field incubation study

Treatment	1 month		3 month		6 month		12 month	
Control	6.0	f	5.7	f	6.3	g	5.8	c
10-20 mesh	6.2	e	5.9	e	6.6	f	6.5	b
20-40 mesh	6.2	e	6.1	e	6.9	e	7.1	a
40-60 mesh	6.2	e	6.4	d	7.2	d	7.1	a
60-100 mesh	6.5	d	6.9	c	7.5	bc	7.1	a
100-200 mesh	6.8	c	7.0	c	7.6	abc	7.2	a
Microna Ag lime	7.6	a	7.4	ab	7.7	ab	7.2	a
Microna Ag H2O	7.6	a	7.5	a	7.7	a	7.1	a
Ashgrove Ag lime	7.4	b	7.4	ab	7.7	ab	7.1	a
Ashgrove dolomite	6.8	c	6.9	c	7.5	c	7.2	a
Ashgrove Flour lime	7.3	b	7.3	b	7.7	ab	7.2	a
Pr>F	<0.001		<0.001		0.001		<0.001	
LSD (0.05)	0.35		0.36		0.34		0.31	

The liming efficiency of each particle size fraction over the study is given in Table 11. Results from 2 liming studies are given in Tables 12 and 13 for comparison. Although the size fractions are slightly different in the Scott et al. (1992) study, the results at 6 months are similar for the coarse fraction, but lower for the fine fraction. For the Motto and Melsted (1960) study, they used the similar size fractions, but used <100 mesh as the reference. Despite this, their lime efficiency is similar to ours at 6 months. However, at 1-yr, the efficiency of the size fractions is much higher than their study.

Oregon uses a lime score to estimate the acid neutralizing potential of a liming material, which is used to determine a liming material's application rate. This score takes into consideration the efficiency (i.e., reactivity) of various particle size fractions within 1 to 3 years after addition to soil and is called the *fineness factor* (ff). The ff calculation estimates the reactivity (efficiency) of the following particle size fractions ~1 yr after addition- 10-20 mesh 30%, 20-40 mesh 60%, and <40 mesh 100%. Based on the data in Table 11, OSU's fineness factor underestimated reactivity for coarse particle fractions 10-40 mesh at 1 year after application. However, this is not very important because most commercial flourlime products have few particles >60 mesh (Table 2).

Table 10. Exchangeable calcium (X-Ca) for research farm in-field incubation study. Different letters for each column (sampling date) indicate a statistical difference (LSD 0.05).

Treatment	1 month		3 month		6 month	12 month	
	------------------------ mg/kg ------------------------						
Control	2379	f	2296	c	2454	2357	c
10-20 mesh	2573	ef	2320	c	2112	2869	b
20-40 mesh	2562	ef	2438	c	2620	2851	b
40-60 mesh	2641	ed	2558	c	2892	3301	ab
60-100 mesh	2845	cd	2874	a	2575	3153	ab
100-200 mesh	2945	bc	2898	a	2685	2929	b
Microna Ag lime	3464	a	2782	ab	2945	3507	a
Microna Ag H2O	3179	b	3082	a	2795	3209	ab
Ashgrove Ag Lime	3087	bc	2959	a	2620	3484	a
Pr>F	<0.001		<0.001		0.086	0.001	
LSD (0.05)	248		311		NS	484	

Table 11. Percentage efficiency of particle size in increasing soil pH, relative to the finest particle size fraction from the research farm pot incubation study. The <200 mesh fraction is the Microna Ag H2O product.

Months after application	US mesh particle size fractionation					
	10-20	20-40	40-60	60-100	100-200	<200
	% efficiency compared to <200 mesh					
3	14	24	38	65	71	100
6	22	39	66	84	89	100
12	48	92	93	95	100	100

Table 12. Percentage efficiency of particle size in increasing soil pH, relative to the finest particle size taken at 6 months from a field trial in Australia (adapted from Scott et al., 1992).

Months after application	US mesh particle size fractionation					
	4-8	16-30	30-60	60-100	100-200	<200
	% efficiency compared to <200 mesh					
6	13	41	53	61	64	100

Table 13. Percentage efficiency of particle size in increasing soil pH, relative to the finest particle size taken at 20 weeks from a greenhouse incubation study (adapted from Motto and Melsted, 1960). The efficiency given is the average of 3 different soils.

Months after application	US mesh particle size fractionation				
	10-28	28-40	40-60	60-100	<100
	% efficiency compared to <100 mesh				
5	15	39	55	76	100
12	16	41	58	78	100

Our results contradict those from Scott et al. (1992) which found no plateau of lime particle size effectiveness. In our study, the particles <20 mesh were as effective as the <200 mesh fraction (which is the Microna Ag H20 product with 99% of particles <325 mesh and in this study is considered to be 100% effective) at 12 months (Figs. 4 and 5). Based on research from the 1950's through the 70's, most states have guidelines that assume particle size fractions <60 mesh (<100 mesh for several states) are 100% reactive 1 to 4 years after application. Although this study is using one soil, our results support these guidelines.

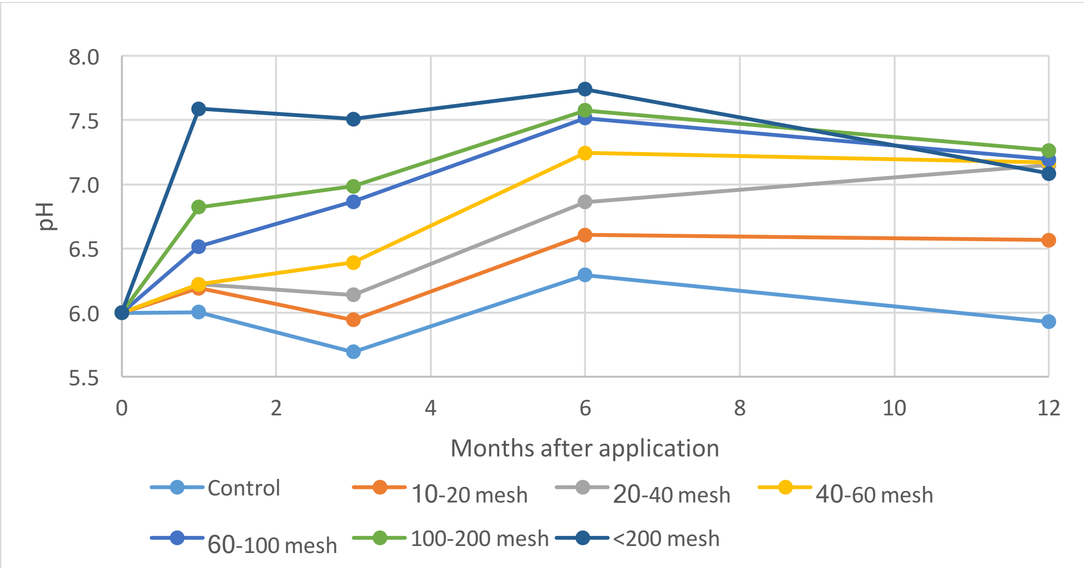

Figure 4. Soil pH from in field pot incubation study after incorporation of lime particle size fractions at a rate of 2 ton/acre calcium carbonate equivalence (CCE). The fraction <200 mesh is the Microna Ag H2O product with a mesh size of 99% passing a 325 mesh (44 microns).

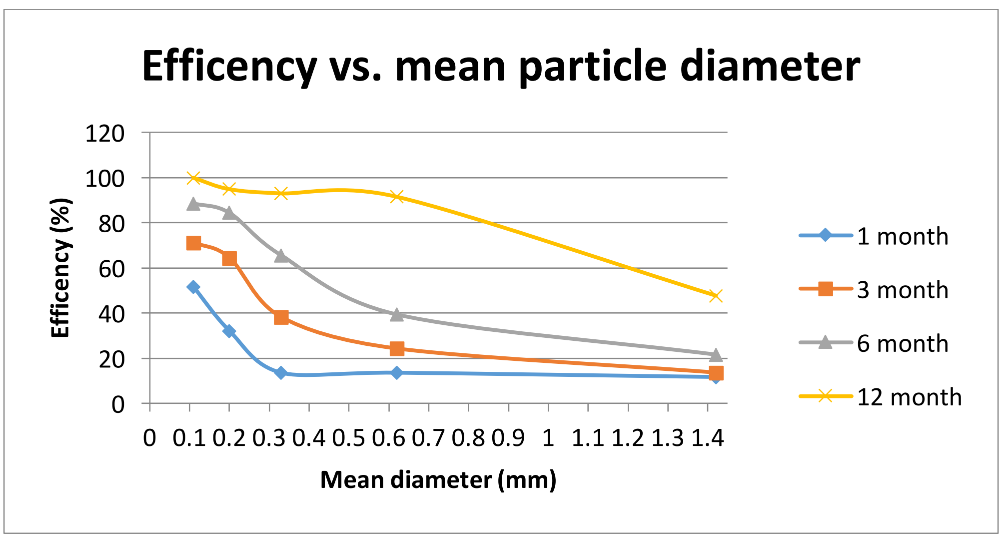

Figure 5. Influence of mean particle diameter on efficiency of lime particle size fractions applied at a rate of 2 ton/acre calcium carbonate equivalence (CCE). Efficiency is relative to Microna Ag H2O, which is assumed to be 100% efficient due to its small particle size.

Laboratory evaluation of short-term lime reaction with soil acidity (via CO2 evolution measurement)

The pattern of CO2-C evolution as a percentage of added carbonate (CO3) is given in Figs. 6, 7, and 8. The calcitic lime products (Ashgrove Ag lime and Microna products) reacted rapidly following addition to soil, releasing from 20 up to 54% of added carbonates in 1 day. At the end of 31 days, the rate of CO2-C evolution from the calcitic lime products had significantly slowed and was only slightly greater than the control.

Although the Microna Ag H2O's particles were very small, only 56 to 85% of the added lime reacted compared to 74 to 89% from reagent grade CaCO3 (Table 11). However, there was either no difference or slight difference in soil pH between these treatments.

Less lime reacted for the particle size fractions 60-100 mesh and 100-200 mesh compared to the calcitic lime products, however, their rate of reaction at 31-d was higher than the lime products (steeper slope of line), indicating that they will continue to react for a longer time than the flour limes.

The Microna Ag lime released 22, 7, and 18% more CO2-C than the Ashgrove Ag lime for soil A18, EF, and on-farm, respectively (Table 11). However, based on the change in soil pH measured at the end of the incubation, the Microna Ag lime was 31, 34, and 42% more effective than the Ashgrove Ag lime for soil A18, EF, and on-farm, respectively (see methods for explanation of how lime efficiency was calculated, for the lab incubation the reagent grade CaCO3 was assumed to be 100% efficient).

Table 11. Percent of added carbonate (CO3-C) evolved as CO2-C and pH following a 31 day laboratory incubation.

Treatment	A18		EF		On-farm		A18		EF		On-farm	
	----- % of added CO3-C -----						------------- pH -------------					
Control	NA		NA		NA		6.0	e	5.7	h	6.3	i
10-20 mesh	5.9	g	0.0	h	7.1	g	6.1	e	5.7	gh	6.4	h
20-40 mesh	11.3	g	3.0	h	6.1	g	6.1	e	5.8	g	6.4	h
40-60 mesh	24.9	f	11.2	g	14.4	f	6.4	d	6.0	f	6.6	g
60-100 mesh	34.0	e	31.7	f	26.0	e	6.6	c	6.4	e	6.8	ef
100-200 mesh	43.1	d	43.0	e	32.0	d	6.7	cb	6.8	d	6.9	de
Ahsgrove Dolomite	49.4	d	53.1	d	31.4	d	6.6	c	6.6	e	6.7	f
Ashgrove Ag lime	**63.1**	**c**	**73.8**	**c**	**47.5**	**c**	**6.9**	**b**	**6.6**	**c**	**6.9**	**d**
Microna Ag lime	**76.8**	**b**	**78.7**	**cb**	**56.3**	**b**	**7.2**	**a**	**7.0**	**b**	**7.2**	**c**
Microna Ag H2O	84.5	a	79.8	b	55.7	b	7.3	a	7.2	a	7.3	b
CaCO3	88.5	a	85.5	a	74.0	a	7.3	a	7.2	ab	7.4	a
Pr>F	<0.001		<0.001		<0.001		<0.001		<0.001		<0.001	
LSD (0.05)	2.9		5.4		5.3		0.21		0.12		0.09	

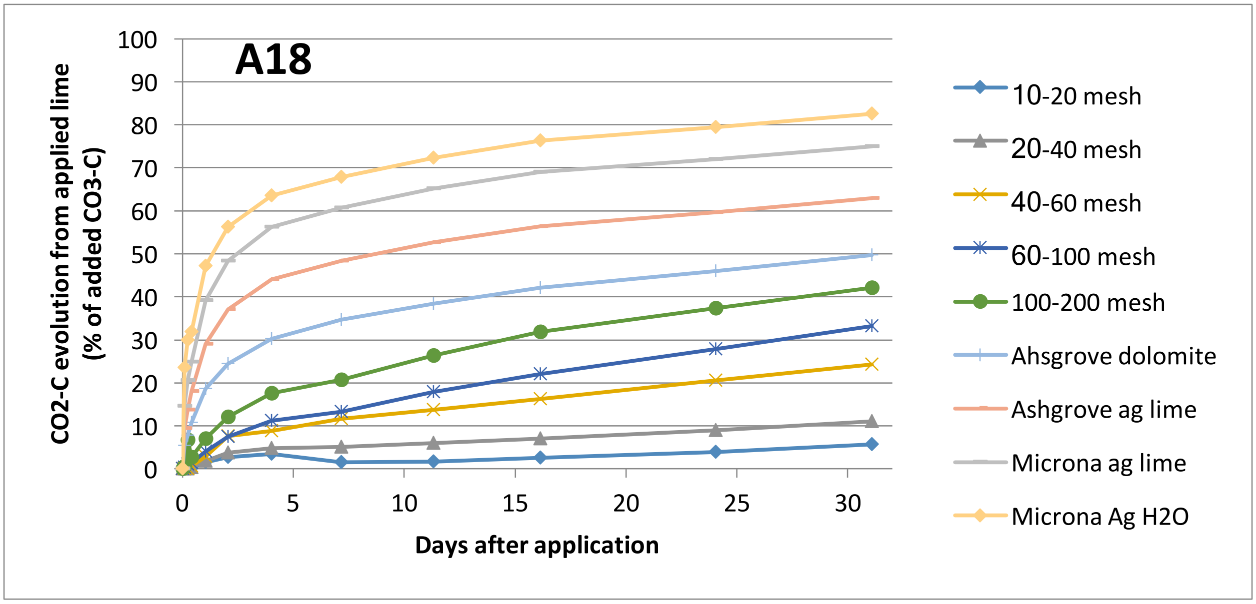

Figure 6. Percent of added carbonate (CO3-C) evolved as CO2-C during a 31 day laboratory incubation using soil from A18. Each value is the average of 3 replicates from which the soil-only control has been subtracted.

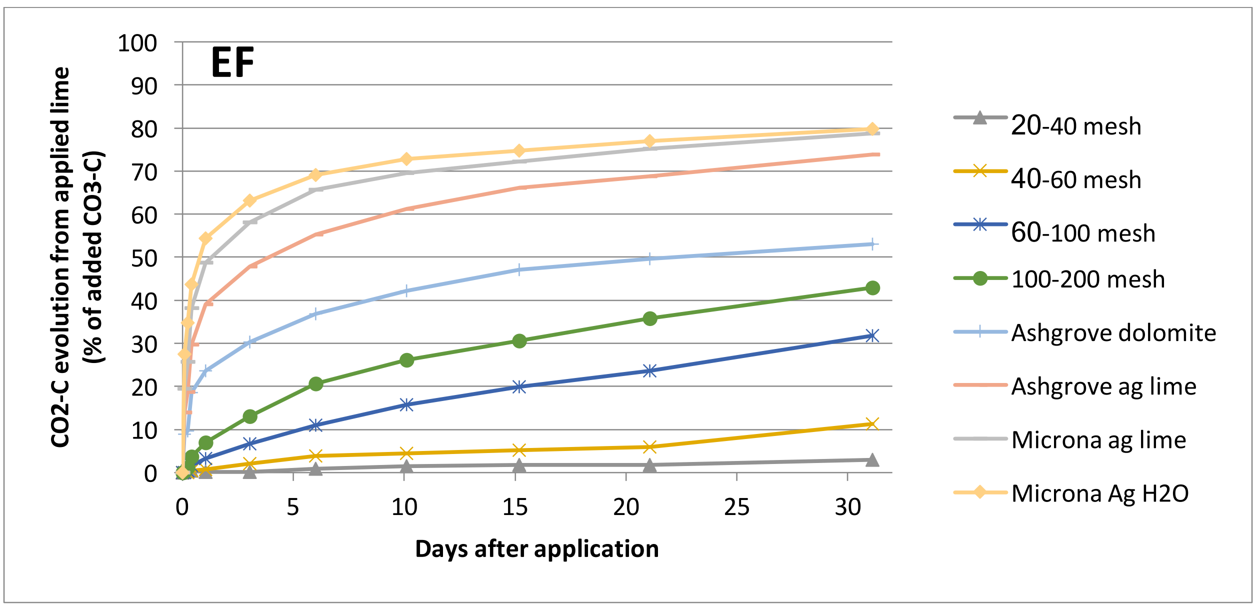

Figure 7. Percent of added carbonate (CO3-C) evolved as CO2-C during a 31 day laboratory incubation using soil from EF. Each value is the average of 3 replicates from which the soil-only control has been subtracted.

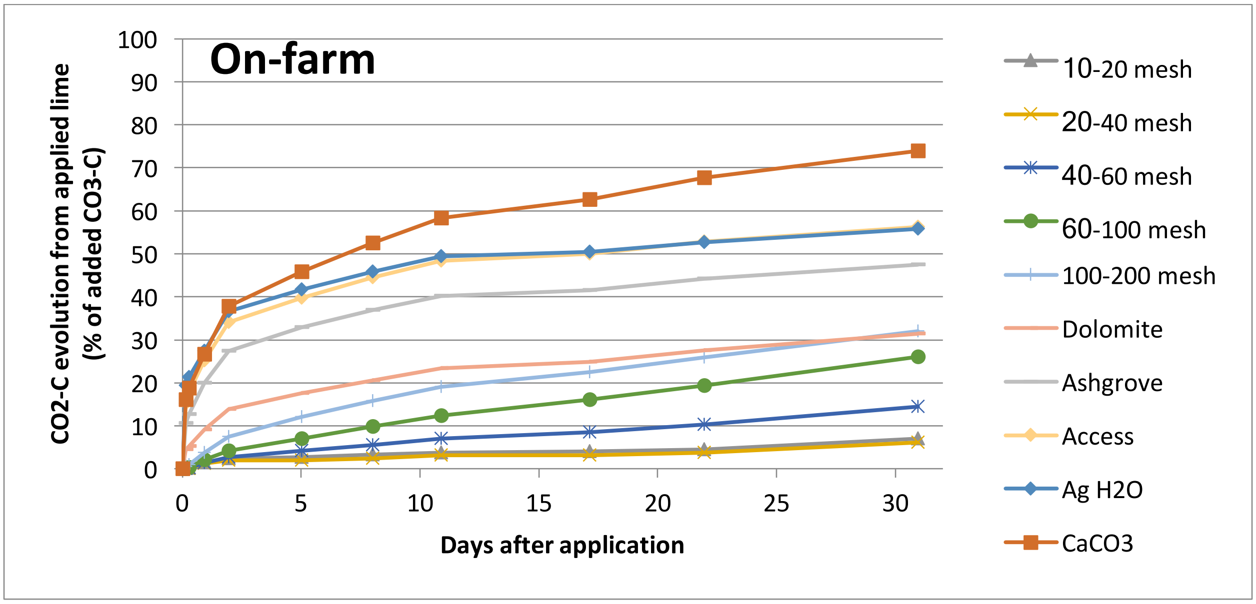

Figure 8. Percent of added carbonate (CO3-C) evolved as CO2-C during a 31 day laboratory incubation using soil from On-farm. Each value is the average of 3 replicates from which the soil-only control has been subtracted.

Assessing lime reactivity using a citric acid reactivity test

Figure 9 shows the relationship between reactivity as measured by a citric acid reactivity test (R_{CA}) and lime efficiency (compared to reagent grade CaCO3) at the end of the 31-d laboratory incubation. The relationship appears to be logarithmic. Figure 10 shows the relationship between R_{CA} and efficiency for the field incubation over 12 months. During the first 6 months, the relationship is similar to that measured in the lab incubation. However, by 12 months, a lime with an R_{CA} value of 13 or greater could be considered to be 100% effective. At this time, there is no compelling reason to change methods for assessing reactivity using a fineness factor (ff, which is currently used) due to the increased cost of this method as well as the need for extensive field validation.

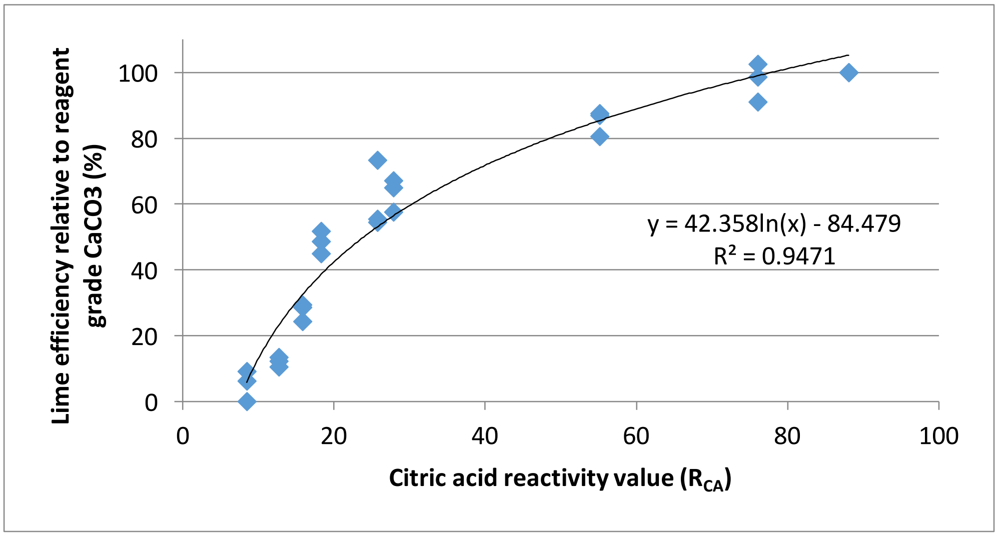

Figure 9. Relationship between citric acid reactivity value (R_{CA}) and lime efficiency relative to reagent grade CaCO3 in a 31-d laboratory incubation. Each point represents the average of 3 reps and the data-set is from 3 different soils.

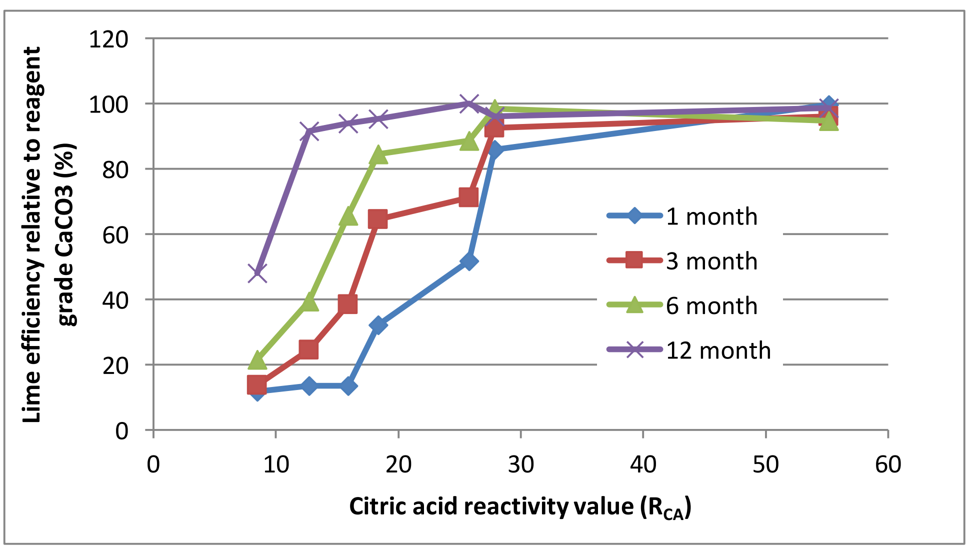

Figure 10. Relationship between citric acid reactivity value (R_{CA}) and lime efficiency relative to Microna Ag H2O in a 12-m field incubation. Each point represents the average of 4 reps.

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BUDGET HISTORY:

Expenses		Year 1	Year 2
Salary and	Faculty research assistant	6000	700
benefits:	OPE (61.6%)	3960	462
Wage and	Student worker ($11/hr for 80 hrs)	880	880
benefits:	OPE (8%)	141	141
Equipment:		0	0
Supplies:	Commercial lime application	800	0
Travel:	To and from field sites	200	50
Plot fees:	Land rental OSU research farm (0.3A @ $1385/A)	416	416
Other:	Complete soil analysis (7*$20/sample)	140	0
	Exchangeable Ca (140*$5/sample)	700	2500
	Total:	**13,236**	**5,002**