OPVC FINAL PROJECT REPORT: 2015 **PROJECT YEAR:** 2 of 2

Project title: Clubroot (*Plasmodiophora brassicae*) control strategies on brassicas

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Cooperators: Sauvie Island Organics and Gathering Together Farm

Total Project Request
Year 1: $9,618 Year 2: $9,715 Total: $19,333

Executive summary

The goals of this project were to determine 1) if liming controls clubroot, 2) the pH that must be attained to achieve commercially viable levels of control, and 3) how best to lime (materials, timing, incorporation strategies) to achieve that pH.

Research conducted in 2014 showed that liming clubroot infected soils to a pH ≥7.1 is an effective practice for reducing both the incidence and severity of clubroot. Liming does not kill the pathogen but rather prevents disease spores from infecting the plant. In 2015 the research was focused on the relationship between disease incidence and severity when pH <7.1, better understanding when to apply lime, and how to incorporate to maximize pH change.

In 2015 the project further demonstrated that pH 7.1 is the threshold for clubroot management. In the field, there is not a linear relationship between pH and clubroot incidence. Instead, control is achieved when soil pH is >7.1, but not when pH is lower than 7.1.

An important finding of this project is that 'Ashgrove Ag Lime', the aglime that is most widely available in the Willamette Valley, is as effective as the more finely ground and expensive product 'Access Lime' produced by Columbia River Carbonates, Woodland, WA.

Another important finding is the importance of good soil incorporation to maximize the value of lime in the short term. Liming followed by a single pass of a rotary hoe reduced clubroot incidence and severity by 41% and 48%, respectively, compared to the control. When the plots received a second tillage pass with a rototiller, incidence and severity were reduced by 86% and 87%, respectively, compared to the control. This reduction was attributed to more complete mixing, which increased the soil pH relative to the single tillage pass, and also to the homogenization of soil pH (i.e., elimination of low pH microsites where infection could occur).

This project has also shown that farmers have some flexibility in the timing of lime application for clubroot control. Liming weeks before planting may not be possible during the spring and summer when farmers are busy and land is tight. For some farmers and crops, fall applications would be advantageous if the higher soil pH could be maintained into the spring and summer. This project showed that fall lime amendments generated a rise in pH that was maintained throughout the following spring, so fall applications had the potential to control clubroot in spring-planted crops. Two additional benefits of fall applications are that 1) there is more time to effectively incorporate the lime and allow the pH to rise, and 2) soil pH can be tested in later winter and additional lime can be applied before a susceptible crop is planted if the fall application did not achieve the target pH.

All of the above research findings highlight the need to implement an integrated clubroot liming strategy that incorporates the 4R's: 1) Right target pH (≥7.1), 2) Right lime rate to reach target, 3) Right timing, and 4) Right incorporation followed by verification by soil pH testing.

The profitability of liming Willamette Valley soils to a target pH of ≥7.1 as a clubroot control strategy will depend on several factors: the degree to which clubroot will reduce yield if no lime were applied, the cost of the lime product used and the lime rate (which depends on the pH

buffering capacity of the soil as influenced by clay content, organic matter, and pH), and the value of the crop. Liming should always be used as one tool in an integrated clubroot management tool box that also includes rotation (4 or 5+ years), soil and irrigation management (to minimize waterlogging), and sanitation (use of clubroot-free transplants and prevention of clubroot movement from field to field).

Background

Clubroot (causal organism, *Plasmodiophora brassicae*) is a major disease of brassica crops in the Willamette Valley. Some processed vegetables growers have told us that once clubroot has shown up in a field, they abandon that field to future brassica production. By doing so, they have less flexibility in their ability to implement long and diversified crop rotations and may have to search for clubroot-free ground off-farm.

Dealing with clubroot is a challenge. Thick-walled resting spores have been shown to remain viable in soil for 10 - 20 years, making it difficult if not impossible to eliminate the pathogen from an infested field. Therefore, once pathogen populations have developed to levels that cause economically damaging clubbing, the goal of the farmer is to manage rather than eradicate clubroot. Control measures include liming to raise the soil pH to >7.0; rotation with non-host crops on a 5-6 yr cycle, which will not eliminate the pathogen from the soil but prevents build-up of very high pathogen populations; irrigation and soil management to reduce the likelihood of soil waterlogging, which promotes infection; chemical controls (such as fumigation) and growing resistant varieties. Unfortunately there are few clubroot resistant broccoli cultivars available, and what is available is not suitable for processing. Syngenta has several resistant cauliflower varieties available in Europe, but the company is currently not interested in supplying the US market.

Of the control measures listed above, soil pH management is considered to be the most practical and effective control measure (Webster and Dixon, 1991; Meyers and Campbell, 1985; Dobson et al. 1983). Liming the soil to a pH of >7.0 has been so effective at controlling clubroot in areas such as the Salinas Valley of California, which is a major producer of brassicas, that the plant pathologist for the region does not work on the disease (Steve Koike, UC Cooperative Extension plant pathologist, personal communication). Liming does not kill the pathogen but reduces spore germination, thus reducing infection and clubbing (Dixon, 2009). By reducing clubbing, fewer spores are released back into the soil, helping to reduce future infection rates and severity.

Why is clubroot a problem if liming is effective and California farmers have successfully implemented pH management? To answer this question, in 2012 we surveyed a group of 37 conventional and organic fresh market and processing vegetable farmers (who grow significant quantities of cabbage family crops) in western Oregon about the importance of clubroot and their experiences with pH manipulation. Eighty three percent had used lime in an attempt to control clubroot, yet only 21% of those that had used lime aimed for a pH of at least 6.8 (the minimum pH shown to control the disease). And of those that had used lime, 38% never followed up to determine if the target pH was reached. These survey results suggest that there is a general acknowledgement that pH manipulation can control clubroot, but that there is a need for step-by-step recommendations on how to successfully increase pH to >7.0 during the period the crop is most susceptible to clubroot infection.

In 2014 we showed that liming soil to pH ≥7.1 almost completely eliminated clubroot in the greenhouse, but in the field, clubroot incidence and severity were reduced but not eliminated. This is likely due to the degree of homogeneity of pH in the soil. In the greenhouse lime was thoroughly mixed in sieved soil, resulting in a homogenous pH. But in the field where the soil particle size is non-uniform (i.e., soil clods of various sizes) and lime is not completely mixed, soil pH is heterogeneous. As a result infection can occur at lower pH microsites even though the bulk soil pH is >7.0. Work in western Washington in the early ‘80’s showed the relationship between lime and degree of mixing on clubroot infection and severity (Dobson et al., 1983).

Objectives

1. **Evaluate the impact of minimal versus thorough lime incorporation on clubroot incidence and severity.**
   In 2014 we showed that liming to pH ≥7.1 or above completely eliminated clubroot under greenhouse conditions and but did not completely suppress clubroot under field conditions. This discrepancy was likely due to non-uniform mixing of lime under field conditions. In 2015, we added an additional tillage treatment to determine if incorporating the lime earlier and thoroughly improves the efficacy of a lime application.
2. **Evaluate the longer term impact on pH of high rate lime applications**
   In 2014 we showed that high rate lime applications immediately before planting could raise pH sufficiently to reduce clubroot incidence to economically viable levels. However, in some cases the pH did not rise to >7.1 by the time of planting, and then rose above 7.1 over the next few months. For effective clubroot management through liming, farmers need to know how long it takes for pH to rise to 7.1 or greater after an application, and for how long pH then remains at that level. In the bigger picture, they need to understand how to most efficiently and inexpensively lime a field within the context of a rotational system so peak pH coincides with brassica planting. For example, can a field be limed in the fall to generate a soil of pH 7.1 or greater in the spring so a clubroot susceptible crop can be planted in the spring?
3. **Develop outreach materials on liming and other clubroot management strategies.**
   Information gained from the 2 years of this study will be incorporated into a clubroot extension publication (estimated publication date early 2017). This publication will include information on liming rates, application timing, sources, and incorporation practices, as well as other management practices including sanitation and resistant varieties.

Significant findings

Tillage and clubroot control

- When 4.4 ton/acre of lime was applied to a soil with a pH of 6.8, the pH increased to 7.1 when it was incorporated with a single pass of a rotary hoe, but when the rotary hoe was followed by an additional pass with a rototiller, the pH increased to 7.5.
- Liming followed by a single pass of a rotary hoe reduced disease incidence and severity by **41% and 48%**, respectively, compared to the control. When the plots received a second tillage pass with a rototiller, disease incidence and severity were reduced by **86% and 87%,** respectively, compared to the control.
- Increased tillage resulted in a higher pH and a more homogenous pH in the soil, reducing the number of microsites of pH <7.1 where infection could occur.

Clubroot control when pH <7.1

- When pH was <7.1, liming did not reduce disease incidence or severity. **This indicates that there is a threshold pH (~7.1), below which liming provides no control.**

Timing of lime application

- When 4 ton/acre of lime was fall-applied in mid-August to 6 fields of pH ranging from 6.3-7.0, the pH in the spring (200 days after incorporation of the lime) was ~7.4 in all fields. **This**

indicates that if the appropriate quantity of lime is applied, a fall application can maintain a high pH through an Oregon winter and spring, and therefore could be used to control clubroot in spring-planted crops.

- Fall lime applications give farmers more flexibility in timing; farmers may be too busy in the spring/summer to apply lime shortly before brassica planting. Fall applications also give farmers more time/opportunities to incorporate the lime thoroughly. In addition, fall applications would permit farmers to test soil pH in late winter and apply additional lime before a spring planting if the fall lime application didn't raise soil pH to above 7.1.

Methods

Liming material characteristics

Ashgrove Limestone Flour was used in all 2015 field studies. It had the following characteristics: CCE of 98% (CCE= calcium carbonate equivalent defined as the acid-neutralizing capacity of a liming material expressed as a weight percentage (%) of pure CaCO3), Oregon limescore of 98, 97% CaCO3, and 91% passing a US #100 mesh screen.

Field soil characteristics

Soil characteristics from field experimental sites are described in Table 1.

Table 1. Properties of soils used in 2015 field experiments

Site	Soil series/ texture	pH	SMP buffer pH	CEC	Bray 1P	K
				meq/100g	----- ppm -----	
1- SAV	Burlington fine sandy loam	6.1	6.4	15	133	238
2- GTF	Chehalem silty clay loam	6.8	6.6	30[1]	71	358

1- estimated by summation

Clubroot rating scale

Root disease severity was evaluated based on this rating scale: 0= no visible clubbing, 1= small clubs on lateral roots, 2= <50% of main root system clubbed, and 3= >50% of main root system clubbed. Disease severity was calculated as:

$$\frac{(R1 * 2 + R2 * 3 + R3 * 5)}{5}$$

Where R1, R2, and R3 are the % of plants evaluated with a rating of 1, 2, and 3, respectively (Dixon and Robinson, 1986). Analysis of variance was used to evaluate differences amongst treatments, and the LSD test was used to assess the significance of treatment differences.

Field trial locations and management

The following field sites were selected because they had a recent history of severe clubroot. We were unable to locate any processed vegetable fields that met these criteria.

Field trial 1- Sauvie Island Organics (Sauvie)
A trial was conducted at Sauvie Island Organics located on Sauvie Island outside of Portland on a soil mapped as a Burlington fine sandy loam. Soil characteristics are given in Table 1. The experiment consisted of 3 treatments: Control (no lime), Lime 1x (2.7 ton/acre), Lime 2x (5.4 ton/acre) replicated 3 times in a randomized complete block design. The lime was applied by hand on March 26 and incorporated to a depth of ~8" on April 6 with a spader. Eighteen days after incorporation, the cabbage variety 'Farao' was transplanted with a plant spacing of 8". The field was irrigated with overhead sprinklers. On July 15 (100 DAI), cabbage head yield and root disease severity were evaluated. Soil was sampled 18 and 100 DAI to a depth of 6", air dried, and analyzed for pH (1:2 water).

Field trial 2- Gathering Together Farm (GTF)
A field trial was conducted at Gathering Together Farm (GTF) located outside of Philomath on a soil mapped as a Chehalem silty clay loam. Soil characteristics are given in Table 1. The trial consisted of the following treatments: 1) No lime 1x tillage, 2) Lime 1x tillage, 3) No lime 2x tillage, and 4) Lime 2x tillage. On July 29, 4.4 ton/acre of Ashgrove Limestone Flour lime was hand applied followed by incorporation with a rotary hoe (1x tillage). The rotary hoe was lifted between plots to prevent movement of soil between plots. Following the rotary hoe, a rototiller made a pass in select plots (2x tillage). Kale ('Lacinato') was transplanted on August 11 (12 DAI) on 1 ft spacing. The field was irrigated with overhead sprinklers. On October 22 (85 DAI), aboveground biomass and root disease severity was evaluated. Soil was sampled at 12 and 85 DAI to a depth of 6", air dried, and analyzed for pH (1:2 water).

<u>Liming dynamics over a year</u>
In August of 2014, GTF embarked on an aggressive liming program. They applied 4.0 tons/acre of Microna Ag lime (sold under the name "Access" lime) to 6 fields using a drop spreader followed by incorporation with a disc and/or rotary hoe. Although the lime was applied to spatially diverse fields, the soil textures were either silty loam or silty clay loam. Soil samples were taken from a 6" depth from each field on different dates over the course of 400 days.

Results and Discussion

Field trial 1- Sauvie Island Organics (Sauvie)
The goal at Sauvie was to raise the pH to ~6.8 and >7.0 with the 1x and 2x lime rates, respectively, to determine if disease severity decreased as pH increased. However, the target pH was not obtained (Fig. 1) as too little lime was applied and it was incorporated to a deeper depth than anticipated. The lime rate was based on a 6" incorporation depth, but the lime was incorporated to 8". Also, the lime was not thoroughly incorporated, as 100 days after application, visible unreacted lime was present in soil samples. The pH of the control soils ranged from 6.1 to 6.3 during crop development, compared to an increase from 6.1 to 6.75 during crop develpment in the limed soils. At planting, soil pH in the limed treatments was 6.3, well below the pH required to suppress clubroot infection. In all treatments, clubroot incidence was 100%, and there was no difference between treatments in clubroot severity. Therefore, raising the pH from 6.1 to 6.3 (at planting) and 6.7 (by harvest) did not have any effect on clubroot incidence or severity.

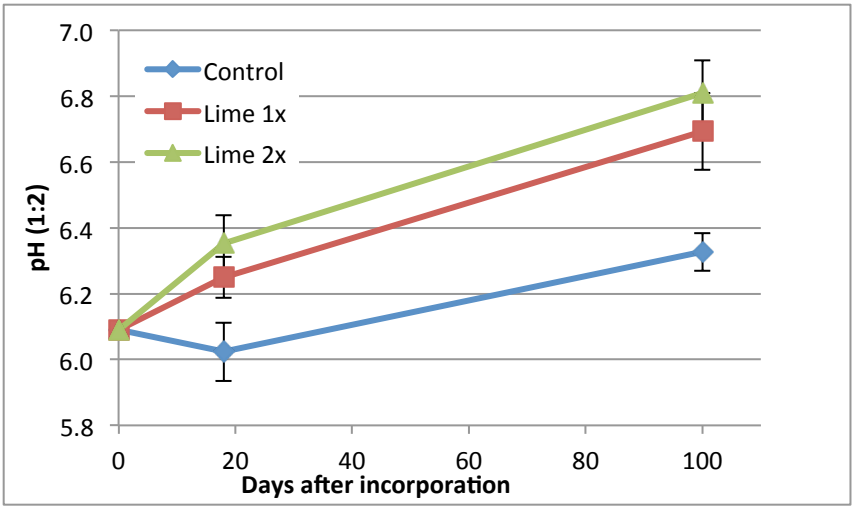

Figure 1. pH (0-6") following incorporation of 2.7 (1x) and 5.4 (2x) ton/acre of lime in the Sauvie experiment. Plants were transplanted on the second sampling date 18 days after incorporation. There was no difference in disease incidence and severity between the control and the lime treatments. Unreacted lime was present in the soil on the last sampling date. Error bars represent the standard error (n=3).

The crop rotation history for the field where the clubroot trial was conducted is provided in Table 2. Brassicas were grown (to some degree) every other year from 2009 until a clubroot-induced crop failure in 2013. The farmer did not notice any damage due to clubroot until the crop failure in 2013. Rotation and disease history data from other Willamette Valley farms suggest that a rotation of at least 4 or 5 years is necessary to keep pathogen populations below an economically damaging threshold.

Table 2. Crop rotation history for Sauvie field experiment. Brassica crops are bolded and italicized.

Year	Crop
2015	***clubroot trial (brassicas)***
2014	potatoes
2013	***spring broccoli (crop failure)***
2012	herbs, fennel, carrots
2011	***salad mix (including leafy brassicas)***
2010	alliums
2009	***spring broccoli***
2008	potatoes
2007	favas, solanums, fallow
2006	peas, cucurbits
2005	***peas, brassicas west half***
2004	***brassica east half***
2003	cover crop

Field trial 2- Gathering Together Farm (GTF)

The change in soil pH following the addition and incorporation of lime is given in Fig. 2. Tillage had no effect on the no lime treatments (pH 6.8), but the 2x tillage treatment increased the pH by 0.2 - 0.3 units on the two sampling dates compared to the 1x treatment. At 12 days after

incorporation (planting), the pH in the 1x treatment was 7.1 and the 2x treatment was 7.3. At 91 days after incorporation (harvest), the pH in the 1x treatment was 7.4 and in the 2x treatment, 7.7. The higher pH in the 2x tillage treatment is due to the action of the rototiller, which breaks up soil clods and more thoroughly mixes the lime into the soil (Fig. 3). As the result, the lime reacts with a greater proportion of the soil particles, generating fewer soil microsites of pH < 7.1 (Fig. 2).

Liming reduced disease incidence in both tillage treatments, but reduced severity only in the 2x tillage (Table 3 and Fig 4.). The no lime 2x tillage treatment reduced both incidence and severity compared to the no lime 1x tillage treatment. Because rototilling did not increase the pH, it may have changed the soil physical conditions, and that change resulted in a decrease in incidence. The difference between the tillage treatments for the limed plots is likely due to a more homogeneous soil pH with fewer microsites of lower pH. Dobson et al. (1983) showed that soil limed to the same bulk pH but with different degrees of lime mixing affected disease incidence and severity. In the less thoroughly mixed soil, they attributed a higher disease incidence to low pH microsites where spore germination was not inhibited.

Table 3. Clubroot disease incidence and severity in the GTF liming and tillage trial. Numbers followed by the same letter are not statistically different (LSD p=0.05).

Treatment	Disease incidence (%)	Disease severity
No lime 1x tillage	59a	39a
Lime 1x tillage	35b	20b
No lime 2x tillage	33b	22b
Lime 2x tillage	8c	5b

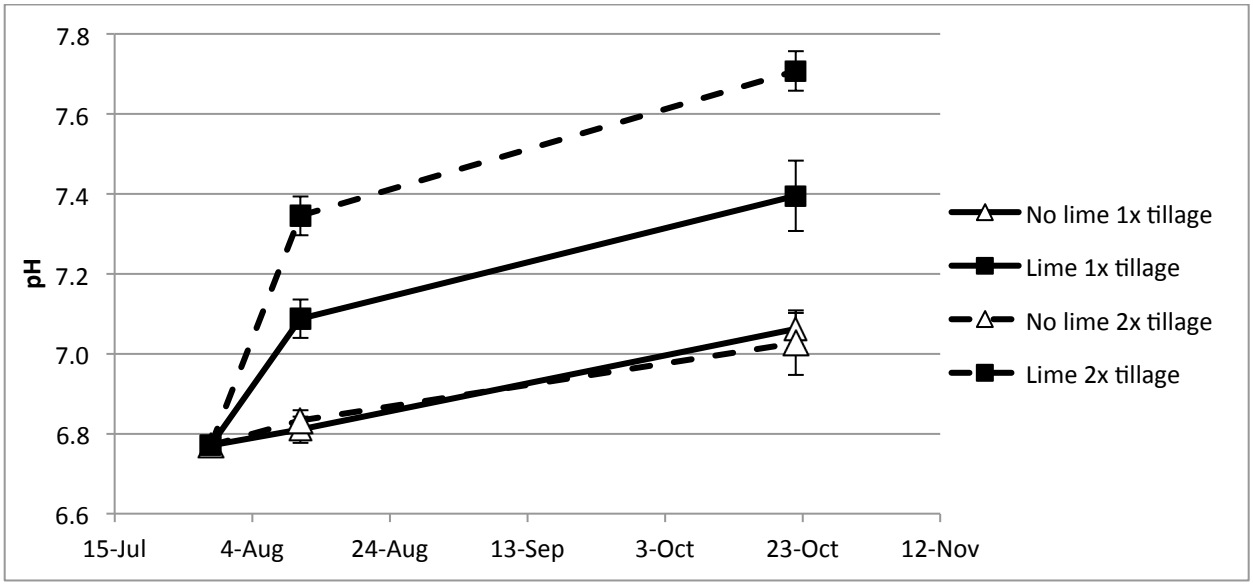

Figure 2. pH (0-6") following a lime application of 4.4 ton/acre and incorporation with a rotary hoe (1x tillage) or a rotary hoe followed by a rototiller (2x tillage) in the Gathering Together Farm experiment. Plants were transplanted on the first sampling date 12 days after incorporation. Error bars represent the standard error (n=4).

Figure 3. Incorporation of 4.4 ton/acre with a rotary hoe (left; 1x tillage) and a rotary hoe followed by a rototiller (right; 2x tillage) in the Gathering Together Farm experiment. The additional rototilling generated a finer seed bed, more thorough mixing of lime, a higher pH, and lower disease incidence and severity.

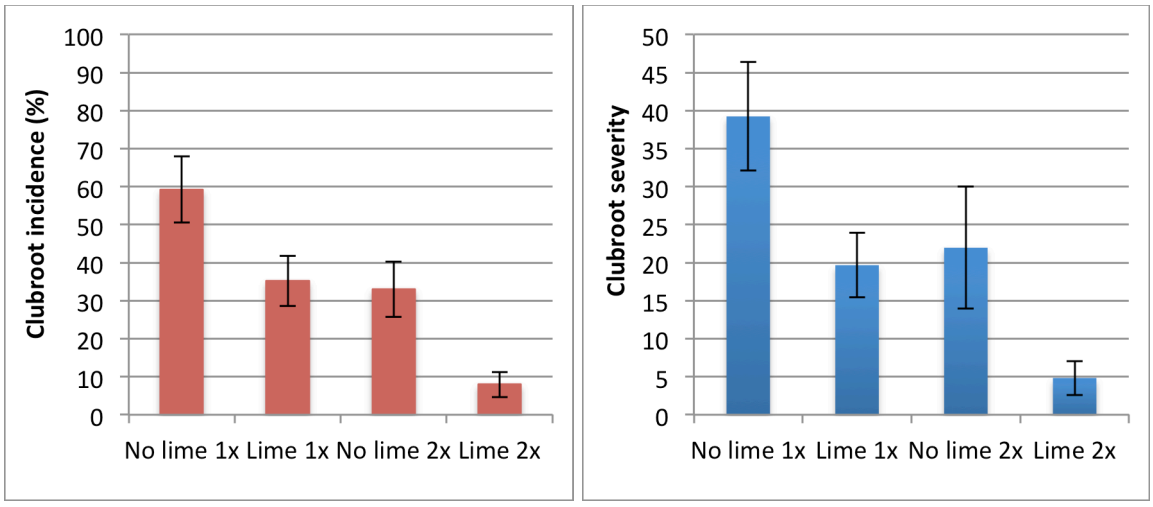

Figure 4. Clubroot incidence and severity in the GTF liming and tillage trial. Error bars represent the standard error (n=4, 30 plants evaluated per plot)

Liming dynamics over a year

The change in pH over approximately 400 days in 5 fields following application of 4 ton/acre of Microna Ag lime in August is given in Fig. 5. Site 4 was removed as we were unsure if we were sampling in the correct location. In all fields, the highest pH reached was ~7.4, and most fields achieved this pH within approximately 90 days after incorporation. For all sites, the average difference between the starting pH and the maximum pH measured was 0.7 units (range 0.4 to 1.1). After 1 year, the average pH was 0.5 units higher (range 0.1 to 1.1) than the starting pH. The data suggests that the pH will be high enough in the spring to control clubroot when fields are limed in the fall. Fall lime applications give farmers more flexibility in timing; farmers may be too busy in the spring/summer to apply lime shortly before brassica planting. Fall applications

also give farmers more time/opportunities to incorporate the lime thoroughly. In addition, fall applications permit farmers to test soil pH in late winter and apply additional lime before a spring planting if the fall lime application didn't raise soil pH to 7.1 or above.

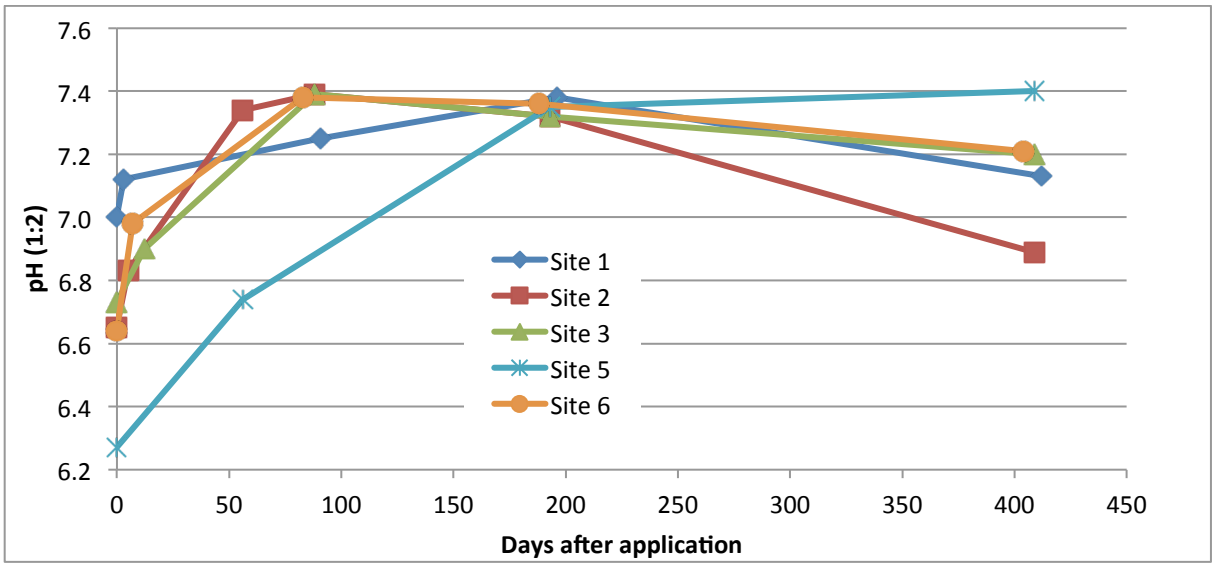

Figure 5. Changes in soil pH (0-6") in 5 fields at Gathering Together Farm following the application and incorporation of 4 tons/acre lime in August 2014.

References

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Budget history

Item	2014	2015
FRA salary @ 0.11 FTE (Aaron Heinrich)	4,307	4,500
OPE (62%)	2,886	2,790
Summer help (40 hrs @ $11/hr)	440	440
OPE (8%)	35	35
Equipment	0	0
Supplies	200	200
Travel	500	500
Plot fees	750	750
Other (lab fees)	500	500
Total	9,618	9,715