TEN YEARS AFTER A SINGLE FIELD APPLICATION OF SPENT LIME: EFFECTS ON SOIL pH, APHANOMYCES ROOT ROT, AND SUGARBEET YIELD AND QUALITY

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Aphanomyces cochlioides (= *A. cochlioides*) is an economic pathogen infesting over 90% of township sections planted to sugarbeet in the Red River Valley (RRV) and many fields in southern Minnesota. The pathogen is favored by warm and wet soil conditions and can cause damping-off, root rot, and chronic root rot of older plants. *Aphanomyces cochlioides* survives in soil for years, even when sugarbeet is not planted. Recommendations for growing sugarbeet in infested fields include early planting of partially resistant varieties treated with the fungicide Tachigaren and implementing cultural practices (e.g. cultivation and improved drainage) to avoid or reduce disease. When inoculum densities of the pathogen are high and soil is wet and warm, however, these measures are inadequate for economic yields - and fields may be abandoned or yield poorly. This chronic disease has generated interest in finding effective, alternative methods to supplement control of *A. cochlioides*.

The sugar purification process results in the by-product "spent lime". Lime (calcium carbonate) precipitates impurities in sugarbeet juice. Purified juice is further processed into crystal sugar, but spent lime (14% less acid neutralizing power than fresh lime) contains impurities and becomes a factory by-product. Seven factories in the RRV and southern Minnesota generate 500,000 tons (dry weight) of spent lime annually and some has been stockpiled for 20 years. Information on uses of sugarbeet spent lime is limited and publications usually are in government and company documents. Most spent lime generated in Europe is applied to land as an amendment to increase soil pH and supply nutrients. In Great Britain, it is marketed and sold to conventional and organic growers as "LimeX".

There is limited information in the literature on use of spent lime to reduce plant diseases. Campbell and Greathead (3) applied spent lime (2 to 4 tons A^{-1}) from a sugarbeet processing factory to fields (pH < 6.8) severely infested with the clubroot pathogen, *Plasmodiophora brassicae*, in the Salinas Valley, California. A single application gave "virtually complete control" of clubroot of crucifer crops grown repeatedly for 2 to 3 years. In other areas of the world, various forms of lime (not spent lime) have been applied for over 200 years to control clubroot of crucifers, but results have been inconsistent and little is known about how various forms of lime affect the pathogen. Sugarbeet growers in southern Minnesota apply spent lime the year before planting sugarbeet (typically every 3 years) and have observed less Aphanomyces root rot. In the RRV, application of spent lime also reduces *Aphanomyces* on sugarbeet (1,2,5-12).

OBJECTIVES

Our objectives were to evaluate a field trial where several rates of spent lime had been applied <u>ten years earlier</u> for: 1) long-term effects on Aphanomyces diseases and 2) sugarbeet yield and quality.

MATERIALS AND METHODS

Establishment of field trials. Trials were established in a grower's field near Breckenridge, MN (pH = 6.3) in April, 2004. At that time, the Breckenridge field plot area had a history of severe Aphanomyces root rot with a soil index value (SIV) of 98 (0 to 100 scale, 0 = no disease, 100 = potential for severe disease).

The site was divided into four, 1-acre experiments. Experiments included four rates of spent lime and a non-limed control in a randomized block design of four replicates (Fig. 1). Spent lime treatments were 0, 5, 10, 15 and 20 tons wet weight A^{-1} (= 0, 2.7, 5.3, 8, and 10.6 tons dry weight, respectively); each plot was 33 x 60 ft. To allow lime treatments to stabilize in 2004, spring wheat was sown. Sugarbeet has been grown in one experiment each year

Experiment 1

5	0	10	20	15
10	5	20	15	0
10	15	20	0	5
0	5	10	15	20

Experiment 2

0	15	20	10	5
20	5	0	10	15
5	10	15	20	0
0	5	10	15	20

Experiment 3

10	15	0	5	20
15	5	20	0	10
20	10	15	0	5
0	5	10	15	20

Experiment 4

15	5	20	0	10
5	0	10	15	20
20	0	15	5	10
0	5	10	15	20

Breckenridge, MN (illustrated above)

Crop sown/yr:	2004	wheat	wheat	wheat	wheat
	2005	**sugarbeet**	wheat	wheat	wheat
	2006	soybean	**sugarbeet**	soybean	soybean
	2007	wheat	wheat	**sugarbeet**	wheat
	2008	corn	corn	corn	**sugarbeet**
	2009	**sugarbeet**	soybean	soybean	soybean
	2010	corn	**sugarbeet**	corn	corn
	2011	soybean	soybean	**sugarbeet**	soybean
	2012	wheat	wheat	wheat	**sugarbeet**
	2013	**sugarbeet**	soybean	soybean	soybean
	2014	corn	**sugarbeet**	soybean	corn

Fig. 1. Four experiments were established at Breckenridge, MN in April 2004. Each experiment was treated with spent lime at 0, 5, 10, 15 and 20 tons wet weight A^{-1}; experiments were arranged in a randomized complete block design with four replications (illustrated above). Sugarbeet plots are noted in **bold** the year when planted in an experiment; in 2014, sugarbeet test trials were planted in Experiment 2.

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from 2005 to 2014; two other experiments were planted with the same crop grown in the field by the grower-cooperator as noted in Fig. 1. Experiment 3 was planted to soybean. Results have been reported from 2004 to 2013 (1,5-12).

2014 Sugarbeet field trial. Two Roundup Ready sugarbeet varieties were sown in Experiment 2 (last planted to sugarbeet in 2010, Fig. 1). This was the third time Experiment 2 had been planted to sugarbeet since the original application of lime. The *Aphanomyces*-susceptible variety had a two-year disease rating of 5.7 (1-9 scale) and seed was not treated with Tachigaren; the partially resistant variety had a two-year rating of 3.2 and was treated with 45 g Tachigaren per unit. Approval as an Aphanomyces specialty variety requires a 2-year rating of <= 4.4 (4). Varieties were sown as subplots in limed and non-limed control plots on May 22. Seed was sown every 4.7 inches in rows 60-feet long and 22-inches apart (six rows of each variety centered within plots). Twenty-foot alleys were cut later leaving 40-ft plots. Experiments followed standard fertility and production practices to obtain maximum sucrose yield and quality.

Stand counts were made 5 and 7 weeks after planting. Sugarbeet roots were harvested September 22 (two middle rows per subplot). Twenty roots per subplot were rated for Aphanomyces root rot (0 to 7 scale, 0=healthy and 7=root completely rotted and foliage dead). Ten roots were randomly selected and analyzed for yield and sucrose quality by the American Crystal Sugar Company Quality Laboratory, East Grand Forks, MN.

***2*014 Soil pH and Aphanomyces soil index values (SIVs).** Soil samples were collected from plots in June. Five samples (6-inch depth) were collected randomly across each plot, combined, screened through 0.25-inch hardware cloth, and assayed (within 1 month after collection). Subsamples were sent to Agvise Laboratories, Northwood, ND for pH, calcium, and other nutrient level determination.

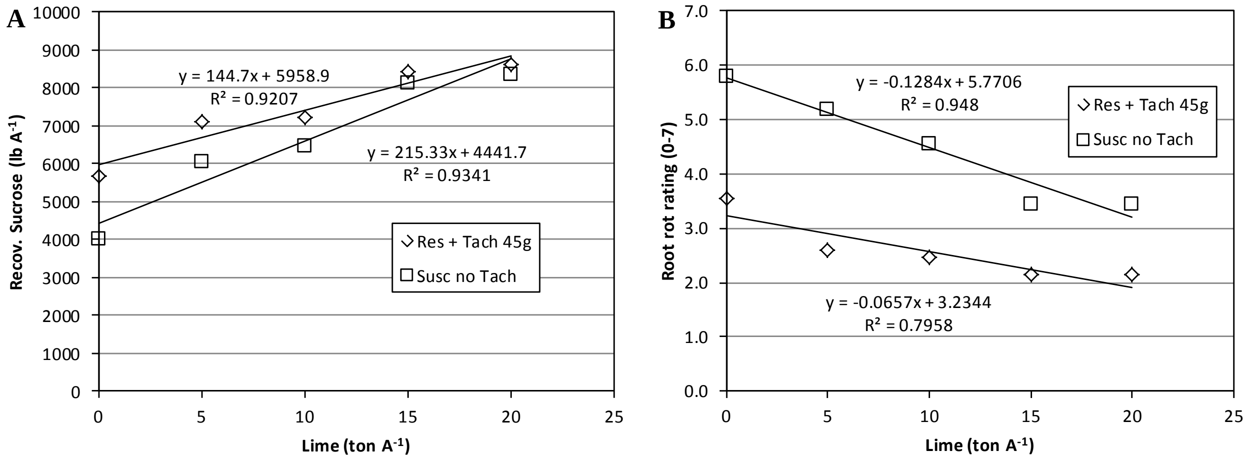

Fig. 2 Regression of **A)** recoverable sucrose and **B)** Aphanomyces root rot rating vs. rates of lime per acre in Breckenridge, MN illustrating lime rate x variety interaction (note steeper slope = greater response with the susceptible variety).

Bioassays to determine Aphanomyces soil index values (SIVs, which indicate potential for *Aphanomyces* activity and populations under warm and wet conditions) were conducted by filling four (4 x 4 x 4-inch) plastic pots with soil from each sample. Then 25 seed of sugarbeet 'Crystal 985' were sown per pot to "bait" *A. cochlioides* from soil. Pots were placed in a growth chamber and arranged in a randomized block design at 70 $\pm$ 2 °F for 1 week. Temperature then was increased to 77 $\pm$ 2°F (14-hour photoperiod) and soil was kept moist to favor infection by *A. cochlioides*. Stand counts were made three times per week (beginning at emergence) and dying seedlings were removed to prevent disease spread, assayed in the laboratory, and examined microscopically to verify infection with *A. cochlioides*. At 4 weeks after planting, an Aphanomyces SIV was calculated (0 to 100 scale, 0 = *Aphanomyces*-free and 100 = all seedlings dead and soil severely infested with *A. cochlioides*) for each pot.

Statistical analysis. Data were analyzed for effect of variety by analysis of variance and for effect of lime rate and variety by lime interactions using linear and quadratic contrasts for significance at P = 0.05, 0.01, and 0.001. Regression analyses were made for recoverable sucrose per acre and Aphanomyces root rot rating vs. rate of lime.

RESULTS

2014 Sugarbeet field trial. There were significant interactions between rate of lime and sugarbeet variety for stand at 5 and 7 weeks after planting. For the susceptible variety without Tachigaren, there were significant linear and quadratic responses to lime rate; stands at 7 weeks after planting were 125, 175, 201, 219, and 221 plants per 100 ft of row for 0, 5, 10, 15, and 20 ton lime A^{-1}, respectively (data not shown). For the resistant variety treated with Tachigaren, stands were protected so that they were not significantly lower without lime, and 7 weeks after planting averaged 218, 229, 228, 227, and 233 plants per 100 ft of row for 0, 5, 10, 15, and 20 ton lime A^{-1}, respectively (data not shown).

There were significant (P = 0.05) lime rate by variety interactions for number of harvested roots, Aphanomyces root rot rating, yield, and recoverable sucrose A^{-1}, so data for those parameters is shown separately for each variety in Table 1. The significant interaction is explained by the greater response of the susceptible variety to increasing rates of lime (Table 1), which is illustrated for recoverable sucrose A^{-1} and Aphanomyces root rot rating in Fig. 2. The susceptible variety showed a very strong linear response to rate of lime for all harvest parameters (Table 1). The resistant variety also had a significant, but not as steep response to lime rate for number of harvested roots, Aphanomyces root rot rating (Fig. 2B), yield, (Table 1) and recoverable sucrose A^{-1} (Table 1 and Fig. 2A). There was no lime rate by variety interaction for percent sugar as both varieties responded similarly to lime rate (Table 1).

2014 Soil pH and Aphanomyces soil index values (SIVs). In June, 2014, 10 years after lime was applied, soil pH was 6.5, 7.2, 7.5, 7.9, and 8.0 in plots treated with 0, 5, 10, 15, and 20 ton lime A^{-1}, respectively (data not shown). These pH values followed a similar trend as those measured 3 months after lime was applied in 2004 (5).

Table 1. Root rot ratings and harvest data for sugarbeet sown May 22, 2014, 10 years after several rates of spent lime were applied in a field near Breckenridge, MN naturally infested with *Aphanomyces cochlioides.*

Lime[W] (ton A^{-1})	No. roots harv./100 ft[X] Res.	No. roots harv./100 ft[X] Susc.	Aph rating (0-7)[XZ] Res.	Aph rating (0-7)[XZ] Susc.	Yield (ton A^{-1})[X] Res.	Yield (ton A^{-1})[X] Susc.	Percent sucrose[X] Across varieties	Recov. sucrose (lb A^{-1})[X] Res.	Recov. sucrose (lb A^{-1})[X] Susc.
0	168	79	3.6	5.8	19.1	13.8	15.9	5656	4007
5	197	126	2.6	5.2	24.6	20.3	16.0	7123	6034
10	199	154	2.5	4.6	23.9	21.0	16.5	7211	6473
15	198	184	2.2	3.5	27.4	25.8	16.8	8408	8109
20	208	189	2.2	3.5	27.7	26.5	16.9	8631	8352
Linear[Y]	*	***	**	***	**	***	**	***	***
Quadratic[Y]	NS	*	NS	NS	NS	NS	NS	NS	NS

W Spent lime was applied in April, 2004 in a randomized block design of four replicates per experiment (total of four experiments) and incorporated by cultivation. In 2014, sugarbeet was sown on May 22, 10 years after spent lime had been applied. Plots were harvested on September 22, 2014.

X Two Roundup Ready sugarbeet varieties were sown as subplots within each plot; one was susceptible (Susc.) to *Aphanomyces* and not treated with Tachigaren and the other was partially resistant (Res.) and treated with 45 g Tach per unit of seed. There was significant lime x variety interaction for all harvest parameters except percent sucrose, so data is shown separately for each variety.

Y * = significant at P = 0.05, ** = significant at P = 0.01, *** = significant at P=0.001, NS = not significant.

Z Aphanomyces root rot rating, 0-7 scale (0 = roots healthy; 7 = root completely rotted and foliage dead).

Aphanomyces SIVs were high in all plots, but there was a significant (P = 0.05) linear response to rate of lime. Aphanomyces SIVs averaged 100, 100, 100, 93, and 94 in plots treated with 0, 5, 10, 15, and 20 ton lime A^{-1}, respectively (data not shown). There was a significant linear effect of lime rate on extractable calcium, which averaged 3013, 3806, 3883, 4476, and 4639 in plots treated with 0, 5, 10, 15, and 20 ton lime A^{-1}, respectively (data not shown).

DISCUSSION

Conditions in Breckenridge, MN were conducive for early-season damping-off and root rot throughout the season. Planting was late (May 22) and rainfall in June at the Wahpeton, ND North Dakota Agricultural Weather Network station was 5.80 inches, 2.52 inches above normal. This resulted in warm, moist, favorable soils for infection by *A. cochlioides*. During this period, the resistant variety was protected by Tachigaren and had good stands, regardless of lime rate. The susceptible variety without Tachigaren, however, lost seedlings to damping-off in non-limed control plots and plots treated with lime at 5 ton A^{-1}. Rainfall in July was 1.16 inch, 2 inches below normal, so plants that survived were able to recover. High rainfall again in August (3.12 inches) resulted in new infections so that harvest parameters were affected for both varieties. September was dry with just 1.11 inch of rainfall, so root rot ratings at harvest were based on scarring and malformed roots, indicative of earlier infections from which roots had tried to recover.

Similar to 2012 and 2013, there were significant variety by lime rate interactions in 2014. In contrast to 2012 and 2013 however, disease pressure both early and late in the season resulted in significant linear responses to rate of lime for both varieties. The partially resistant variety with Tachigaren was better able to withstand early disease pressure and had less yield loss without lime resulting in a lower slope in response to lime rate (Fig. 2). The susceptible variety without Tachigaren, however, performed very poorly without lime but resulted in excellent yields and recoverable sucrose as lime rate increased (Table 1) with a steeper response to lime rate (Fig. 2). This 2014 response is intermediate between results in 2012 and 2013 when lime rate had no effect on the resistant variety and those in 2011, when extreme disease pressure throughout the season resulted in similar effect of lime on both varieties, but unacceptably low yield and recoverable sucrose (12).

Ten years after the original lime application, 2014 was the last season of the trial in its original format. In October of 2014, plots in experiment 3 were split and another 5 ton lime A^{-1} added to half of each plot. Soil samples were taken prior to the addition of new lime to determine Aphanomyces SIVs, pH, and calcium concentration. In 2015 sugarbeet will be sown to the plots and soil samples collected to determine effect of the additional lime application on Aphanomyces root rot, pH, calcium, and sugarbeet production compared with original lime applied in 2004.

SUMMARY AND CONCLUSIONS

1. Ten years after application of spent lime, there was a significant reduction in Aphanomyces root rot and increased yields at Breckenridge, MN.
2. Soil pH levels initially increased with application of spent lime and have remained relatively stable for ten years; soil index values (SIVs) in limed plots were high in 2014, but have fluctuated over the 10-year period since lime was applied.

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