A SINGLE FIELD APPLICATION OF SPENT LIME REDUCES APHANOMYCES ROOT ROT AND INCREASES SUGARBEET YIELD AND QUALITY EIGHT YEARS LATER

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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. In 2011, the pathogen re-appeared after several years of low activity because of a late planting season combined with warm and wet soil conditions, which are conducive to Aphanomyces 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. Indeed, Aphanomyces root rot was so severe in some fields in 2011, that they were abandoned. 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 (2) 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, 4-11).

OBJECTIVES

Our objectives were to evaluate a field trial where several rates of spent lime had been applied <u>eight 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

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**

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 2012, sugarbeet test trials were planted in Experiment 4.

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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 from 2005 to 2011; the three other experiments were planted with the same crop grown in the field by the grower-cooperator as noted in Fig. 1. Results have been reported from 2004 to 2011 (4-11).

2012 Sugarbeet field trial. Two Roundup Ready sugarbeet varieties were sown in Experiment 4 (last planted to sugarbeet in 2008, Fig. 1). The *Aphanomyces*-susceptible variety had a three-year disease rating of 6.3 (1-9 scale) and seed was not treated with Tachigaren; the partially resistant variety had a three-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 <= 4.90 (3). Varieties were sown as subplots in limed and non-limed control plots on April 26. 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 weekly from 3 to 7 weeks after planting. Sugarbeet roots were harvested September 28 (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 Co. Quality Laboratory, East Grand Forks, MN.

2012 Soil pH and Aphanomyces soil index values (SIVs). In May, soil samples were collected in plots sown to sugarbeet. Six samples (6-inch depth) were collected randomly across each plot, combined, screened through 0.25-inch hardware cloth, and assayed (usually within 1 month after collection). To determine pH, small quantities of soil were air-dried for 24 hours and ground into powder with a mortar and pestle. A 5 gram quantity was removed and mixed with 5 ml of deionized water. After 10 minutes, a pH probe was inserted into the mixture, gently stirred for 3 seconds, and the pH was read (Accumet® pH Meter 15, Fisher Scientific).

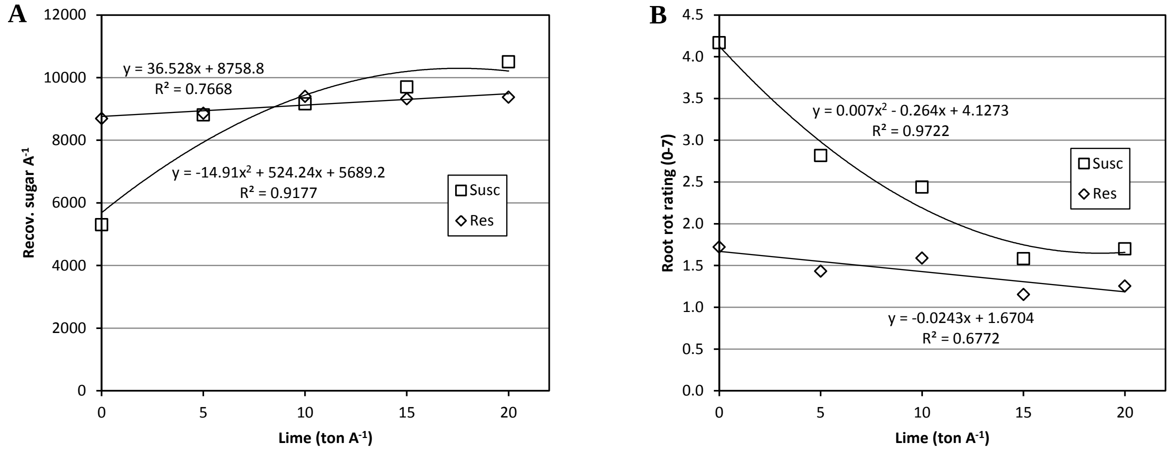

Fig. 2 Regression of **A)** recoverable sucrose and **B)** Aphanomyces root rot rating vs. rates of lime per acre in Breckenridge, MN illustrating lime rate x variety interaction.

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 'ACH 261' 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. At 4 weeks after planting, an Aphanomyces SIV was calculated (0 to 100 scale, 0 = *Aphanomyce*s-free and 100 = all seedlings dead and soil severely infested with *A. cochlioides*) for each plot.

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

RESULTS

2012 Sugarbeet field trial. There were no interactions between rate of lime and sugarbeet variety for early season stand. There was a significant linear response to lime rate, so that stands at 5 wk after planting averaged across both varieties were 100, 123, 120, 134, and 140 plants per 100 ft of row for 0, 5, 10, 15, and 20 ton lime A^{-1}, respectively (data not shown). Stands at 5 wk after planting were significantly higher for the partially resistant variety treated with Tachigaren (131 plants per 100 ft of row) compared to the susceptible variety without Tachigaren (116 plants per 100 ft of row, data not shown).

There were significant (P = 0.05) lime rate x variety interactions for all harvest parameters, so harvest data is shown 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 resistant variety had no significant response to lime rate for percent sucrose (Table 1) and recoverable sucrose A^{-1} (note flat slope of line for resistant variety in Fig. 2A). There was a significant but mild response of the resistant variety to rate of lime for number of harvested roots (Table 1), Aphanomyces root rot rating (Fig. 2B), and yield (Table 1). The susceptible variety showed a very strong response to rate of lime for all harvest parameters (Table 1). There was significant linear response to increasing lime rates for all harvest parameters and significant quadratic response for yield and percent sucrose (Table 1), recoverable sucrose A^{-1} (Fig. 2A), and Aphanomyces root rot rating (Fig. 2B).

2012 Soil pH and Aphanomyces soil index values (SIVs). In May, 96 months (8 years) after lime was applied, soil pH was 6.2, 6.9, 7.0, 7.6, and 7.5 in plots treated with 0, 5, 10, 15, and 20 ton lime A^{-1}, respectively (data not

Table 1. Root rot ratings and harvest data for sugarbeet sown April 26, 2012, 96 months 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.	Susc.	Aph rating (0-7)[XZ] Res.	Susc.	Yield (ton A^{-1})[X] Res.	Susc.	Percent sucrose[X] Res.	Susc.	Recov. sucrose (lb A^{-1})[X] Res.	Susc.
0	113	70	1.7	4.2	25.6	15.9	19.0	18.8	8684	5301
5	123	111	1.4	2.8	25.9	24.5	19.2	19.9	8857	8806
10	114	106	1.6	2.4	27.9	25.5	19.0	19.9	9395	9164
15	142	119	1.2	1.6	27.7	26.3	18.9	20.3	9318	9698
20	137	134	1.3	1.7	27.7	28.7	19.0	20.1	9367	10506
Linear[Y]	*	***	**	***	*	***	NS	***	NS	***
Quadratic[Y]	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 2012, sugarbeet was sown on April 26, 96 months after spent lime had been applied; each value in this portion of the table is averaged across two sugarbeet varieties. Plots were harvested on September 28, 2012.

[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, 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).

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shown). These pH values remained nearly identical to those measured 6 months after lime was applied in 2004 (4). There was a significant ($P = 0.05$) linear response to rate of lime for Aphanomyces SIVs which averaged 100, 85, 98, 64, and 66 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, but as the season progressed, soil moisture decreased and plants that survived recovered. Rainfall in April at the Wahpeton, ND North Dakota Agricultural Weather Network station was 3.16 inches, 1.41 inches above normal. This resulted in moist, favorable soils for infection by *A. cochlioides*. From 3 to 5 weeks after planting, a period when sugarbeet seedlings are very susceptible to Aphanomyces damping-off, stands dropped across all treatments by ~10%. At the time of the first stand count (3 wk after planting), stands were already significantly lower for the non-limed plots compared to limed plots and for the susceptible variety without Tachigaren compared to the partially resistant variety with Tachigaren. Rainfall in May-September was lower than normal for each month, so plants that survived recovered and yields were high. Root rot ratings at harvest were based on scarring, indicative of early-season infections from which roots had recovered.

The combination of high early-season disease pressure and moderate mid- and late-season disease pressure resulted in strong interactions for rate of lime and variety. The partially resistant variety with Tachigaren was better able to withstand early disease pressure and had high yield and recoverable sucrose regardless of rate of lime (Table 1). The susceptible variety without Tachigaren, however, performed very poorly without lime but resulted in exceptional yields and recoverable sucrose as lime rate increased (Table 1). This is in contrast to 2011, when high disease pressure throughout the season resulted in similar effect of lime on both varieties, but unacceptably low yield and recoverable sucrose (11).

SUMMARY AND CONCLUSIONS

1. Eight 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 eight years; soil index values (SIVs) in limed plots were reduced in 2012, but have typically remained high over the 8-year period since lime was applied.

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