

RESEARCH PROJECT TITLE: Seed-Placed Lime to Reduce the Acidifying Affects of Nitrogen Fertilizer in Long-term Direct Seed Systems

INVESTIGATORS: David Huggins, USDA-ARS; Jim Harsh, WSU; Bill Pan, WSU
Cooperators: David Bezdicek, WSU; Tim Murray, WSU; R. James Cook WSU; Mary Fauci, WSU;
Cooperator-growers: Frank Lange (Palouse) and Steve Mader (Pullman)
Graduate Student (2001-2002): Ian Wildley

PROJECT OBJECTIVES:

1. Assess the effects of seed placed lime and fertilizer on seed zone pH and exchangeable aluminum using DS planting methods.
2. Determine the effects of lime source and starter fertilizer source on dry matter accumulation, early season nutrient uptake, grain yield, and grain protein.
3. Evaluate the long-term effects on soil pH and plant growth of applying low rates of pelletized lime in combination with acid forming or pH neutral starter fertilizers using two DS rotations.

KEY WORDS: Acidification, Lime, Direct-Seed, Nitrogen Fertilizer

STATEMENT OF PROBLEM:

Long-term direct seeding (DS) in the Pacific northwest offers growers many benefits such as reduced soil erosion, increased water use efficiency, improved soil quality, and increased sustainability, as compared to conventional tillage methods. One threat to the long-term viability of continuous DS is an increase in soil acidity in the upper rooting zone associated with the use of nitrogen fertilizers.

Anhydrous ammonia (82-0-0) and aqua ammonia (20-0-0) are the main nitrogen fertilizers used for wheat production in the Pacific northwest, because of their low price and high percentage of nitrogen per unit weight. Both of these fertilizer materials are normally applied in a band four to eight inches below the soil surface either prior to or during planting. As microbes convert the ammonium to nitrate, hydrogen ions are produced. In a conventional tillage system, this acidity would be mixed with the remainder of the surface layer each year during plowing, but in the DS system, the acidity tends to be localized in the region of N application. The amount of acidity produced is simply a function of amount and type of nitrogen fertilizer applied. For example, to neutralize the effect of applying 1 kg of nitrogen as anhydrous ammonia or ammonium-phosphate-sulfate (16-20-0) 1.8 kg and 5.5 kg of calcium carbonate are needed, respectively (Mortvedt et al., 1999). In the high precipitation zone, growers planting DS wheat commonly apply 112 kg N ha⁻¹ as 82-0-0 and 18 kg N ha⁻¹ as 16-20-0. This fertilizer combination requires 300 kg ha⁻¹ of pure CaCO₃ yearly to completely neutralize the hydrogen ions produced. The continuous additions of acid producing fertilizers pose a serious threat to the long-term sustainability of the DS as well as conventional systems. At least one grower has already abandoned DS because of low soil pH.

There are many problems associated with crop production on low pH soils. Soil microbiological activity, nutrient availability, and nutrient uptake are all reduced as the soil becomes more acid. Plant availability of nitrate, phosphorus, potassium, magnesium, sulfur, and many micronutrients decrease to such an extent that additional fertilizers are needed to obtain yields comparable to higher pH soils. In addition to the reduced availability of essential nutrients, the solubility of some nonessential nutrients

like aluminum and manganese can increase to toxic levels. A four year study conducted in Kansas showed a 62% decrease in wheat yields when extractable Al^{3+} levels increased from 26 ppm to 102 ppm (soil pH dropped from 5.1 to 4.6) (Whitney and Lamond, 1993). Soil pH also has an impact on the incidence of some diseases. Cephalosporium stripe, a fungal disease of winter wheat and winter barley, severity and incidence increase as soil pH drops below 6.0 (Veseth, 1987). The occurrence of Pythium is also decreased with liming (Fukui et al., 1994). A combination of these factors was probably responsible for the 43% reduction in winter wheat (cv 'Stephens') yield observed by Mahler and McDole (1987) in soil with pH 5.0 compared to soil pH 5.4.

University of Idaho researchers have determined the minimum pH required to obtain maximum yield for lentils, spring peas, and wheat to be 5.65, 5.52, and 5.19, respectively (Mahler and McDole, 1987). At a soil pH of 5.0, lentil and spring pea yields were reduced to 50% of maximum. As soil pH drops below minimum levels, crop selection for rotations is limited to acid tolerant species (cereals) making control of grassy weeds increasingly difficult. In eastern Washington, Bezdicek (et al., 1998) reported pH of 4.6 and 4.9 in the 10-15 cm layer of two long-term no-till fields while the pH of adjacent conventionally tilled fields were 5.5 and 5.3. Microbial activity at the 10-15 cm layer for the no-till fields was also significantly lower compared to the adjacent conventionally tilled fields.

The success of long-term DS is dependent upon profitability. Increased soil acidity in the seed zone can potentially reduce wheat yields by 40-60%, and limit rotations to only acid tolerant crops. Since nitrogen fertilizer application is responsible for most of the acidity, it is extremely important to limit N use to economical rates. The addition of large amounts of agricultural lime to DS fields is not feasible because of the high cost of lime and the difficulty in spreading. Low rates of pelletized lime applied with the seed seem to be an alternative. Although pelletized lime is more expensive, it can be applied directly into the acid zone with no additional disturbance of the surface residue. We hypothesize that yearly applications of lime in combination with DS based N recommendations will greatly reduce the acidifying affects of nitrogen fertilizer, thus maintaining crop productivity in long-term DS rotations.

AGRONOMIC ZONE OF INTEREST:

Agronomic zones where soil acidification is decreasing surface soil pH below 6.0. Primarily, but not restricted to high precipitation zone where greatest ammonical N use and soil acidity occurs.

ABSTRACT OF RESEARCH FINDINGS:

Seed-placed lime did not affect wheat seedling emergence or grain yield. Lime rates of 200 lbs/ac placed with the seed did increase soil pH at shallow depths while starter fertilizer (16-20-0-15) reduced soil pH. Levels of extractable Al increased exponentially as soil pH decreased. Seed-placed lime (200 lb/ac rate) did reduce extractable Al near placement depth. The application of pelletized lime within the seed row does show promise as a strategy to reduce the acidity produced by ammoniacal fertilizers to soils in the Palouse. The increase in soil pH or lack of pH decline may be more beneficial for growth of rotational crops such as peas and legumes, as these crops tend to be more sensitive to acidic soils. With yearly applications of lime in the seed row a continual decline in pH may be avoided as well a persistent decline in soil fertility.

RESULTS AND INTERPRETATION:

1. Assess the effects of seed placed lime and fertilizer on seed zone pH and exchangeable aluminum using DS planting methods.

Field studies were initiated at two sites (Pullman: 7 yr. continuous direct seed; Palouse: 25 yr. continuous direct seed), in the fall of 2000. Treatments consisted of two sources of pelletized lime, Pacific Calcium (PC) and Golden Brown Sugar Lime (SB), at three rates, 0, 110, and 220 kg ha⁻¹, with and without 110 kg ha⁻¹ starter fertilizer (ammonium phosphate sulfate (16-20-0-14) (Table 1). Calpril is the trade name of the pelletized lime provided by Pacific Calcium, in Tonasket, WA. This product has an analysis of CaCO₃ > 91% and MgCO₃ <1%. The Golden Brown Sugar Lime is a by-product of the sugar beet processing industry and was provided by Hanson Processing L.L.C., Spokane, WA. This product has a guaranteed analysis (before prilling) of CaCO₃ - 77%, Ca - 31%, MgCO₃ - 0.4%, and Mg from limestone - 1%.

Table 1. List of treatments including lime source, lime application rate and with or without starter fertilizer, on each of the sites for the 2000 lime study.

Treatment Number	Lime Source	Lime Rate (kg ha ⁻¹)	Starter Fertilizer
1	None	0	-
2	None	0	+
3	Pacific Calcium	110	-
4	Pacific Calcium	110	+
5	Pacific Calcium	220	-
6	Pacific Calcium	220	+
7	Sugar Beet	110	-
8	Sugar Beet	110	+
9	Sugar Beet	220	-
10	Sugar Beet	220	+

Soil pH levels prior to treatments showed marked stratification with depth (Table 2), with lowest pH occurring in 5-10 cm (2-4 in) depth, likely due to history of fertilizer placement.

Table 2. Initial soil pH prior to treatment applications at Palouse and Pullman, WA sites.

Soil Depth (cm)	-----Site Location-----	
	Palouse	Pullman
cm	-----pH-----	
0-5	5.62	5.34
5-10	5.11	4.94
10-25	5.32	5.48

The Palouse site was planted to a soft white winter wheat (cv. Madsen) on October 5, 2000 and the Pullman site was planted to a hard red winter wheat (cv. Columbia 1) on October 19, 2000

(approximately 110 kg seed ha⁻¹). A Fabro no-till plot drill (15 cm–7.5 in spacing, Fabro Inc., Canada) with off-set double-disk openers placed lime and starter fertilizer with seed about 5 cm (2 in) below the soil surface while urea (110 kg N/ha) was deep banded below the seed (7-13 cm) at planting.

At the Palouse site, there was no significant effect of lime source on soil pH (data not shown). Neither lime source had an effect on soil pH of samples collected 1 month after planting (data not shown); however, samples taken after harvest had higher soil pH in seed-placed lime treatments (220 kg ha⁻¹ material) *versus* no lime treatments in first 4 depth increments (Table 3).

Table 3. Mean pH values based on samples taken after harvest for rate of lime applied at the Palouse site.

Treatment	Depth (cm)					
	0-2.5	2.5-5.0	5.0-7.5	7.5-10	10-12.5	12.5-15
Lime Rate	pH					
0 kg ha ⁻¹	5.98	5.44	5.13	5.03	5.07	5.33
10 kg ha ⁻¹	6.08	5.65	5.22	5.07	5.05	5.27
220 kg ha ⁻¹	6.12	5.67	5.30	5.16	5.15	5.36
Contrasts (P>F ₀)						
No Lime vs.	S	S	NS	NS	NS	NS Lime
No Lime vs.	NS	S	NS	NS	NS	NS
110 kg/ha Lime						
Lime vs.	S	S	S	S	NS	NS
220 kg/ha Lime						

Contrasts show significant (S) or non-significant (NS) treatment affects (p<0.1).

The Palouse site had higher overall mean extractable Al values for the samples taken after harvest than those taken one month after planting at the same site (Table 4). Only one statistically significant difference occurred at the 4th depth where application of 220 kg ha⁻¹ of lime produced a lower amount of extractable Al than those found with 0 and 110 kg ha⁻¹ of lime applied. Throughout the depths sampled, consistently lower Al values were found with 220 kg ha⁻¹ of lime applied. Amounts of extractable Al were also higher with the application of starter fertilizer, although these differences were not statistically significant.

Table 4. Treatment effects on the mean amount of extractable soil Al for the Palouse study site after harvest.

Treatment	Extractable Al ³⁺ by Depth (cm)					
	0-2.5	2.5-5.0	5.0-7.5	7.5-10	10-12.5	12.5-15
	-----mg kg ⁻¹ -----					
0 kg ha ⁻¹	6.58 a	10.37 a	27.08 a	44.20 b	33.26 a	13.13 a
110 kg ha ⁻¹	6.94 a	7.87 a	21.34 a	40.37 b	33.40 a	13.16 a
220kg ha ⁻¹	7.01 a	6.62 a	15.35 a	26.12 a	27.87 a	12.79 a
No Lime	6.58 a	10.37 a	27.08 a	44.20 a	33.26 a	13.13 a
Sugar Lime	6.59 a	7.07 a	18.63 a	35.56 a	36.96 a	11.71 a
Pac. Cal. Lime	7.47 a	7.47 a	17.97 a	30.28 a	22.50 a	13.96 a
No Starter	6.87 a	6.78 a	17.01 a	33.60 a	28.00 a	11.48 a
Starter	6.92 a	8.95 a	23.17 a	37.27 a	34.31 a	14.53 a

*Values with same letter, within the same column are not significantly different with Fishers Protected LSD ($p < 0.10$). No interactions were observed between source and rate of lime, therefore data are pooled over lime source.

The starter fertilizer treatment decreased soil pH (after harvest) at all depths (Table 5). These results underscore the acidifying potential of 16-20-0-15. These results also indicate that further reductions in soil pH will continue if no remedial strategies are utilized.

Table 5. Mean pH values as related to the application of starter fertilizer at the six different depths sampled after harvest at the Palouse site.

Starter Fertilizer Rate (kg ha ⁻¹)	Depth (cm)					
	0-2.5	2.5-5.0	5.0-7.5	7.5-10	10-12.5	12.5-15
	-----pH-----					
0	6.18 a	5.78 a	5.32 a	5.14 a	5.16 a	5.37 a
110	5.99 b	5.49 b	5.16 b	5.05 b	5.03 b	5.27 a

*Values with same letter, within the same column are not significantly different with $p > 0.10$.

2. Determine the effects of lime source and starter fertilizer source on dry matter accumulation, early season nutrient uptake, grain yield, and grain protein.

No effects of lime treatments on wheat emergence were measured (data not shown). Grain yield was not affected by lime treatments; however, starter fertilizer treatment did increase yield at Pullman site (Table 6). Yields at Pullman site were low due to poor seed placement by Fabro drill in heavy residue and severe rodent damage. The lack of statistically significant differences in yield may indicate that there is not a severe enough pH problem within the depths sampled to warrant the application of lime.

Although pH levels at the 3rd, 4th, and 5th depths sampled are rather low and seem to be reaching growth inhibition levels for most varieties of wheat, the roots of these plants may have the ability to proliferate into the lower zones of soils where the pH is higher and more favorable for growth.

Table 6. Treatment effects on the mean amount of grain harvested from the Pullman and Palouse study site August 2001.

Treatment	Pullman	Palouse
	-----Grain Yield (Mg ha ⁻¹)-----	
0 kg ha ⁻¹ lime	4.4 a	7.3a
110 kg ha ⁻¹ lime	4.1 a	7.2 a
220kg ha ⁻¹ lime	4.1 a	7.2 a
No Lime	4.1 a	7.2 a
Sugar Lime	4.0 a	7.1 a
Pacific Calcium Lime	4.2 a	7.2 a
No Starter	4.0 b	7.1 a
Starter	4.4 a	7.3 a

*Values with same letter, within the same column are not significantly different with Fishers Protected LSD_{0.10}.

A trial experiment was conducted to determine the relationship between acidified soil, soil pH, extractable Al, and plant response. Palouse silt-loam soil from depths of 0 to 5 cm and from 5 to 10 cm was utilized. Ten soil samples of 5 g from each depth were prepared and incremental amounts of 0.121 M HCl were added to acidify the soil to different levels. The acidified soils were then placed into pots with four replication of each pH level. Ten seeds of soft white spring wheat (cv. Zak) were then placed into the pots and 100 ml of 2.5 x10⁻⁴ M calcium nitrate [(Ca(NO₃)₂ · 4H₂O)] was added to moisten the soil and to provide a source of N for the developing seedlings. The pots with seeds were then placed into a growth chamber that was maintained at 22°C for the daytime temperature and 17°C for the nighttime temperature. The chamber was also set for 16-hour day lengths. The growth of the seedlings was observed daily and the pH of the soil was measured every three days throughout the experiment. The plants were allowed to develop to for 14 days at which time the plants were removed from the pots to observe the root development as well as to determine the moist weight of the plant, dry weight of the plant, and dry weight of the shoots and roots. After the plants were removed from the pots, the extractable Al content of the soils was again determined and the root dry weight was graphed as a function of final extractable Al concentrations.

The initial application of the 0.121 M HCl to the experimental soils created an acceptable range of pH values to derive information about extractable Al concentrations (Figure 1). This curve was utilized to determine the amount of acid that would be needed to create a range of acidic soils for the plant growth experiment. It also displays relationship between soil pH and exchangeable Al.

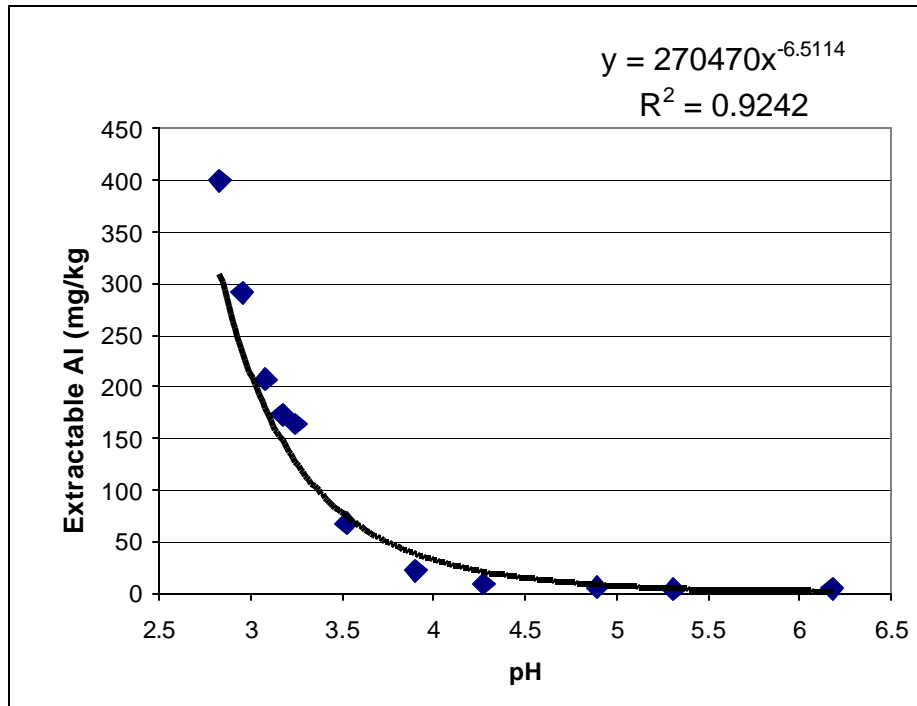


Figure 2. Amount of 1 M KCl extractable Al found for with incremental 0.121M HCl additions to experimental soil. Curve used to determine amount of acid needed to develop acidic soils for plant growth experiment

After 3 days in the growth chamber all experimental pots had seedlings emerging. The control pots had more seedlings germinating and the seedlings were taller in this experimental unit than other pots. Germination and growth seemed to decrease as the amount of acid add to the pots increased, an expected out come. Five days after the seedlings were planted the control plants were still taller than others and germination was still highest in these pots. The pH 3.5 pots had the least amount of seedlings and the shortest plants of all pots with many of the seedlings just beginning to come through the soil surface. Final results are shown in Table 7.

As with the results found in the pots with surface soil, the control pots in the soils obtained from 5-10 cm maintained significantly ($p < 0.10$) greater shoot, root, overall plant dry weight as well as significantly greater shoot height (Table 8). The pots receiving the most acid again had the least shoot, root, and overall plant dry weight production as well as the shortest shoot height. Although root growth was lowest in the pots receiving the most acid additions, the dry weight was not significantly different from the high or moderate acid additions.

Table 7. Treatment effects on final soil pH, extractable Al, plant dry weight, shoot dry weight, root dry weight and shoot height for 0 to 5 cm soil.

Target pH	pH Measured	Ext. Al	Plant Dry wt.	Shoot Dry wt.	Root Dry wt.	Shoot Height
		mg kg ⁻¹	g			cm
Control	5.92 a	12.84 a	0.898 a	0.408 a	0.490 a	28.16 a
5.0	5.70 ab	16.01 ab	0.568 b	0.260 b	0.308 b	20.53 b
4.5	5.57 b	14.35 ab	0.498 b	0.273 b	0.225 b	20.19 b
4.0	5.05 c	18.29 b	0.540 b	0.298 b	0.243 b	20.23 b
3.5	4.36 d	60.34 c	0.460 b	0.203 b	0.258 b	15.15 c

*Values with same letter, within the same column are not significantly different with Fishers Protected LSD_{0.10}. Values listed are mean values averaged over four replications

Table 8. Treatment effects on final soil pH, extractable Al, plant dry weight, shoot dry weight, root dry weight and shoot height for the 5 to 10 cm soil.

Treatment	pH	Ext. Al	Plant Dry wt.	Shoot Dry wt.	Root Dry wt.	Shoot Height
		mg kg ⁻¹	g			cm
Control	5.88 a	19.43 a	0.770 a	0.380 a	0.390 a	23.39 a
5.0	5.46 b	19.95 a	0.518 b	0.208 b	0.310 b	13.72 cb
4.5	5.47 b	19.11 a	0.425 bc	0.188 bc	0.238 bc	14.19 b
4.0	4.98 c	39.94 b	0.465 bc	0.205 b	0.260 b	14.13 b
3.5	4.37 d	105.83 c	0.368 c	0.135 c	0.233 c	12.43 c

*Values with same letter, within the same column are not significantly different with Fishers Protected LSD_{0.10}. Values listed are mean values averaged over four replications.

3. Evaluate the long-term effects on soil pH and plant growth of applying low rates of pelletized lime in combination with acid forming or pH neutral starter fertilizers using two DS rotations.

Trials were initiated within the long-term continuous no-tillage rotation fields at the Palouse Conservation Field Station in the fall of 2001 and spring of 2002. Treatments consisted of lime placed with the seed (200 lb/ac), surface applied lime (6T/ac), surface applied elemental S (0.25 T/ac) and control. These treatments were imposed on each crop of two three year rotations: winter wheat/spring barley/spring wheat and winter wheat/winter pea/spring wheat. The surface applied lime and S were one time treatments and will not be repeated, whereas the seed-placed lime will be applied as each crop is seeded at the 200 lb/ac rate. Measurements of soil pH and yield will be monitored over time. Initial levels of soil pH showed distinct stratification with the lowest pH levels occurring at 2-4 in.

PUBLICATIONS AND PRESENTATIONS:

Several presentations regarding preliminary findings have been made at Direct Seed Conference (2001) and at soil seminar at WSU.