

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; Rich Koenig, WSU; Jim Harsh, WSU; Bill Pan, WSU. Cooperators: David Bezdicek, WSU; Tim Murray, WSU; R. James Cook WSU; Mary Fauci, WSU; Eric Harwood, WSU. Cooperator-growers: Frank Lange (Palouse) and Steve Mader (Pullman). Graduate Students: Ian Wildley (2001-2002); Tabitha Brown (2004-2005)

INTERIM OR FINAL REPORT: Final report

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-Seeding, Nitrogen

STATEMENT OF PROBLEM:

Due to relatively low price per unit of nitrogen (N), anhydrous ammonia (82-0-0) and aqua ammonia (20-0-0) are the main N fertilizers used for wheat production in the Pacific Northwest. These materials are normally applied in a band four to eight inches below the soil surface either prior to or during planting. Nitrification of ammoniac fertilizers produces acid, lowering soil pH in the fertilizer band. In a conventional tillage system, this acidity would be mixed with the remainder of the surface layer each year during plowing. But, in direct seeded (DS) systems the acidity is localized in the region of N application. The continuous addition of acid producing fertilizers could pose a serious threat to the long-term sustainability of DS systems, and conventional systems if surface soil pH continues to decline.

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 ammoniac 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 220 kg ha⁻¹ 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 (220 kg ha⁻¹) reduced extractable Al near the depth of placement. Broadcast lime increased soil pH to depths of 8 to 10-cm, and reduced soluble Al levels. Both the annual application of pelletized lime in the seed row, or periodic broadcasting of lime on the soil surface, show promise as strategies to reduce soil acidity produced by ammoniac fertilizers. At this time 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. It is inevitable that continued soil acidification will affect the yields of cereal crops.

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; and 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 >91% CaCO₃ and <1% MgCO₃. The Golden Brown Sugar Lime is a by-product of the sugar beet processing industry and was provided by Hanson Processing, L.L.C., in Spokane, WA. This product has a guaranteed analysis (before prilling) of 77% CaCO₃ and 0.4% MgCO₃.

Table 1. List of treatments including lime source and application rate, and presence or absence of starter fertilizer, 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 treatment application showed distinct stratification with depth (Table 2), with lowest pH occurring in 5-10 cm depth. This stratification is likely due to history of subsurface band fertilizer placement.

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 row spacing, Fabro Inc., Canada) with off-set double-disk openers placed lime and starter fertilizer with the seed about 5 cm below the soil surface, while urea (110 kg N ha⁻¹) was deep banded below the seed (7 to 13 cm) at planting.

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

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

At the Palouse site, there was no significant effect of lime source on soil pH (data not shown); however, samples taken post-harvest had overall higher soil pH in seed-placed lime treatments (220 kg ha⁻¹ material) versus no lime treatments in the first 4 depth increments (Table 3).

Table 3. Mean pH in post harvest samples collected from the Palouse site.

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

*Contrasts show significant (S) or non-significant (NS) treatment effects (p<0.10).

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 that 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.

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

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

Lime rate (kg ha ⁻¹)	Extractable Al by Soil Depth (cm)					
	0 to 2.5	2.5 to 5.0	5.0 to 7.5	7.5 to 10	10 to 12.5	12.5 to 15
	-----mg kg ⁻¹ -----					
0	6.58 a*	10.37 a	27.08 a	44.20 b	33.26 a	13.13 a
110	6.94 a	7.87 a	21.34 a	40.37 b	33.40 a	13.16 a
220	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.

Table 5. Mean pH values by depth for the starter fertilizer treatments sampled after harvest at the Palouse site.

Starter Fertilizer rate (kg ha ⁻¹)	Soil Depth					
	0 to 2.5	2.5 to 5.0	5.0 to 7.5	7.5 to 10	10 to 12.5	12.5 to 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 the 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.

Field studies at Palouse and Pullman

Lime treatments did not affect wheat emergence (data not shown). Grain yield was also not affected by lime treatments; however, starter fertilizer treatment did increase yield at the Pullman site (Table 6). Yields at Pullman were low due to poor seed placement by the 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 at this time. 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 lower depths of soil where the pH is higher and more favorable for growth. Though no response to liming was measured in these studies, continued decline in soil pH will inevitably result in a yield-limiting condition.

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

Treatment	Location	
	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
220 kg 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}.

Growth chamber study

A separate 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 used. 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 x 10⁻⁴ 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 were then placed into a growth chamber that was maintained at 22 °C for daytime temperature and 17 °C for nighttime temperature. The chamber was 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 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.

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 used to determine the amount of acid needed to create a range of acidic soils for the plant growth experiment. Figure 1 also displays relationship between soil pH and exchangeable Al.

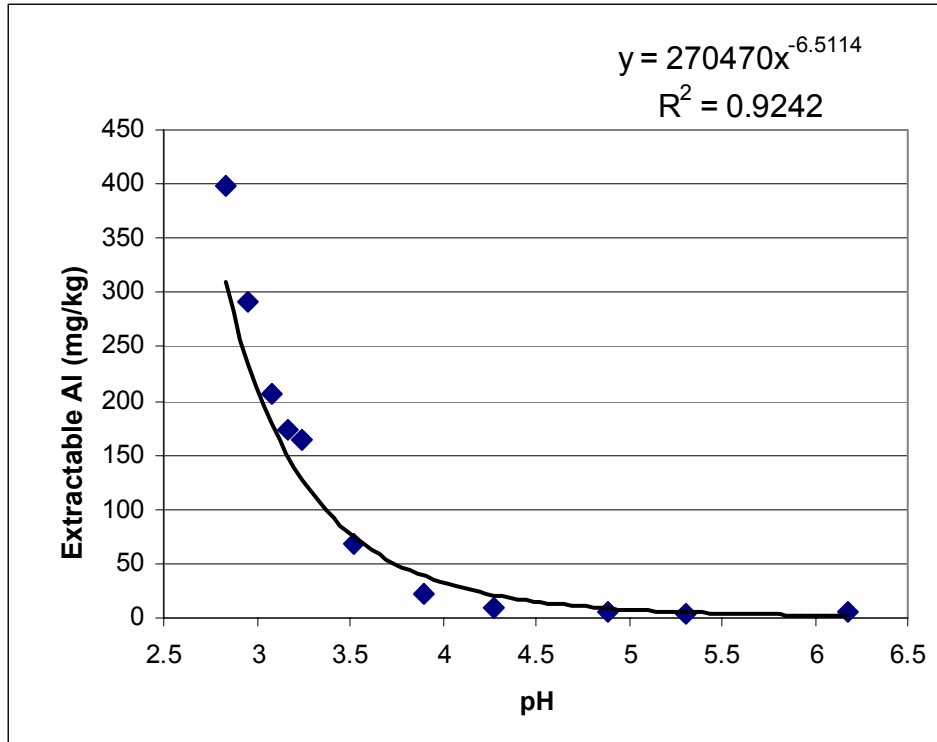


Figure 1. The relationship between the concentration of 1 M KCl-extractable Al and pH for the soils acidified with 0.121M HCl.

Germination and growth appeared to decrease as the amount of acid added to the pots increased. Although root growth was lowest in the pots receiving the most acid additions in the 0 to 5-cm soil, the dry weight was not significantly different from the high or moderate acid additions (Table 7). The pots receiving the most acid in the 5 to 10-cm soil again had the least shoot, root, and overall plant dry weight production as well as the shortest shoot height (Table 8). 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.

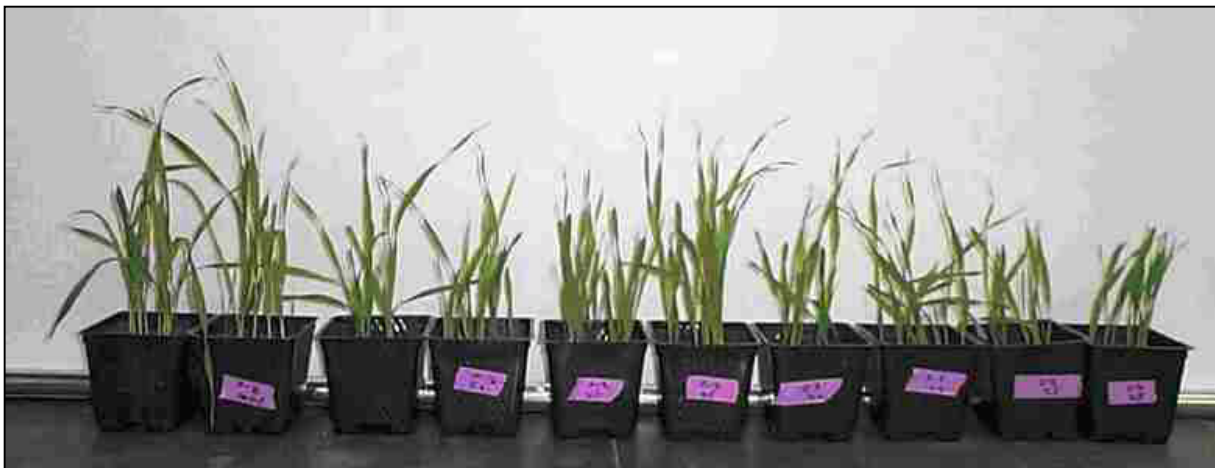


Figure 3. The effect of decreasing pH on wheat seedling growth in a controlled environment. The soil pH declines from 6.2 (left) to 4.1 (right).

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	Measured pH	Extractable Al (mg kg ⁻¹)	Plant dry weight (g)	Shoot weight (g)	Root Weight (g)	Plant height (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 0 to 5 cm soil.

Target pH	Measured pH	Extractable Al (mg kg ⁻¹)	Plant dry weight (g)	Shoot weight (g)	Root Weight (g)	Plant height (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 long-term continuous DS 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 (220 kg ha⁻¹ rate), surface applied lime (6,000 kg ha⁻¹), surface applied elemental sulfur (S) (1000 kg ha⁻¹) and a 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 is applied as each crop is seeded at the 220 kg ha⁻¹ rate. Measurements of soil pH and yield will be monitored over time in this long-term study.

In 2004 one complete set of long term treatments were intensively sampled to assess the spatial variability of soil pH. A soil core from each treatment of one replication was removed with a 2.0 cm thick by 12.5 cm wide by 15 cm long wedge-type sampling device. The core was dissected vertically into 0.5 cm increments and pH measured in a 1:1 soil:water extract passed through a 2 micrometer filter. A pit was also excavated in each plot and a 30-cm deep by 60-cm wide surface intensively sampled by removing a soil core every 5 cm (72 cores per face sampled).

Data from the wedge samples showed evidence of pH stratification, with the lowest pH levels in most treatments occurring at depths of 3 to 6 cm (Figure 3). The broadcast lime treatment also appears to be influencing (increasing) soil pH to a depth of approximately 8 cm below the surface. The elemental sulfur treatment is clearly acidifying the soil surface. Figure 4 shows similar results in terms of pH stratification, with an acid zone present at the depth of fertilizer placement and an indication that broadcast lime is partially neutralizing the acidic layer.

Data on intensive sampling of the pit grids is still being analyzed. Additional work is also ongoing to characterize the spatial variability of soil pH from the pits, and to model Al speciation in the soil solution. Using detailed soil solution and aluminum speciation modeling data, the effect of different amendments on phytotoxic Al species and concentrations will be explored. Amendments such as phosphate, sulfate, and lime are known to reduce phytotoxic Al species in soil. Based on modeling results, additional growth chamber studies will be conducted to assess wheat response to these amendments. Additional studies are also planned to assess wheat responses to stratified and uniform acidity to determine if plants have the capability to avoid damaging effects of stratified acidity created in DS systems.

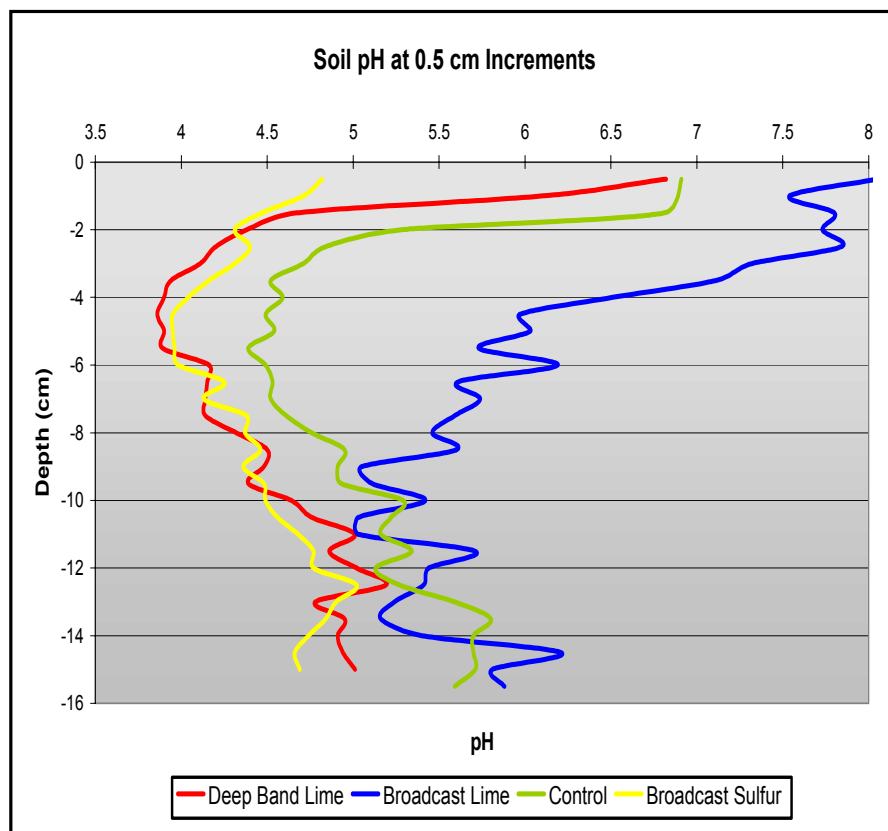


Figure 3. Variation in soil pH with depth and treatment in 2004 at the Palouse Conservation Field Station.

Variation in

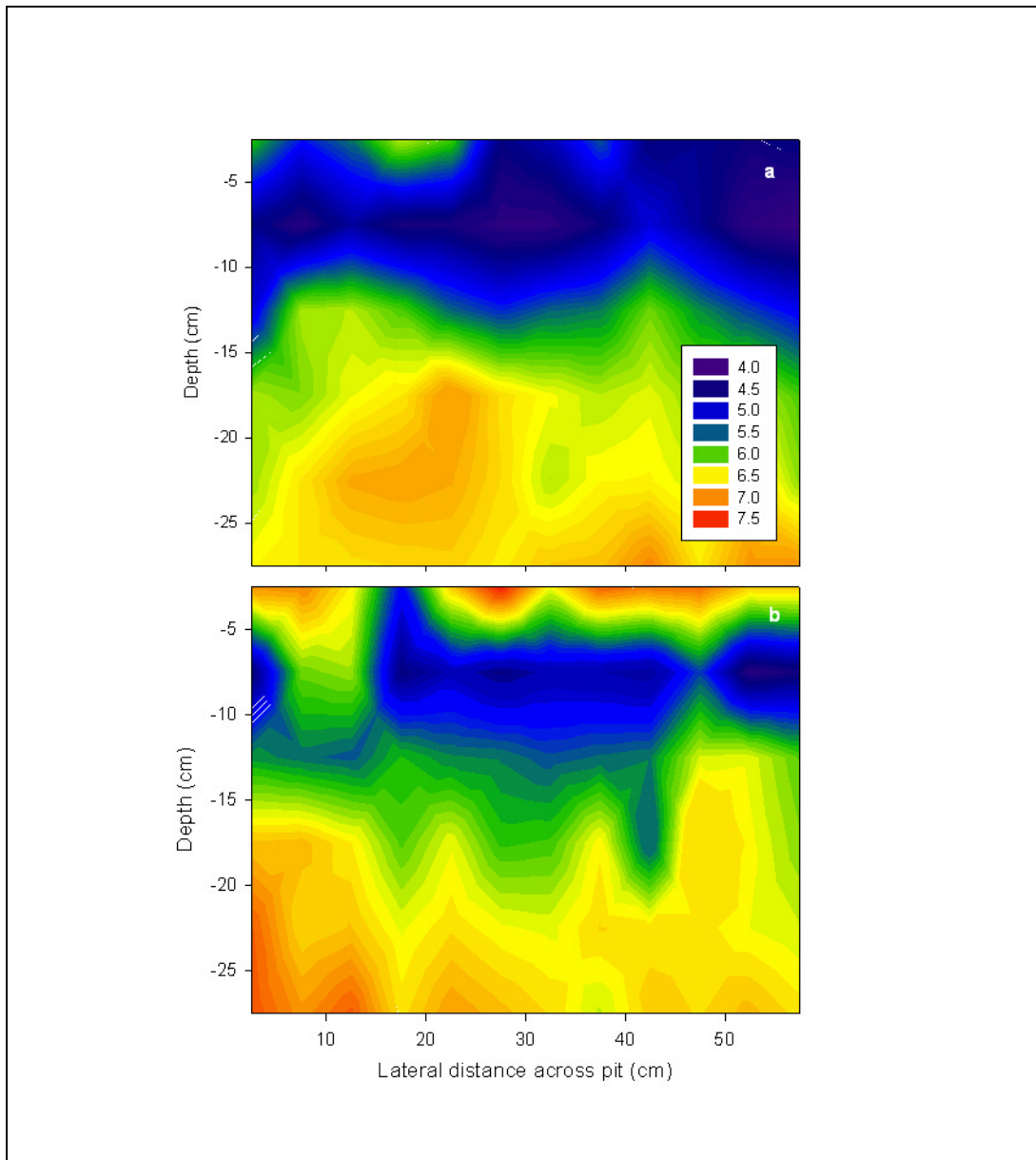


Figure 4. Color contour plots showing the spatial variability of soil pH with depth and distance across a 60-cm pit. Plot “a” is a control treatment while plot “b” is a broadcast lime treatment. The legend is soil pH measured in a 1:1 soil:water extract.

INTERACTION (COOPERATION) WITH OTHER SCIENTISTS CONDUCTING RELATED ACTIVITY

Dr. Greg Schwab initiated this project and had solicited the involvement of a group of scientists from Washington State University. Drs. Dave Huggins, Dave Bezdicek, Jim Harsh, Bill Pan and others in Plant Pathology were also involved in various aspects of the project from soil quality, soil chemistry and plant disease perspectives. Researchers in Oregon and Idaho have also extensively studied the issue of soil acidification in DS systems. Results of this work have been communicated to researchers in Oregon and Idaho, and will lead to additional interaction and

collaboration in the future.

PUBLICATIONS AND PRESENTATIONS:

Several presentations regarding preliminary findings were made at Direct Seed Conference in 2001, and at soil seminar at WSU.

Willey, T.I. 2002. The influence of seed placed lime to reduce the acidifying effects of nitrogen fertilizers in direct seeding systems. Washington State University MSc. thesis, 81pp.

Brown, T., R. Koenig, D. Huggins, R. Rossi and J. Harsh. 2004. Spatial Variability of pH in a Direct Seed Cropping System: Implications and Management Strategies. Abstract for the 2004 annual meetings of the American Society of Agronomy.

Brown, T., R. Koenig, D. Huggins, R. Rossi and J. Harsh. 2004. Spatial Variability of pH in a Direct Seed Cropping System: Implications and Management Strategies. Poster presentation made at the 2004 American Society of Agronomy meetings, Seattle, Washington.