TECHNICAL NOTE

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SOIL pH
IT'S RELATIOSHIP WITH CROP BIODIVERSITY and PRODUCTION

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What does pH and Biodiversity mean to Idaho's Agriculture?

Reductions in crop yield resulting from soil acidity have been well documented in the high precipitation areas of the United States and other countries around the world. During the early 80's University of Idaho (UofI) Research showed that increasing soil acidity was becoming a potential crop production limitation in northern Idaho and other Northwest cropland areas receiving intermediate precipitation levels.

Originally, cropland soils in northern and eastern Idaho were slightly acid (pH 6.5) to slightly alkaline (pH 7.2) when the sod was broken before the turn of the century. In 1984, UofI soil scientists estimated that over 45 percent of agricultural soils in northern Idaho were expressing pH values less than 5.6. A trend that is continuing today with soil analysis showing that not only are surface soil pHs declining but also the percent Base Cation Saturation, a measure of the percent hydrogen that is starting to occupy the negative charged surface of the soil colloids (organic matter, clays and fine silts). This acidification, which is present mainly in the surface 6 to 8 inches of soil, is attributed primarily to high application rates of ammonium-based nitrogen fertilizer over the past 60 years.

The major effect that this pH trending has is the potential loss of legumes in cropping systems for Idaho producers, a major resource concern for maintaining the biodiversity of Idaho's crops. Economics may drive a grower rotation; however, maintaining the option to use legume cover crops as an alternative to synthetic nitrogen is critical to organic farming systems and potentially to the sustainability of traditional crop production across Idaho.

What is an acid soil?

Soil pH is a measure of the soil acidity or alkalinity and is sometimes called the soil "water" pH. This is because it is a measure of the pH of the soil solution, which is considered the active pH that affects plant growth. Soil pH is the foundation of essentially all soil chemistry and nutrient reaction and should be the first consideration when evaluating a soil test. The total range of the soil pH scale is from 0-14. Values below the mid-point (pH 7.0) are acidic and those above pH 7.0 are alkaline. A soil pH of 7.0 is considered to be neutral. Most plants perform best in a soil that is slightly acid to neutral (pH 6.0-7.0). Some plants like blueberries require the soil to be more acid (pH4.5-5.5), and other, like alfalfa will tolerate a slightly alkaline soil (pH 7.0-7.5).

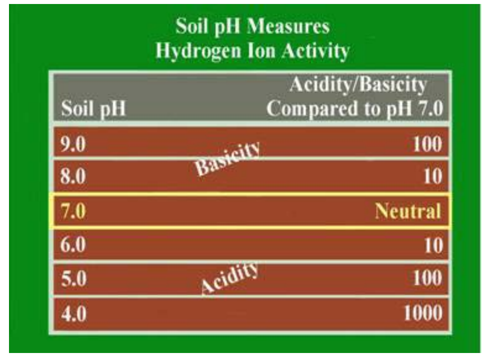


Fig 1. Soil pH 2008/9 Schools Wikipedia

Soil pH and balance between acidity and alkalinity expressed by measuring pH is a major indicator of the health of one of the major resource concern, its soils and sustainability of crop production. Crop nutrients whether macronutrients (large quantity- Primary N-P-K building blocks, Secondary a-Mg-S) or micronutrients (small quantity – specialty Zn, Fe, Mn, Cu, B and Mo) are all impact by soil pH and the soil chemistry that take place at soil acidity and alkalinity imbalance. The vary soil microbes that have impacted the pH of Idaho soils are affected by soil pH. These organisms and crop are affected by the pH of the soil. N is supplied as ammonium (NH_4) or nitrate (NO_3) in fertilizer amendments, and dissolved N will have the highest concentrations in soil with pH 6-8. Concentrations of available N are less sensitive to pH than concentration of available P. In order for P to be available for plants, soil pH needs to be in the range 6.0 and 7.5. If pH is lower than 6, P starts forming insoluble compounds with iron (Fe) and aluminum (Al) and if pH is higher than 7.5 P starts forming insoluble compounds with calcium (Ca).

What is the affect of Nitrification?

Nitrification the biological conversion of ammonium to nitrate nitrogen has an long term effect on soil pH. Nitrification is a two-step process involving two groups of bacteria, *Nitrosomonas* and *Nitrobacter*. The reactions are generally coupled and proceed rapidly to the nitrate form; therefore, nitrite levels at any given time are usually low. These bacteria known as “nitrifiers” are strict “aerobes,” meaning they must have free dissolved oxygen to perform their work. Nitrification occurs only under aerobic conditions at dissolved oxygen levels of 1.0 mg/L or more. At dissolved oxygen (DO) concentrations less than 0.5 mg/L, the growth rate is minimal.

The biological oxidation of ammonia results in the formation of two new forms of nitrogen, nitrite and nitrates. The oxidation of ammonia to nitrite is usually the rate limiting step of nitrification. Nitrification is an important step in the nitrogen cycle in soil and in the production of crops in Idaho. The oxidation of ammonia into nitrite is performed by two groups of organisms, ammonia-oxidizing bacteria and ammonia-oxidizing archaea. In soils the most studied Ammonia Oxidizing Bacteria (AOB) belong to the genera *Nitrosomonas* and *Nitrosococcus*. The second step (oxidation of nitrite into nitrate) is done (mainly) by bacteria of the genus *Nitrobacter*. Nitrifying organisms are chemoautotroph’s, and use carbon dioxide as their carbon source for growth. Some AOB possess the enzyme, urease, which catalyzes the conversion of the urea molecule to two ammonia molecules and one carbon dioxide molecule. *Nitrosomonas europaea*, as well as populations of soil-dwelling AOB, has been shown to assimilate the carbon dioxide released by the reaction to make biomass, and harvest energy by oxidizing ammonia (the other product of urease) to nitrite. This feature may explain enhanced growth of AOB in the presence of urea in acidic environments. These bacteria known as “nitrifiers” are strict “aerobes,” meaning they must have free dissolved oxygen to perform their work. Nitrification occurs only under aerobic conditions at dissolved oxygen levels of 1.0 ppm or more. At dissolved oxygen (DO) concentrations less than 0.5 ppm, the growth rates are minimal. This may be important in how slowly ammonium coverts in cold saturate or near saturated soils, like we have in parts of Northern and Eastern Idaho. Nitrification requires a long retention time, a low food to microorganism ratio, and adequate buffering (alkalinity).

The nitrification process produces and acidic environment. This acid formation lowers the pH of the biological population environment and can cause a reduction of the growth rate of nitrifying bacteria. Nitrification equations

$$2NH_4^+ + 3O_2 = 4H^+ + 4H_2O + 2NO_2^- + O_2 = 2NO_3^-$$

(*Nitrosomonas* and *Nitrosococcus*) (*Nitrobacter*)

The nitrification reaction in the conversion of 1-lb-N of anhydrous ammonia (82-0-0), Urea (46-0-0) and Urea Ammonium Nitrate-UAN (32-0-0) consumes 4.2 pounds of oxygen and generates enough acidity to neutralize 1.8 pounds of alkalinity as $CaCO_3$. The most acidifying form of nitrogen is ammonium

Table 1 shows the calculated equivalent acidity of common nitrogen materials.

Table 1. Calculated Equivalent Acidity/Alkalinity of Common Nitrogen Fertilizers

N Source	% N	Chemical Formula	100 Lb of Nitrogen or Phosphorus[1]	100 Lb of Fertilizer
Ammonium Sulfate	21	$(NH_4)_2SO_4$	524A	110A
Anhydrous Ammonia	82	NH_3	180A	148A
Ammonium Nitrate	34	NH_4NO_3	180A	61A
Urea	46	$CO(NH_2)_2$	180A	83A
UAN	28-32	$CO(NH_2)_2+NH_4NO_3$	180A	50A-58A
Calcium Nitrate	15	$Ca(NO_3)_2$	133B	20B
Sodium Nitrate	16	$NaNO_3$	180B	29B
Potassium Nitrate	13	KNO_3	200B	26B
Ammonium Phosphate	11-52-0	$NH_4H_2PO_4$	144A-P	75A
Ammonium Polyphosphate	10-34-0	$(NH_4)_2H_3P_2O_7$	212A-P	72A
Ammonium Phosphate Sulfate	16-20-0-14S	$NH_4H_2PO_4.(NH_4)_2SO_4$	440A-P	88A

Adapted from the Potash and Phosphate Institutes Soil Fertility Manual

[1] Pounds of calcium carbonate ($CaCO_3$) needed to neutralize the acidity formed from 100 pounds of nitrogen, or nitrogen containing fertilizer. The "B" denotes a basic (pH increasing) effect, the “P” denotes Phosphorus based. These are theoretical values and may differ somewhat in actual soil.

sulfate where each lb-N neutralizes 5.4 pounds of alkalinity as $CaCO_3$.Note that fertilizers with nitrate-N as the sole nitrogen form create alkalinity when applied to the soil. The fertilizer industry in North

Europe have used Calcium Nitrate for decades to offset the problems with soil acidification and assuring plant available Nitrate-N for spring and early summer crop production. As a topdress product each pound of N applied using Calcium Nitrate will generate an alkalinity equivalent of 1.35 pounds as $CaCO_3$.

Figure 2 shows that in a calcareous soil following the application of ammonia the solution pH is elevated to above a pH of 10. Following nitrification the solution pH is buffered back to the original pH through neutralizing reaction between the acidity generated through nitrification and the natural lime and calcium in the calcareous soil. Figure 3 shows the same reaction for an acid soil. This time the pH is not buffered back because of the lack of natural calcium carbonate and exchangeable calcium on the soil colloids.

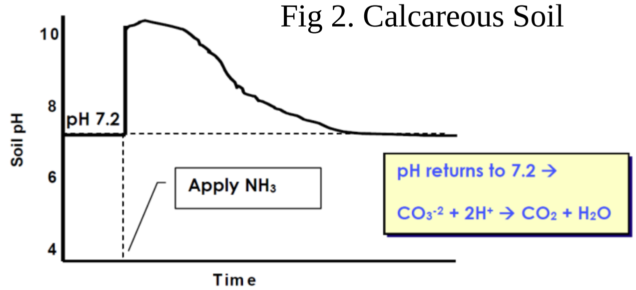


Fig 2. Calcareous Soil

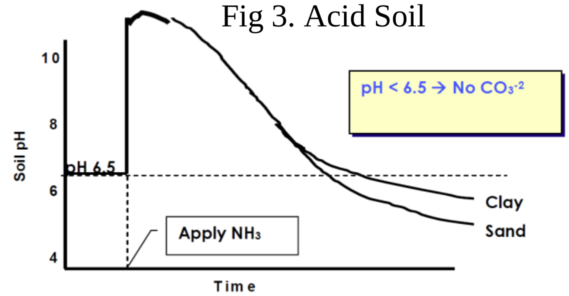


Fig 3. Acid Soil

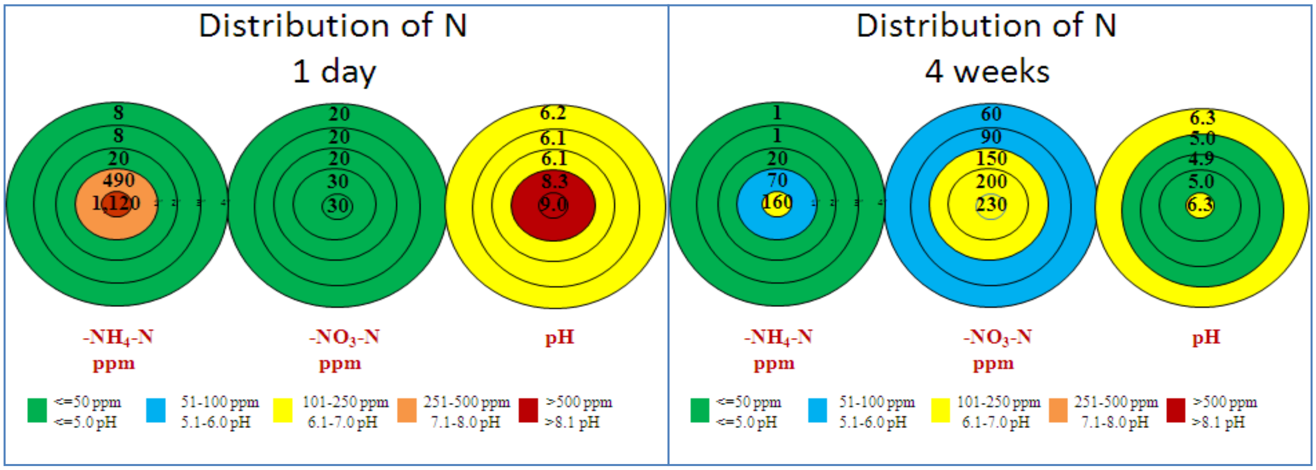
Stratification of soil acidity under direct seeding

A potential problem that has been discussed since the early 80's throughout Northern Idaho has been the affect of continuous direct seeding on the potential buildup of soil acidity in the zone of N fertilizer application. Under tilled systems, the surface soil is normally inverted and mixed with soil lower in the profile that usually contains higher amounts of soil bases (higher in pH).

The example as depicted in Figures 4 shows the pH shift and ammonia conversion NH_3-N (Soil Solution) at 0-1, 1-2, 2-3 and 3-4 inches from the point of injection at 1-day, 1-week, 2-weeks and 4-weeks following injection of 100 lb-N/A of NH_3 on loamy fine sand with 3.1% OM at 75% of field capacity. The optimum pH for Nitrosomonas and Nitrobacter is between 7.5 and 8.5. Nitrification slows down or stops at a pH below 6.0. Figure 4 shows the actual pH and ammonium and nitrate at 0 to 4 inches from the ammonia injection band. The nitrification process produces free Hydrogen (H^+), which when diffused through the cell walls of the root creates an acid environment surrounding the root. This acidification of the root surface lowers the pH of the soil solution surrounding the root and median in which the biological population is growing. This can cause a reduction of the growth rate of nitrifying bacteria. The optimum pH for *Nitrosomonas* and *Nitrobacter* is between 7.5 and 8.5. Nitrification stops at a pH below 6.0. The active acidity resulting from ammonium nitrification is buffered by the adsorb Base Cations (Ca^{+2}, Mg^{+2}, K^+, and Na^+) and soil carbonates salts (CO_3^{-2}) and soil solution bicarbonates (HCO_3^-) and hydroxides (OH^-) in the soil.

The buffering capacity of the soil is dependent on Cation Exchange Capacity, quantity of Base Cations and the presence of Free Lime. The sum of Base Cation and Free Lime determines the passive pH. As the alkaline of the soil solution is neutralized the soil pH (Active pH) drops. One of the visual effects of low soil pH is the presence of poor growth of a sensitive crop such as alfalfa. However, a soil test is the only reliable way of determining whether soil is acid or not. A lime requirement test (Buffered pH) should be used to determine the rate of lime to apply.

Fig 4. –Ammonia NH_3 conversion effect on Nitrogen form and soil pH



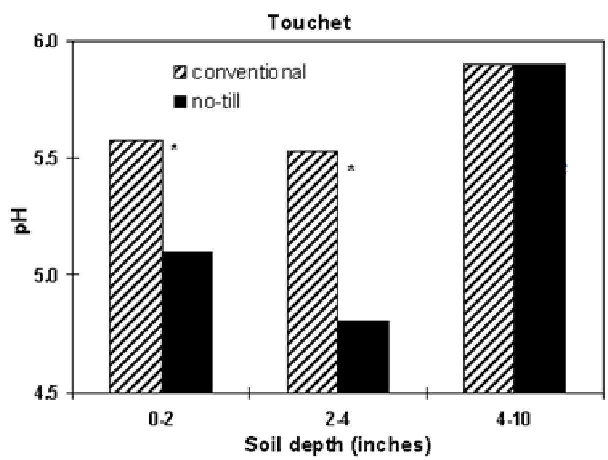


Fig. 5. Impacts and Management of Soil Acidity under Direct Seed Systems, Effects of Beneficial Soil Microbes and Soil Fauna. Department of Crop and Soil Sciences, WSU, Pullman, WA

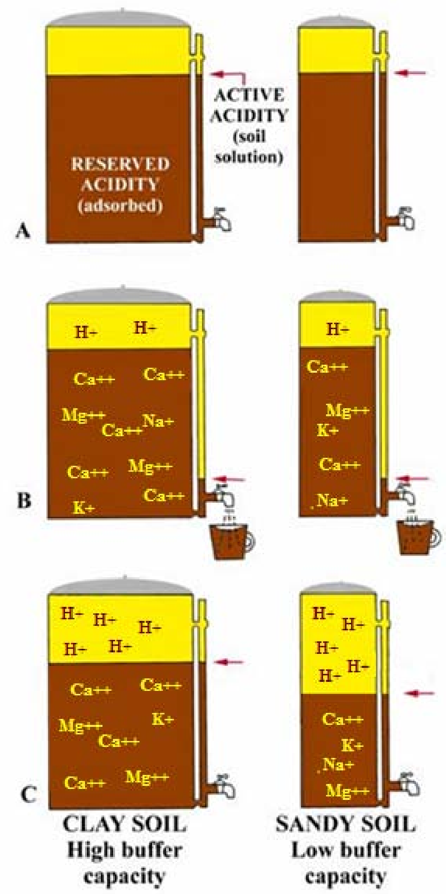
Figure 5 compares soil pH with depth under conventional and no till management at Touchet,WA (14 years no till) shows the trend observed in five of six paired conventional-no till sites where soil pH was substantially lower in the 2-4 inch zone under no till as compared to conventional management. This zone is where the majority of starter fertilizer (often 16-20-0 + S) is applied and close to where the majority of N is applied. Soil pH above this zone at the soil surface is usually higher in pH from deposition of bases from surface residue. Soil below this zone is higher in pH as well. A number of questions arise on whether long-term no till fields need to be tilled periodically to redistribute soil nutrients and to bring up higher pH soil to the soil surface. The trend analysis suggest the potential for limited liming of no till fields, however current University of Idaho recommendation is to take a wait and see strategy with crop selection tolerant to low pH being the current practice. However, as Conservation Planners our strategy is to assist the producer in maintaining soil chemical properties that offer producers the flexibility of using legume forage and cover crops in the rotation to attain compliance with a conservation practices resulting from identifying and addressing a resource concern.

Soil Testing for Lime Requirement - Buffer pH (SMP)

The Shoemaker, McLean and Pratt (SMP) lime requirement test is used to estimate the amount of lime required to raise the pH of the surface 3” of soil. This is a value that is generated in the laboratory; it is not an existing feature of the soil. Laboratories perform this test in order to develop lime recommendations, and it actually has no other practical value. In basic terms, the SMP is the resulting sample pH after the laboratory has added a liming material. In this test, the laboratory adds a chemical mixture called a buffering solution. This solution functions like extremely fast-acting lime. Each soil sample receives the same amount of buffering solution; therefore the resulting pH is different for each sample. To determine a lime recommendation, the laboratory looks at the difference between the original soil pH and the ending pH after the buffering solution has reacted with the soil. If the difference between the two pH measurements is large, it means that the soil pH is easily changed, and a low rate of lime will be sufficient. If the soil pH changes only a little after the buffering solution has reacted, it means that the soil pH is difficult to change and a larger lime addition is needed to reach the desired pH for the crop.

The reasons that a soil may require differing amounts of lime to change the soil pH relates to the soil CEC and the "reserve" acidity that is contained by the soil. Soil acidity is controlled by the amount of hydrogen (H^+) and the aluminum (Al^{+++}) ions that are either contained in, or generated by the soil and soil components. Soils with a high CEC have a greater capacity to contain or generate these sources of acidity. Therefore, at a given soil pH, a soil with a higher CEC (thus a lower buffered pH) will normally require more lime to reach a given target pH than a soil with a lower CEC

The following analogy (adapted and modified from University of Nebraska, Bulletin G74-153) may give a simple explanation. Consider two-coffee pots (figure to left) one 50-cup capacity and one 10 cup, both having the same size indicator tube and spigot. Coffee in the indicator tube represents the active acidity (measured by regular pH) and that coffee in the pot represents the reserve acidity (measured by buffer pH). Let the large pot represent a clay soil high in organic matter while the small pot represents a sandy soil. Both pots have equal amounts of coffee in the indicator tube; i.e., same active hydrogen, so same soil pH. Now open the spigot and remove one-cup of coffee from each pot (figure B). Removing one cup of coffee from each pot could be equated to the addition of small amount of limestone to an acid soil. Opening the spigot will cause the level of coffee in the indicator tube to drop below the level in the pot, but will return to almost the original level (clay soil) when the spigot is closed. The momentary drop of coffee in the indicator tube represents the initial increased in pH when lime is added (affects active hydrogen), but reserve hydrogen (similar to coffee in the pot) soon equalizes the effect from the lime and the pH returns to essentially its original level (clay soil, figure C). Thus, if the pH is 6.5 or lower, a buffer pH is run to measure the reserve acidity. The result of the buffer pH shows the amount of lime required to neutralize a major portion of the reserve acidity. The relative amounts of coffee in the two pots (figure C) show why a



sandy soil and clay soil with the same pH result in different lime requirements. For example, the small addition of limestone (equivalent to removing one cup of coffee from each pot) reduced the total coffee (reserve acidity) by 10% in the small pot (sandy soil), but only 2% of the large pot (clay soil). In a similar manner, 1 ton of agricultural limestone will make a greater difference in the pH of a sandy soil than of a clay soil.

Effects on crops of liming acid soils

The effect of soil acidity on a crop can occur at various pH levels. These effects can be divided into two general categories **- Direct and Indirect**. Table 3 profiles these effects on soil acidity and suggests beneficial effects from the application of lime to the various pH ranges found in Idaho soils. Soil acidity and the net effect of application of acid forming fertilizers has had an effect on the bio diversity of Idaho

Table 3. The effect of liming soil acidity on yield of crops.

<table>
<tr><th>Rating</th><th>Soil pH</th><th>Direct effects on crops</th><th>Indirect effects on crops</th></tr>
<tr><td rowspan="2">Slightly acid</td><td rowspan="2">6.1 to 6.5</td><td>No direct effect of liming on most crops.</td><td>Liming may improve the physical properties of some medium and fine textured soils (particularly ash influenced cutover soils).</td></tr>
<tr><td>Fields with an average pH just above 6.0 may have areas where the pH is below 6.0. Alfalfa and sweet-clover yields will be increased on the more acid areas.</td><td>Improved soil structure and reduced crusting will be particularly beneficial for small seeded crops such as canola.</td></tr>
<tr><td rowspan="4">Moderately acid</td><td rowspan="4">5.6 to 6.0</td><td>Improved survival and growth of rhizobium bacteria which fix nitrogen in association with alfalfa, lentils and sweet clover.</td><td>Liming may improve the physical properties of some medium and fine textured soils as indicated above.</td></tr>
<tr><td rowspan="2">Yields of alfalfa, lentils and sweet clover are increased.</td><td>Plant availability of phosphorous fertilizers is improved.</td></tr>
<tr><td>Increased microbial activity and release of plant nutrients.</td></tr>
<tr><td colspan="2">Increased nitrogen fixation and yield of legumes.</td></tr>
<tr><td rowspan="3">Strongly acid</td><td rowspan="3">5.1 to 5.5</td><td>Soluble aluminum and manganese are reduced to nontoxic levels.</td><td>Indirect effects as outlined above for moderately acid soils.</td></tr>
<tr><td colspan="2">Small increases in yield of barley occur in the first two or three years following lime applications with larger increases (25-30 per cent) occurring in subsequent years. Yields of wheat and canola will be increased less than barley. Yields of more acid tolerant crops may be increased as a result of indirect effects of lime as outlined above.</td></tr>
<tr><td colspan="2">Direct effects as outlined above for strongly acid soils.</td></tr>
<tr><td>Very strongly acid</td><td>Less than 5.1</td><td>Direct effects as outlined above for strongly acid soils.</td><td>Indirect effects as outlined above for moderately acid soils.</td></tr>
</table>

soils. As soils become acidic there is a strong correlation with loss of legumes, an very important rotational crops and a crop that may be critical to the sustainability of agriculture as we know it in Northern and Eastern Idaho.

Direct effects

Direct effects of acid soils are often expressed as metal toxicities and usually involve a soluble form of

aluminum and/or manganese. Trace nutrients are not major components of plant tissue, but, for example, make up key components of catalyst, enzymes and vitamins. Both macro and trace nutrient availability (Fig 6.) is controlled by soil pH. Organic crop production requires no commercial fertilizers but relies on both macro and trace nutrients being supplied by degradation of plant material through the activities of micro flora and fauna in the soil and nitrogen fixation through having legumes in the crop rotation. These organisms and crop are affected by the pH of the soil. N is supplied as ammonium (NH_4) or nitrate (NO_3) in fertilizer amendments, and dissolved N will have the highest concentrations in soil with pH 6-8. Concentrations of available N are less sensitive to pH than concentration of available P.
As soil acidity increases (pH decreases), soluble aluminum and manganese increase to toxic levels. Aluminum toxicity restricts root growth and phosphorus uptake. Manganese toxicity causes black necrotic spots or streaks on leaves of cereals and chlorosis on leaf margins and cupping of leaves of canola and legumes. Aluminum and manganese toxicity often reduce the yield of crops grown on acid soils. Soil acidity also has a direct effect on the survival and growth of rhizobium bacteria which fix nitrogen in association with legumes. The rhizobium bacteria associated with alfalfa and sweet-clover are especially sensitive to acidity. The application of lime reduces soil acidity (pH increases) which reduces soluble aluminum and manganese to nontoxic levels and creates a suitable environment for rhizobium bacteria.

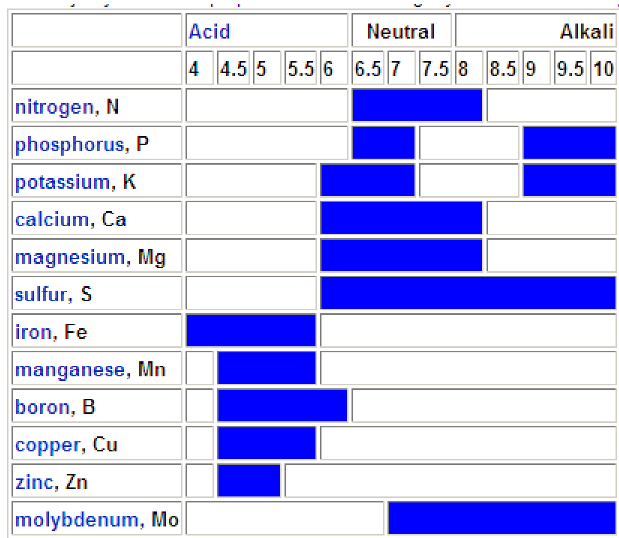


Fig 6. Nutrient availability in relation to soil pH

Specific to Idaho Crops

Several studies have looked at the effect of soil acidity directly on yield of Idaho crops. The relationships of soil pH to the potential yield of crops commonly grown in Idaho are shown in Table 2.

Table 2. The relationship of soil pH on the percentage maximum yield of crops grown in Northern Idaho

	Soil pH									
Crop	4.8	4.9	5.0	5.1	5.2	5.3	5.4	5.5	5.6	5.7
Alfalfa	-	-	-	-	-	-	70	80	90	100
Barley	54	64	74	83	93	100	100	100	100	100
Bluegrass	-	-	90	90	100	100	100	100	100	100
Lentils	36	43	50	57	65	72	79	86	93	100
Peas	33	33	51	59	68	77	86	94	100	100
Wheat	34-76	47-81	57-8.6	67-90	76-100	95-100	100	100	100	100

IMPACTS AND MANAGEMENT OF SOIL ACIDITY UNDER DIRECT SEED SYSTEMS- STATUS AND EFFECTS ON CROP PRODUCTION UOFI

In general, legume crops are most sensitive to acid soil conditions while cereal and grass crops are more tolerant to low soil pH.

Indirect effects

The application of lime to acid soils can affect biological, chemical, and physical properties of the soils.

The increase in soil pH resulting from the application of lime provides a more favorable environment for soil microbiological activity which increases the rate of release of plant nutrients, particularly nitrogen. Reduced soil acidity following liming also increases the availability of several other plant nutrients, notably phosphorus. Only about 20 per cent of fertilizer phosphorus is taken up by a crop in the year of application. The remainder is fixed in the soil in various degrees of availability to succeeding crops. On acid soils (pH less 6.0) the fixed phosphorus is retained in less available forms than on slightly acid and neutral soils (pH 6.1 to 7.5). Therefore one of the benefits of liming acid soils is the increased utilization of residual fertilizer phosphorus by crops.

The application of lime can also improve the physical properties of some soils. Reduced soil crusting, improved emergence of small seeded crops such as canola, and reduced power requirements for tillage have been noted as a result of lime applications on ashy cut over soils.

Management of acid soils

The first step in the management of acid soils is to identify the extent and severity of the problem. Poor yields of acid sensitive crops may indicate an acid soil condition, but soil tests are the only sure method of identifying an acidity problem. With careful sampling of fields, soil tests can determine the extent and severity of soil acidity, the rate of lime required, and provide an estimate of crop response to lime. An estimate of crop response along with the cost of lime provides a basis for assessing the economics of liming.

Each field that is to be limed should be carefully sampled. Divide a field into areas on the basis of soil type or differences in crop growth and sample each of these areas separately. Some areas of a field may require higher rates than others and some areas may not require any. A lime requirement test should be requested in order to determine the amount of lime required to bring the soil to pH 6.5.

In some cases, growing crops that are more tolerant to acidity is an alternative to liming. But as soils gradually become more acid, the choice of crops becomes very limited. The long-term goal should be to lime soils to a pH value best suited to the crops being grown. After a desired soil pH has been achieved, the amount of lime required to maintain soils in a suitable pH range will depend on fertilizer rates, soil type and cropping practices.

Rate of lime required

The rate of lime required depends on the amount of pH change that is required and the buffering capacity of the soil. Buffering capacity refers to the amount of lime required to change pH a given amount. Sandy soils and soils low in organic matter have low buffering capacities. Clay soils and soils high in organic matter have high buffering capacities. Tables 3 shows a typical lime recommendation chart utilizing a typical silt loam over a range of varying organic matter. Actual recommendations include many more combinations of Original pH, Target pH, and Buffer pH. SMP Buffer lime recommendations are expressed in pounds per acre of pure calcium carbonate ($CaCO_{3)}$ per 7 inch depth and typical finess of grind. *Make appropriate adjustments for the local lime source (see adjustments following lime tables).*

Table 3. Mineral Soil: Typical soils with organic matter between 0% to 5%						
Sample Lime ($CaCO_3$) Recommendations						
		Ton/Acre				
Original pH	Target pH	Soil Buffer pH (SMP)				
		5.0	5.5	6.0	6.5	7.0
4.5	5.0	6.0	4.7	3.3	1.9	0.5
4.5	5.5	8.4	6.5	4.6	2.6	0.7
4.5	6.0	10.1	7.8	5.5	3.2	0.9
4.5	6.5	11.4	8.8	6.2	3.6	1.0
5.0	6.0	8.4	6.5	4.6	2.6	0.7
5.0	6.5	10.1	7.8	5.5	3.2	0.8
5.5	6.0	0	4.6	3.2	1.9	0.5
5.5	6.5	0	6.5	4.5	2.6	0.7
6.0	6.5	0	0	3.2	1.9	0.57

The effect of soil acidity on yield of crops

Soil reaction (pH) affects the physical, chemical, and biological properties of soils and crop yields. Crops also vary greatly in their tolerance to the various components of acidity. As a result, the cause of soil acidity damage to crops is often rather complex. The following discusses the work that was a part of the STEEP Project and published as, "Wheat Response to Lime on Acid Soils". This research conducted by the UofI in early 80's showed that there is the potential of "Increasing acidity in the surface foot of soil has the potential of reducing yield potential of cereal and legume crops in northern Idaho and other Northwest cropland areas". This research has shown that lime (calcium carbonate) applications can increase yields of winter wheat and spring wheat if the soil pH is less than 5.3.

The UofI in a 4 years research project (1983 through 1986) demonstrated that in a 22- to 24-inch precipitation zone on silt loam soils with a saturated paste pH of the soil at 5.1. that addition of either suspension liquid lime (SL) or dry solid lime (DS) responded to the addition of lime when broadcast and incorporated 5 months before planting of the crop.

Liquid Lime Application Rate and Timing

Yield response of spring wheat and winter wheat to three rates of SL lime broadcast and incorporated 5 months before planting was compared with the same applications 2 days before planting, The lime used in the SL lime had a neutralizing value (Calcium Carbonate Equivalent) of 100. The SL lime contained 48 percent 200 mesh lime, 50.5 percent water and 1.5 percent suspension clay. The UofI study found that SL lime applied 5 months before planting at rates of 500 and 1,000 pounds/acre resulted in significant spring wheat yield increases of 50 and 63 percent, respectively (Table 4). The 250 pounds/acre rate, applied 5 months before planting, and all the application rates 2 days before planting did not result in spring wheat yields statistically superior to the check. The UofI scientists point out that this indicates the importance of applying lime in the fall before a spring crop to allow time for the lime to react with the soil and raise soil pH.

Table 4. Yields of spring wheat and winter wheat from plots treated with liquid lime (SL) either 5 months before or 2 days before planting at Moscow, ID, In 1983 and 1984 (Mahler, UofI).

Lime rate (lb/acre)	Application time	Yield[1]	
		Spring wheat 1983 (bu/acre)	Winter wheat 1984 (bu/acre)
0	Control	38d	48.3c
1,000	5 months before	62ab	69.0a
500	5 months before	57abc	58.6b
250	5 months before	53abcd	56.3bc
1,000	2 days before	48bcde	64.7a
500	2 days before	42cde	59.6ab
250	2 days before	37e	56.1bc

[1] Means in the same column followed by the same letter are not statistically different at the 0.05 level of probability.

With winter wheat, 500 and 1,000 pounds/acre applications of SL lime 5 months before planting increased yields 21 and 45 percent, respectively. When the same rates were applied 2 days before planting, yield increases were 23 and 34 percent, respectively. The 250 pounds/acre application rate did not significantly increase yield regardless of application date. In contrast to spring wheat, application date was not a factor in winter wheat response to lime. The winter months apparently allow the time necessary for the liquid lime to react with soil, consequently, masking any potential advantage of an earlier application date.

Liquid and Solid Lime Comparison

In 1985 and 1986, UofI researchers compared five application rates of SL and DS lime broadcast and incorporated 1 day before planting. The SL lime contained 48 percent 200 mesh lime, 50 percent water and 2 percent suspension clay. DS lime had the following particle size distribution: 80 percent passed a 20-mesh sieve, 50 percent passed a 60-mesh sieve and 20 percent passed a 100-mesh sieve. Both sources had a neutralizing value of 100. SL lime application rates of 2,000, 1,500, 1,000, 500 and 250 pounds/acre 1 day before planting resulted in spring wheat yield increases of 25.0, 13.4, 14.4, 11.4 and 11.0 bushels/acre, respectively (Table 5). No significant differences were found between yield responses to SL and DS lime at any application rate.

With winter wheat, SL lime application rates produced yields significantly higher than DS lime. SL lime applied at rates of 2,000, 1,500, 1,000,500 and 250 pounds/acre resulted in winter wheat yields of 38.8, 43.2, 42.7, 27.1 and 15.8 percent greater than the check, respectively. Yield increases with the same application rates of DS lime were only 21.1, 23.5, 9.8, 2.7 and 3.9 percent, respectively. Differences in winter wheat yield between liquid and solid lime were statistically significant at all application rates.

Incorporation vs. Non-incorporation

Wheat response to 500 and 1,000 pounds/acre rates of SL and DS lime broadcast and incorporated one day before seeding was compared with broadcast non-incorporated applications 3 days after seeding (Table 6). Differences were generally not statistically significant when comparing application rates of SL and DS lime on spring wheat and winter wheat yields.

A broadcast non-incorporated option for lime applications could be important in a no-till system. However, in this higher precipitation area, producers are generally not in a continuous no-till system for all crops, so lime could be applied when some tillage incorporation was possible in the rotation.

Table 5. Comparison of spring wheat and winter wheat yield responses to SL and DS lime broadcast and incorporated 1 day before planting near Moscow, ID, in 1985 and 1988 (Mahler, UofI)

Lime rate (lb/acre)	Lime source[1]	Yield (bu/acre)	
		Spring wheat 1985	Winter wheat 1986
2,000	SL	61.5NS	114.4**
2,000	DS	61.0	99.8
1,500	SL	55.8NS	118.0**
1,500	DS	54.1	101.8
1,000	SL	56.3NS	117.6**
1,000	DS	53.0	90.6
500	SL	54.8NS	105.0**
500	DS	52.5	84.6
250	SL	54.4NS	95.4*
250	DS	52.9	85.6
Check		49.2	82.4

[1]SL – Suspension Liquid Lime, DS – Dry Solid Lime
NS, * and ** designate not statistically different, statistically different at the 0.05 level and statistically different at the 0.01 level, respectively (statistical comparisons are only between lime sources at each application rate).

Table 6. Comparison of spring wheat and winter wheat yield response to broadcast Incorporated and non-incorporated applications of solid and liquid lime near Moscow, ID, in 1985 and 1988 (Mahler, Ul).

Lime rate (lb/acre)	Lime source	Application timing[1]	Yield[2](bu/acre)	
			Spring wheat 1985	Winter wheat 1986
1,000	SL	1 day before	56.3NS	117.6NS
1,000	SL	3 days after	55.0	107.8
1,000	DS	1 day before	53.0*	90.6NS
1,000	DS	3 days after	46.0	85.6
500	SL	1 day before	54.8NS	105.0**
500	SL	3 days after	54.3	92.6
500	Solid	1 day before	52.5NS	84.6NS
500	Solid	3 days after	51.7	82.4
Check			49.2	82.4

[1]1 day before — incorporated before-planting application; 3 days after— non-incorporated after-planting application.
[2]NS, * and * * designate not statistically different, statistically different at the 0.05 level and statistically different at the 0.01 level, respectively (statistical comparisons are only between application for each lime source and rate).

In summary

Soil acidity is identified by the measurement of soil reaction (pH). The reaction is alkaline when the pH value is above 7.0; neutral at 7.0; and acid below 7.0. In practical terms, soils between pH 6.5 and 7.5 are considered neutral. Soils in the range 5.6 to 6.0 are moderately acid and below 5.5 strongly acid. Organic crop production requires no commercial fertilizers but relies on both macro and trace nutrients being supplied by degradation of plant material through the activities of micro flora and fauna in the soil and nitrogen fixation through having legumes in the crop rotation. These organisms and crop are affected by the pH of the soil.

Nitrogen is supplied as ammonium (NH_4) or nitrate (NO_3) in fertilizers and soil amendments, and dissolved N will have the highest concentrations in soil with pH 6-8. Concentrations of available N are less sensitive to pH than concentration of available P. In order for P to be available for plants, soil pH needs to be in the range 6.0 and 7.5. If pH is lower than 6, P starts forming insoluble compounds with iron (Fe) and aluminum (Al) and if pH is higher than 7.5 P starts forming insoluble compounds with calcium (Ca).

Nitrification the biological conversion of ammonium to nitrate nitrogen has an long term effect on soil pH. Nitrification is a two-step process involving two groups of bacteria, *Nitrosomonas* and *Nitrobacter*. These bacteria known as “nitrifiers” are strict “aerobes,” meaning they must have free dissolved oxygen to perform their work. The biological oxidation of ammonia results in the formation of nitrates-N is accompanied with the production of hydrogen, which results in the acidification of the soil.

The buffering capacity of the soil is dependent on Cation Exchange Capacity, quantity of Base Cations and the presence of Free Lime. The sum of Base Cation and Free Lime determines the passive pH. As the alkaline of the soil solution is neutralized the soil pH (Active pH) drops. One of the visual effects of low soil pH is the presence of poor growth of a sensitive crop such as alfalfa. However, a soil test is the only reliable way of determining whether soil is acid or not. A lime requirement test (Buffered pH) should be used to determine the rate of lime to apply.

The Shoemaker, McLean and Pratt (SMP) lime requirement test is used to estimate the amount of lime required to raise the pH of the soil surface. The SMP value reflex the acidify effect of the acid in the soil sample on the buffered pH (7.5) of the buffer solution. The proper time to take the soil test for determining buffer pH is before the addition of any fertilizer since the fertilizer itself can have a temporary effect on the soil. Acid soils often contain soluble forms of aluminum and manganese. As soil acidity increases (pH decreases), soluble aluminum and manganese increase to toxic levels. The application of lime to acid soils can affect biological, chemical, and physical properties of the soils. The increase in soil pH resulting from the application of lime provides a more favorable environment for soil microbiological activity which increases the rate of release of plant nutrients, particularly nitrogen.

The application of lime to acid soils can affect biological, chemical, and physical properties of the soils. The application of lime can also improve the physical properties of some soils. Reduced soil crusting, improved emergence of small seeded crops such as canola, and reduced power requirements for tillage have been noted as a result of lime applications on ashy cut over soils.

The effect of soil acidity on a crop can occur at various pH levels. These effects can be divided into two general categories - **Direct and Indirect**. Direct effects of acid soils are often expressed as metal toxicities and usually involve a soluble form of aluminum and/or manganese. As soil acidity increases (pH decreases), soluble aluminum and manganese increase to toxic levels. Several of Idaho crops are directly affected by lowering soil pH and thus their inclusion in the Biodiversity of Idaho Crops.

Management of acid soils

The first step in the management of acid soils is to identify the extent and severity of the problem. Poor yields of acid sensitive crops may indicate an acid soil condition, but soil tests are the only sure method of identifying an acidity problem. With careful sampling of fields, soil tests can determine the extent and severity of soil acidity, the rate of lime required, and provide an estimate of crop response to lime. An estimate of crop response along with the cost of lime provides a basis for assessing the economics of liming. Research in Northern Idaho has demonstrated that in a 22- to 24-inch precipitation zone on silt loam soils with a saturated paste pH of the soil at 5.1 the addition of either suspension liquid lime (SL) or dry solid lime (DS) resulted in significance responded to the addition of lime when broadcast and incorporated 5 months before planting of the crop. The study concluded that:

1. For a spring crop, SL lime was more effective when applied in the fall than in the spring, allowing more soil reaction time under moist conditions. A similar advantage would be expected with DS lime. For winter wheat, SL lime application just before planting appears to be about as effective as application the previous spring. Earlier application of DS lime may be advantageous, however.
2. Fall applications of 500 and 1,000 pounds/acre of SL lime to acid soils (pH 5.1) significantly increased spring wheat and winter wheat yields.
3. When applied in equal amounts, SL lime usually produced wheat yields superior to DS lime. The difference in yield response can be explained by the fact that finer mesh-size SL lime has a greater surface area and contacts more soil than DS lime, consequently, neutralizing soil acidity at a faster rate.
4. Even though SL lime applications were successful in these experiments, the lower cost of DS lime must be considered. When material and application costs are taken into account, SL lime may be as much as three times more expensive than solid lime.
5. SL lime has some advantages that may overcome some of the cost difference. These include:
    a. possible use of commonly available spraying equipment;
    b. quicker reaction time in the soil and improved yield response; and
    c. greater uniformity of application on hilly terrain.
6. SL lime at low rates (500 pounds/acre) may give a yield benefit on the crop in the crop year when-applied, but it does not correct the acid soil problem. Thus, it is only a temporary measure.

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