First Things First

A "pH Neutral" Strategy

CALCIUM PRODUCTS
INCORPORATED

The Challenge to Achieve High Soil Productivity

Soil productivity is determined by the balance of chemical, physical and biological processes in the soil. One of the most important properties of a soil that effects these processes is its **reaction** or **pH**.

A principal reason for this is that pH can be used to indicate the chemical status of soil as it affects many biological processes, including plant growth, Extremes in reaction, resulting from either strong acidity or strong alkalinity, indicate conditions that interfere with these processes. Where adverse conditions of this type exist, it is usually necessary to adjust the pH, if maximum plant growth is desired.

In this booklet you will learn:

- What is soil pH
- Factors affecting soil pH
- What is the ideal soil pH for corn, soybeans and alfalfa
- The impact of soil pH on yield of corn, soybeans and alfalfa
- Why soil pH affects yield
- How to manage soil pH problems with lime ($CaCO_3$) or gypsum ($CaSO_4$)
- Benefits of SuperCal® 98G (pelletized $CaCO_3$) and SuperCal® SO_4 (pelletized $CaSO_4$)

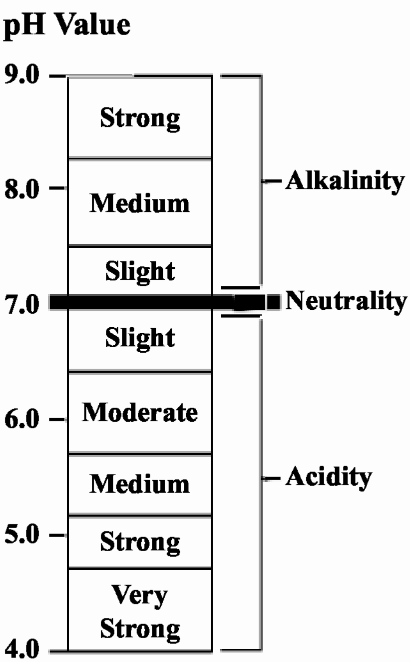
Notice:

Information concerning Pelletized Limestone and Gypsum in this booklet was obtained using SuperCal® 98G (Pelletized Limestone) and SuperCal® SO_4 (Pelletized Gypsum). Our Limestone is usually 99% $CaCO_3$ and Gypsum is 95% $CaSO_4 \cdot 2H_2O$. The Limestone and Gypsum are ground to an average particle size of 100 mesh.

Calcium Products, has the highest quality products in the midwest. So if you are using a product made by a competitor, you more than likely will not experience the results you would experience with our products.

What is Soil pH?

The term pH defines the relative acidity or alkalinity of a substance. The pH scale covers a range from 0 to 14. A pH value of 7.0 is neutral. Values below 7.0 are acid. Those above 7.0 are alkaline. Most productive soils range from a pH of 4.0 to a pH of 9.0 The degree of acidity and alkalinity for such a pH range is shown on this scale.



An acid is a substance that releases hydrogen ions (H^+). When saturated with H^+. a soil behaves as a weak acid. The more H^+ held on the exchange complex, the greater the soil's acidity. Aluminum also acts as an acidic element and activates H^+. Basic ions such as calcium (Ca^{++}) and magnesium (Mg^{++}) make soil less acid (more alkaline) in reaction.

Soil pH simply measures hydrogen ion activity and is expressed in logarithmic terms. The practical significance of the logarithmic relationship is that each unit change in soil pH means a tenfold change in the amount of acidity or alkalinity. The is, a soil with a pH of 6.0 has 10 times as much active H^+ as one with a pH of 7.0. This means that lime need increases rapidly as pH drops.

Source: Soil Fertility Manual. The Potash and Phosphate Institute.

Table 1. Relationship of various pH levels compared to neutral

Soil pH		Acidity/Alkalinity Compared to pH 7.0
9.0	Alkalinity	100
8.0		10
7.0		Neutral
6.0	Acidity	10
5.0		100
4.0		1,000

Source: Soil Fertility Manual. The Potash and Phosphate Institute.

Factors Affecting Soil pH

The degree of soil acidity or alkalinity is influenced by the kinds of parent materials from which the soil was formed. Soils developed from alkaline rocks or parent material generally have higher pH's than those formed from acid rocks.

Rainfall also affects soil pH. Water passing through the soil leaches basic nutrients such as Ca and Mg into drainage water. They are replaced by acidic elements such as hydrogen (H), manganese (Mn) and aluminum (Al). So soils formed under high rainfall conditions are more acid than those formed under arid conditions.

Soils may become more acid when harvested crops remove alkalines such as Ca and Mg. Different crops remove different amounts of Ca and Mg. Legumes generally contain higher amounts than non-legumes. Ca and Mg contents also vary according to the portion of the plant harvested.

Table 2. Crop removal of calcium (Ca) and magnesium (Mg)

Estimated Calcium and Magnesium Removed by Crops			
		lbs/A Removed	
Crop	**Yield/Acre**	**Ca**	**Mg**
Alfalfa	8 tons (hay)	200	40
Corn	150 bu (grain) 4.5 tons (stover)	3 28	14 30
Soybeans	50 bu (grain)	10	15

Source: Soil Fertility Manual. The Potash and Phosphate Institute.

Fertilization, especially with nitrogen (N) fertilizers, speeds up the rate acidity develops. At lower N rates, acidification is rather small. But as N rates increase, acidification can be substantial. (See page 4 showing how N fertilizer affects soil pH.) On calcareous soils, the acidifying effect from fertilization can be beneficial. Where iron (Fe), manganese (Mn) or one of the other micronutrients may be deficient, lowering soil pH will make them more available.

Nitrogen fixation by bacteria on legume roots contributes to soil acidification. Organic matter decomposition adds to soil acidity. One of the first products formed during the process is ammonia. When the ammonia is converted to nitrates, through nitrification, H^+ is released, and acidity increases. The process is illustrated below. (The effects of adding fertilizer ammonia nitrogen are similar.)

$$2NH_3 + 3O_2 \xrightarrow[\text{Bacteria}]{\text{Nitrifying}} 2NO_3^- + 6H^+$$

(Ammonia) (Oxygen) Bacteria (Nitrate) (Hydrogen)

How nitrogen fertilizer affects soil acidity

When the nitrification process converts the ammonium ion to nitrate, hydrogen ions are released, shown by the following reaction.

$$2NH_4 + 3O_2 \xrightarrow[\text{Bacteria}]{\text{Nitrifying}} 2NO_3 + 8H^+$$

(Ammonia) (Oxygen) Bacteria (Nitrate) (Hydrogen)

This is a source of soil acidity. So N fertilizers containing or forming ammonium-N increase soil acidity unless the plant absorbs the ammonium ion directly and an anion with it.

Also, nitrate is a major factor associated with leaching of such alkalines as calcium (Ca), magnesium (Mg), and potassium (K) from the soil. The nitrate and alkalines move out together.

As these alkalines are removed and replaced by hydrogen, soils become more acid. Nitrogen fertilizers containing such strong acid-forming anions, such as sulfates, increase acidity more than other carriers without acidifying anions.

Carriers such as sodium nitrate and calcium nitrate leave the cation in the soil. This makes the soil less acid.

The table on the following page shows how different N sources affect the acidity or alkalinity of soils.

Table 3. How different N sources affect the acidity or alkalinity or soils

N Source	N (%)	Calculated Equivalent Acidity or Alkalinity*
Ammonium Sulfate	21.0	535
Anhydrous Ammonia	82.5	180
Ammonium Nitrate	33.5	180
Calcium Nitrate	15.0	135B
Sodium Nitrate	16.0	180B
Potassium Nitrate	13.0	200B
Urea	46.0	180
* Pounds of calcium carbonate ($CaCO_3$) needed to neutralize the acidity formed from 100 pounds of N. The "B" denotes alkaline effect. These are theoretical values and probably higher than actually takes place in the soil.		

Source: Soil Fertility Manual. The Potash and Phosphate Institute.

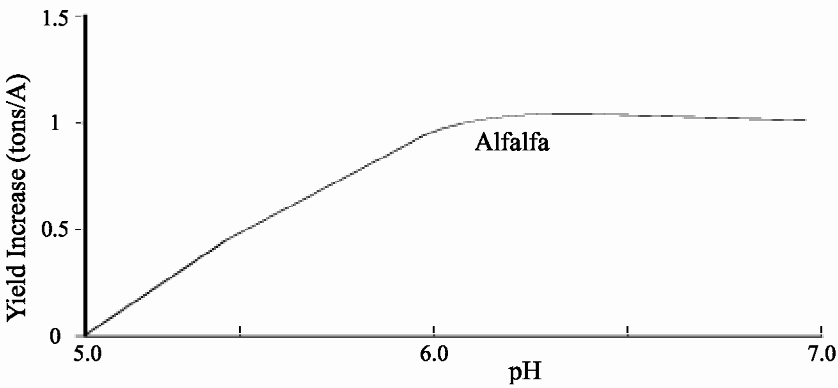
What is the ideal soil pH for corn, soybeans and alfalfa

Table 4. Ideal pH, preferred range and tolerant range in pH for corn, soybeans and alfalfa.

Crop	Ideal pH	Preferred Range	Tolerant Range
Corn	6.8	6.0 to 7.5	5.5 to 8.0
Soybeans	6.8	6.0 to 7.0	5.5 to 7.5
Alfalfa	7.0	6.8 to 7.5	6.5 to 8.0

Source: Midwest Laboratories

Alfalfa yields drop dramatically when pH drops below 6.0.



*Source: R.D. Voss et al., **Iowa Extension Pamphlet** 315, 1965.*

Figure 1. Response of alfalfa to increases in pH above 5.0 induced by soil liming.

Impact of Soil pH on Yield of Corn, Soybeans and Alfalfa

Table 5. Relative percent yield at different pH levels for corn, soybeans and alfalfa.

	Relative (%) Yield at Different pH Levels				
Crop	**pH 4.7**	**pH 5.0**	**pH 5.7**	**pH 6.8**	**pH 7.5**
Corn	34	73	83	100	85
Soybeans	65	79	80	100	93
Alfalfa	2	9	42	100	100

Source: Midwest Laboratories

If a soil pH of 5.7 gives 83% of a potential 200 bu/A corn crop, that represents a 34 bu/A loss of genetic yield potential. If a soil pH of 7.5 gives 85% of a potential 200 bu/A crop, that represents a 30 bu/A loss of genetic yield potential.

The following table illustrates corn yield response in a field to low soil pH, as captured by GPS yield monitor and grid soil sampling. There was a 60 bushels per acre difference from a more desirable soil pH of 6.5 to 6.8 versus 5.1 to 5.6.

Table 7. Corn yield response in a field to low soil pH.

Field Section A	Field Section B
Yield Average	Yield Average
190 bushels	**130 bushels**
Soil pH 6.5 to 6.8	Soil pH 5.1 to 5.6
P & K (Very High)	P & K (Very High)
Organic Matter (Similar)	Organic Matter (Similar)

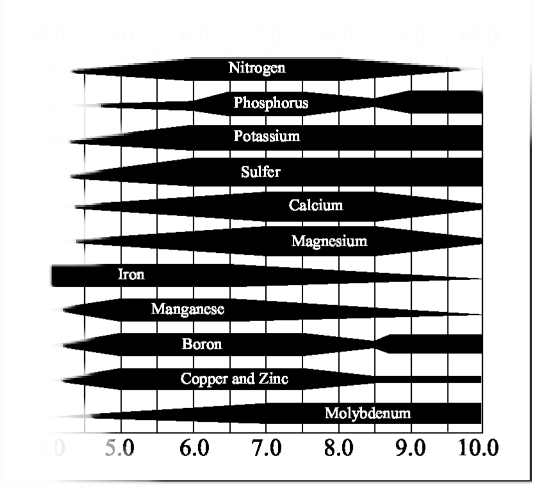
Source: Agri-Growth, Inc.

Why Soil pH Impacts Yield

Soil pH can have a dramatic impact on crop yield because it has a direct effect on nutrient availability and microbial activity in the soil.

Nutrient availability as affected by soil pH

The reason for yield loss when soil pH drops below 6.0 and above 7.0 is primarily due to reduced nutrient availability, as illustrated below.



Source: University of Wisconsin – Extension

Figure 2. Effect of pH on nutrient availability

Table 8. Influence of soil pH on lime requirement and nutrient availability

pH	5.0	5.5	6.0	6.5	7.0	7.5
Lime Requirement	Lime required except for special acid tolerant crops			No lime except for alfalfa and sweet colover		
Phosphate Relation	Phosphates become fixed with iron and aluminum		Phosphates are generally soluble		Phosphates become fixed with calcium	
Trace Element Relation	Manganese, aluminum, iron, copper, zinc, cobalt, and boron are increasingly soluble; manganese and aluminum toxicity may occur		Manganese, iron, copper, boron and cobalt are increasingly available satisfactory amount		Manganese, iron, copper, zinc and boron are increasingly fixed	

Source: Soil Fertility Manual. The Potash and Phosphate Institute.

The availability of phosphorus varies with soil pH. It is most available from a pH 6.0 to pH 7.0.

Soil reaction (pH) greatly influences how soluble different P compounds are in the soil, how available the phosphorus is and how fixed or tied up it becomes in the soil.

In acid soils (decreasing pH), phosphorus reacts with iron, manganese, and aluminum to form insoluble products – making P less available.

In alkaline soils (increasing pH), calcium reacts with phosphorus to lessen the P availability as pH increases above 7.0.

The more soluble or available forms of P exist in the 5.5 to 7.0 pH range. This makes a sound liming program essential on very acid soils.

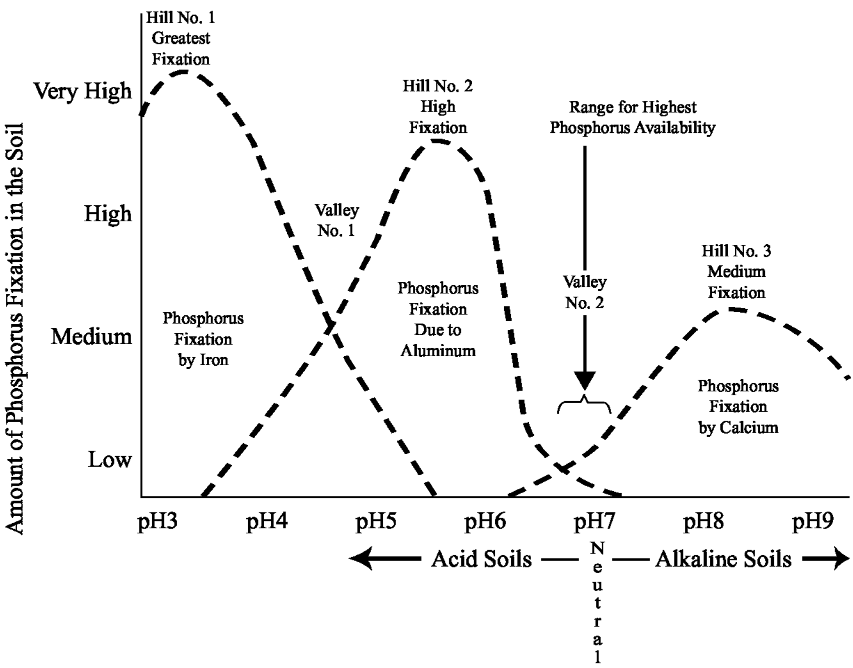
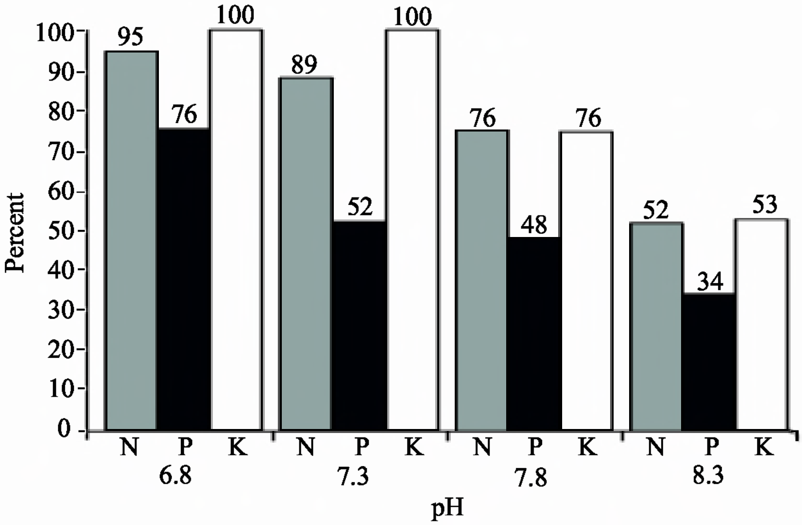


Figure 3. The hills and valleys of phosphorus fixation.

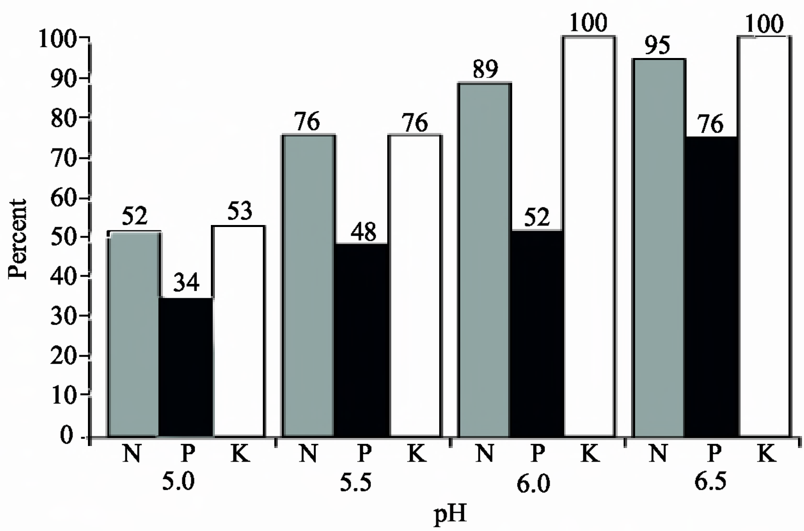
Source: Soil Fertility Manual. The Potash and Phosphate Institute.

The following graphs illustrate the impact soil pH has on the relative availability of N, P_2O_5, and K_2O for plant uptake.



Source: Midwest Laboratories

Figure 4. Neutral to high pH and percent relative availability of N, P_2O_5, and K_2O for plant uptake.



Source: Midwest Laboratories

Figure 5. Neutral to low pH and percent relative availability of N, P_2O_5, and K_2O for plant uptake.

Microbial activity as affected by soil pH

Fungi thrive in lower pH soils and bacteria in higher pH soils. The pH range between 6.0 and 6.5 is most desirable for both fungi and bacteria. Nitrogen is freely fixed between a pH of 6.0 to 7.5.

Table 9. Influence of soil pH on microbial population and activity.

pH	5.0	5.5	6.0	6.5	7.0	7.5
Bacteria and Fungi Activity	Fungi thrive, bacteria languish, nitrogen is not freely fixed.		Desirable bacteria and fungi activity. Nitrogen is freely fixed.		Bacteria thrive, fungi languish, nitrogen is freely fixed.	

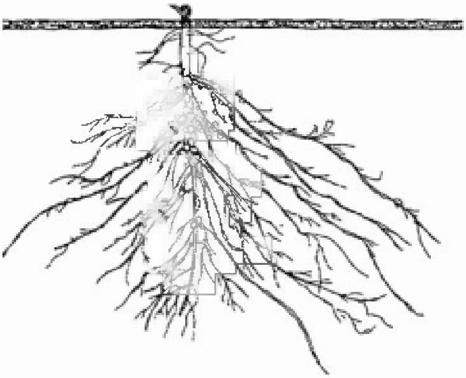
Source: Soil Fertility Manual. The Potash and Phosphate Institute.

As illustrated in Table 10, soil pH has an impact on nodule forming bacteria. When soil pH drops below 6.0 and rises above 7.4 nodulation drops off dramatically.

Table 10. Soil pH effect on nitrogen fixation

Soil pH	Nodules/Plant
4.0	0
5.0	30
6.5	77
7.4	68
8.2	21
8.7	3

Source: Albrecht, W.A. 1933. Inoculation of legumes as related to soil acidity. Agronomy Journal 25: 512-522.



Source: Agri-Growth, Inc.

Figure 6. Nodulation of soybean root system can be affected by soil pH.

How to Manage Soil pH Problems With Lime ($CaCO_3$) or Gypsum ($CaSO_4$)

Knowledge of soil pH allows certain useful judgments about the chemical and nutritional status of the soil. Extremes in pH suggest problems that may need correction before good plant growth can be obtained. In the strongly acid range, the problem may be excess soluble Al^{3+} or Mn^{2+}. The solubility of these ions increases with increasing acidity, and either may be toxic to plants. The availability of plant nutrients such as phosphorus and molybdenum may also be seriously reduced under strongly acid conditions.

Soil problems in the strongly alkaline range are normally associated with excess exchangeable Na^+ or in calcareous soil with high concentrations of bicarbonates (HCO_3^-) or carbonates (CO_3^{2-}). By and large, these problems are the result of poor tilth caused by the inability of exchangeable Na^+ to maintain the soil in a well-structured state.

Where the soil pH falls outside the desired range, it can be adjusted by treating the soil with an amendment such as lime or gypsum.

> An amendment is a material other than fertilizer that is added to the soil to improve conditions for plant growth. The effect may be either physical or chemical.

Lime is used to overcome excess soil acidity; it not only supplies Ca^{2+}, either alone or in combination with Mg^{2+}, to displace exchangeable H^+ and Al^{3+}, but more importantly, it provides OH^- ions for the neutralization and inactivation of soluble H^+ and Al^{3+}.

Excess exchangeable Na^+, HCO_3^- and CO_3^{2-} can be removed from soils by treating with an amendment that increases the supply of soluble Ca^{2+} in the soil solution. Through exchange, the added Ca^{2+} displaces the Na^+, which can then be removed from the soil by leaching. The amount of leaching is dependent on the internal drainage of the soil. HCO_3^- and CO_3^{2-}, which increase in their concentration as soil becomes alkaline, can also be leached from by adding Ca^{2+}. The amendment most often used for supplying soluble Ca^{2+} is gypsum.

Table 11. Guideline use rates for soil amendments

Ca/Mg Base Saturation (Index Number[1])	Pelletized Lime Factor X (lbs/A)[2,3,6]	OR	Pelletized Gypsum (lbs/A)[4,5,6]
0 – 2.5	500 – 1000	OR	300
2.6 – 2.75	400 – 875	OR	250
2.76 – 3.0	300 – 750	OR	200
3.1 – 3.25	200 – 625	OR	100
3.26 – 3.5	0 – 500	OR	0
3.6 +	0		

[1] Index number = % Calcium Base Saturation ÷ % Magnesium Base Saturation
[2] Lime rates will vary by crop, methods of incorporation, and time of year applied
[3] Lime rate/unit of buffer index (7.0 – buffer index = number of units). A maximum economical rate/A for pelletized lime is about 500 lbs/year.
[4] Rate/A of gypsum (suggested high rate for a pelletized product is 300 – 400 lbs/A/year.)
[5] Gypsum should be applied in the fall or winter for best soil conditioning effects.
[6] The use of lime or gypsum will vary with crops grown, soil pH and whether it's sand, silt or clay.

Source: Midwest Laboratories

Table 11 gives guidelines for application of pelletized lime and gypsum based on the Ca/Mg ratio. These are guidelines and all factors relating to the application site and crop to be grown must be considered.

Why acid soils should be limed

Soil acidity affects plant growth in many ways. Whenever pH is low (acidity is high), one or more detrimental effects may depress crop growth:

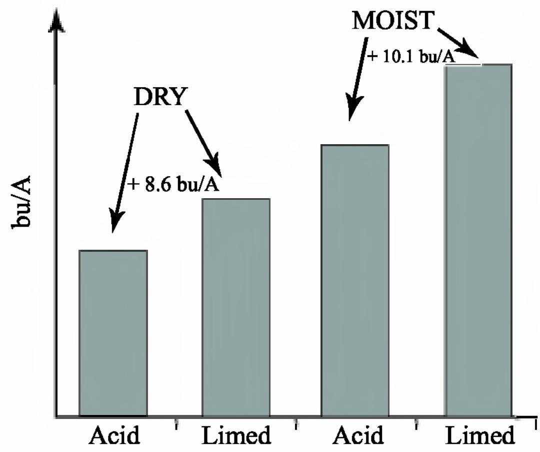
1. Concentrations of such elements as Al and Mn can reach toxic levels because their solubilities increase in acid soils
2. Organisms responsible for decaying organic matter and transforming N, P and S may be low in number and activity.
3. Calcium nay be deficient when the CEC of the soil is extremely low. Magnesium may also be deficient.
4. Symbiotic N fixation by legumes is greatly reduced. The symbiotic relationship requires a narrower pH range for optimum growth than plants not requiring N fixation. The symbiotic bacteria for soybeans function best in a 6.0 – 6.2 pH range, alfalfa best in a 6.8 – 7.0 pH range.
5. Clay soils high in acidity are less highly aggregated. This causes low permeability and aeration, an indirect effect because limed soils produce more crop residue. The residues give better structure.
6. Availability of nutrients such as P and Mo is reduced.

Liming acid soils corrects the above conditions. It also decreases the tendency of K to leach.

Lime does much more than sweeten the soil. It also:

- Improves the physical conditions of the soil.
- Stimulates microbe activity in the soil.
- Makes minerals more available to plants.
- Supplies calcium and magnesium for plants.
- Improves symbiotic N fixation by legumes.

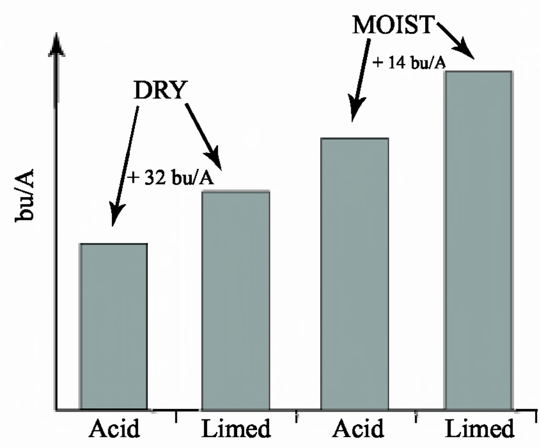
Yields can rise sharply when acidic soybean soil is limed to a near neutral pH 7.0. In figure 7, lime gave an 8.6 bushel per acre increase in dry years, a 10.1 bushel per acre increase in moist years. In all cases, the soybeans were well fertilized. Lime and fertilizer are a high-yield, high profit team.



Source: Soil Fertility Manual. Potash & Phosphate Institute

Figure 7. Soybean response to lime (good fertility).

Farmers can do everything right but one basic step–and lose yields and profits. They can fail to lime acid soils and lose yields in both dry and moist years, as long term research shows in Figure 8. Lime helps the corn and soybean grower get top dollar return from his fertilizer.



Source: Soil Fertility Manual. Potash & Phosphate Institute

Figure 8. Corn response to lime (good fertility).

How lime reduces soil acidity

The process and reactions by which lime reduces soil acidity are very complex. But a simplified view will show how lime works.

As mentioned earlier, the pH of a soil is an expression of the hydrogen ion concentration. Lime reduces soil acidity (increases pH) by converting some of those hydrogen ions into water. Simply, the reaction works like this:

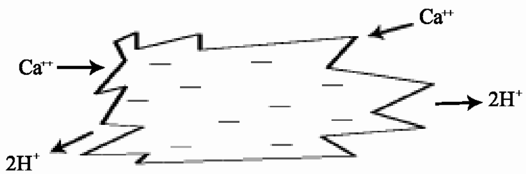
> **ONE** Ca^{++} from the lime replaces **TWO** H^{+} ions on the cation exchange complex. The H^{+} ions are combined with hydroxyl (OH^{-}) ions to form water. So the pH increases since the H^{+} concentration, the source of soil acidity, decreases.

Remember that the reverse of the above process can also occur. An acid soil can become more acid if a liming program is not followed. As alkaline ions such as Ca^{++}, Mg^{++} and K^{+} are removed, usually by crop uptake, they can be replaced by H^{+}. These alkaline ions can also be lost by leaching, again being replaced by H^{+}. The H^{+} activity will steadily increase, lowering soil pH, if the soil is not limed properly.

Liming reactions

	$2H^{+}$-Clay + $CaCO_3$ $\longrightarrow$ Ca^{++}-Clay + H_2CO_3 (Limestone) (Carbonic Acid)
Then:	**H_2CO_3 $\longrightarrow$ H_2O + CO_2** (Carbonic Acid) (Water) (Carbon Dioxide)

Ca^{++} replaces H^{+} on soil surfaces because of simple attraction.



Each Calcium ion replaces 2 Hydrogen Ions.

Timing and frequency of lime applications

The best way to determine liming needs is to soil test. Complete grid samples should be taken every 3 – 5 years and random samples taken yearly. Sandy soils need to be sampled more often.

- **Soil Texture** – Sandy soils must be relimed more often than clay soils.
- **Rate of N Fertilization** – High rates of ammonia-N forms generate considerable acidity.
- **Amount of Lime Applied** – Higher application rates usually mean the soil need not be relimed as often. But don't over lime.
- **The pH Range Desired** – Maintenance of high pH usually means that lime be applied more frequently than where an intermediate pH is satisfactory. Often the desired pH range is not reached because of underliming, poor quality lime (coarse particles) or incomplete mixing. Soil tests can monitor pH changes with lime. Pelletized lime will be more reactive and give a greater return per dollar spent.

Soil pH versus buffer index

While pH is related to soil acidity, it is not a direct measurement of the amount of acidity or the amount of hydrogen ions which must be replaced and neutralized by liming.

A pH reading measures the active acidity, while the buffer pH indicated the potential acidity. The amount of potential acidity for any given soil pH will depend upon the amount and type of clay and the level of organic matter in that soil. Therefore, it is possible to have two soils with the same soil pH but with different buffer pH's. A lower buffer pH represents a larger amount of potential acidity and thus more lime is needed to increase the soil pH to a given level. Table 12 illustrates the relationship between soil pH, buffer index and lime requirements.

Table 12. Example of the relationship of soil pH, buffer index and lime requirements.

Soil Type	Soil pH	Buffer Index	Lime Rec.
Sand	5.6	6.8	1 ton
Silt	5.6	6.6	2 tons
Clay	5.6	6.2	4 tons

Source: Midwest Laboratories

Selecting a liming material–quality aspects

In selecting a liming material, check its neutralizing value, its degree of fineness and its reactivity.

Neutralizing values of all liming materials are determined by comparing them to the neutralizing value of pure calcium carbonate ($CaCO_3$). By setting the neutralizing value of $CaCO_3$ at 100, a value for other materials can be assigned. This value is called the “relative neutralizing value” or “calcium carbonate equivalent” (CCE). Table 12 gives the CCE for several common liming materials.

Table 12. The relative neutralizing values (CCE) for several common liming materials.

Liming Material *	Relative Neutralizing Value (%)
Calcium Carbonate	100
Dolomitic Lime	95 – 108
Calcitic Lime	85 – 100
Baked Oyster Shells	80 – 90
Marl	50 – 90
Burned Lime	150 – 175
Burned Oyster Shells	90 – 110
Hydrated Lime	120 – 135
Basic Slag	50 – 70
Gypsum	None
By-products	Variable
* Dependent on location and quality of quarries	

Source: Soil Fertility Manual. The Potash and Phosphate Institute.

SMP buffer test (pH_{SMP})

The SMP buffer test (pH_{SMP}) was developed in Ohio and measures the total soluble and exchangeable hydrogen and aluminum. It is reliable for soils with a greater than 1 ton/A lime requirement and it is also well adapted for acid soils with a pH below 5.8 containing less than 10% organic matter and having appreciable amounts of aluminum.

If the soil pH is greater than 6.5, the SMP buffer test is not made, since lime is not needed for most crops.

Crops raised on organic soils usually do not benefit from liming unless the soil pH is lower than 5.3.

Table 13 gives the amount of pure $CaCO_3$ or ag-ground limestone to bring mineral and organic soils to a desired pH range.

Table 13. Amounts of lime required to bring mineral and organic soil to indicated pH according to pH_{SMP} test.

Buffer Index (pH_{SMP})	Desired Soil pH				
	Mineral Soils				Org. Soils
	7.0	7.0	6.5	6.0	5.2
	Pure $CaCO_3$	Ag-ground Limestone[4]			
	Application Rate: ton/A[1,2,3]				
7.0					
6.9					
6.8	1.2	2.0	1.5	1.0	1.0
6.7	2.0	3.0	2.5	2.0	1.5
6.6	2.7	4.0	3.5	3.0	2.0
6.5	3.5	5.0	4.5	3.5	3.0
6.4	4.5	6.0	5.5	4.5	3.5
6.3	5.3	7.5	6.0	5.0	4.0
6.2	6.1	8.5	7.0	6.0	4.5
6.1	6.8	10.0	8.0	7.0	5.0
6.0	7.6	11.0	9.0	7.5	6.0
5.9	8.7	12.0	10.0	8.0	6.5
5.8	9.3	13.0	11.0	9.0	7.0
5.7	10.1	14.5	12.0	10.0	7.5
5.6	10.9	15.5	13.0	10.5	8.0
5.5	11.7	16.5	14.0	11.5	9.0
5.4	12.7	18.0	15.0	12.5	9.5
5.3	13.4	19.0	16.0	13.0	10.0
5.2	14.3	20.0	17.0	14.0	10.5
5.1	15.2	21.5	18.0	14.5	11.0
5.0	16.0	22.5	19.0	15.5	12.0
4.9	16.9	23.5	20.0	16.0	12.5
4.8	17.6	25.0	21.0	17.0	13.0

[1] Sampling depth: 9 inches

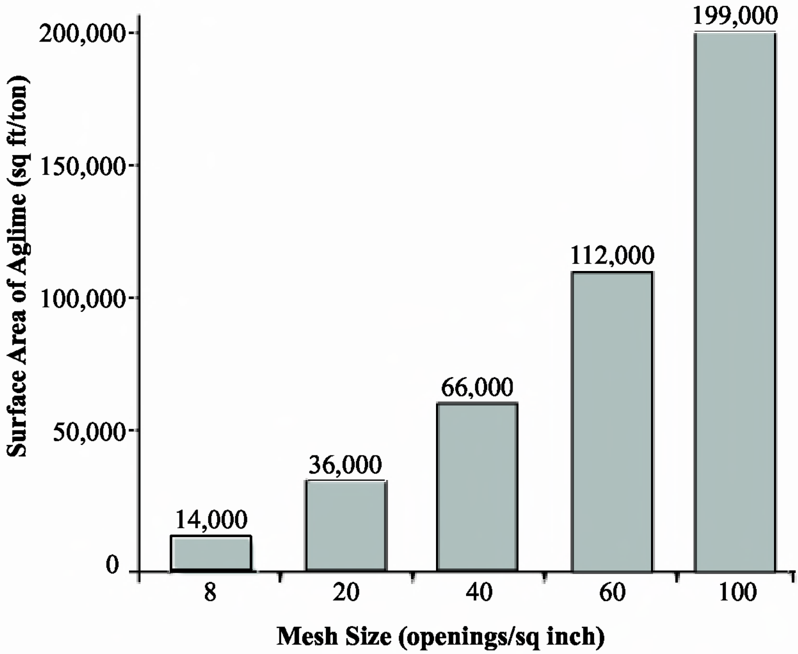
[2] To convert lime recommendations to depth of tillage other than 9 inches, divide above rates by 9 and multiply by the depth of plowing (inches)

[3] Maximum lime recommendation for one season is 5 tons/A. Retest advisable in two to three years for additional lime needs.

[4] Ag-ground lime of 90%+ TNP or $CaCO_3$ equivalent, and fineness of 40% 100 mesh, 50% 60 mesh, 70% 20 mesh, and 95% 8 mesh.

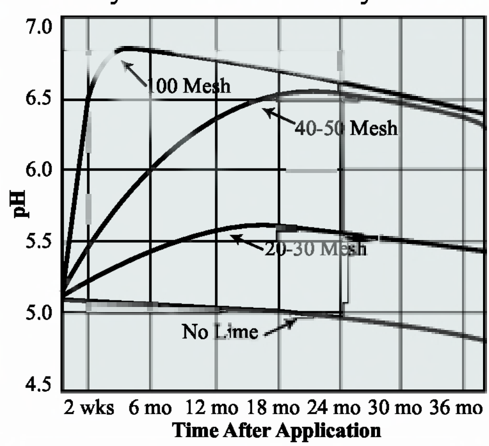
Source: Midwest Laboratories.

When a given quantity of lime is mixed with the soil, its reaction rate and degree of reactivity are greatly determined by particle size. Coarse lime particles react more slowly and less fully. Fine lime particles react more rapidly and much more fully. Figures 8 and 9 show the finer the lime particles, the more surface area available, and the more rapidly the reaction or pH change one can expect.



Source: National Stone Association

Figure 9. $CaCO_3$ is not very soluble in water so it must be finely ground to effectively neutralize soil acidity.



Source: Miller, R.W. and D.T. Gardiner. Soils in our Environment 8th Ed. p. 272

Figure 10. Relationship between particle size and increase in pH.

Cost of lime increases with the fineness of grind, but the increased costs are offset by rapid pH change and improved crop performance. The goal is a material that contains enough fine material to cause a rapid pH change. As a result, agricultural liming material contains both coarse and fine materials. Some states require a certain percentage of lime to pass through certain mesh sizes. This guarantees the lime will be of sufficient quality to neutralize acidity. The importance of particle size is shown in the table below.

Table 13. Effects of fineness on availability of $CaCO_3$.

	Years After Application	
	1	4
Mesh Size	Percent Reacted	
Coarser than 8	5	15
8 to 20	20	45
20 to 50	50	100
50 to 100	100	100

Source: National Stone Association

This table tells a dramatic story about lime particle size and degree of reactivity. Large particles (coarser than 8 mesh) were only 15 percent effective after 4 years. Smaller ones (50 to 100 mesh) reacted completely the first year.

Lime Placement

The most important factor determining the effectiveness of lime is placement. Placement for maximum contact with the soil in the plow layer is essential. To begin with, most common liming materials are only slightly soluble in water, so distribution in the soil is a must for lime reaction. Even when properly mixed with the soil, lime will have little effect on pH if the soil is dry. Moisture is essential for lime-soil reaction to occur.

When applying large amounts of lime to clay soils, best mixing comes from applying part before disking and plowing and the rest after. On sandy soils that can be harrowed or disked four to six inches deep, one application, disked in before or after plowing, will do.

In some cropping systems, such as no-till and perennial crops, mixing can be done only before seeding. Once the crop is established, the lime must be topdressed. Surface-applied lime reacts more slowly–and not as completely– as lime mixed with the soil. It is suggested to take a shallow sample before and after the lime application to get a better determination of the pH change. Fields may not be relimed before pH drops below the desired range to avoid excess acidity in the root zone.

Pelletized lime

Pelletized lime is the ideal way to attack your low pH soil problem. The 99% pure $CaCO_3$ begins reacting in the soil immediately due to the fineness of grind of the pelletized lime and continues over three years. When you use nitrogen, the hydrogen will start to lower the pH of your soil, so an annual application of 100 to 200 pounds of pelletized lime per acre should be applied for proper pH maintenance.

Once work is started on low pH problems, a lot of flexibility exists. Using pelletized lime in low pH soil creates a "friendlier environment" for growth. So if your pH is 5.5, and you desire to take the pH of your soil to 6.5, you have the luxury of doing it over an extended period and spreading the cost over several years. Pelletized lime gradually raises the pH of your soil at $10 to $20 per acre per year with a continual return on your investment each year.

Pelletized lime has a high neutralizing value. A high neutralizing value combined with fineness (usually 100% passing the 50 mesh) gives the grower the way to "power up" his pH the first year (usually with increases yields).

Source: Calcium Products, Inc.

Figure 11. Pelletized lime comes in extremely small particle sizes.

Actual Study of 74.1 Acre Field

Some people consider pelletized limestone (SuperCal 98G) a quick fix. Based on figure 10, page 19 the pH is raised quickly (100 mesh lime) than over the next 30 months loses one half point. Ag-lime takes 18 months to raise the pH 1/2 point (20 mesh lime*) page 19. This is the reason soil testing labs make Ag-lime recommendations in tons. There is a very small amount of extremely fine material in a ton of Ag-lime, therefore to get some reaction a lot of material has to be spread. Notice on page 24 and 25 the field average was increased .4 with the addition of just 600 lbs. of SuperCal 98G over 5 years. Think of all the fuel that was saved by not hauling all the Ag-lime needed to the field, plus the extra spreading and loader work. One ton of SuperCal 98G covered 6.67 acres. It would have taken 13 1/2 tons of Ag-lime to do the same spread (not the same results).

With the high cost of imputs do you really want to wait 3 years for Ag-lime. How about 98G and get your pH increase in days not years, at the same time your P & K will become more available. Look at page 23 P & K for 1999 and 2004.

* Mesh is the number of openings per. square inch, ie. this would equal 20 openings per square inch.

Soil Samples from 1999

	Field Median	Fertility Level				
		V Low	Low	Medium	High	V High
Water pH	5.1					
Phosphorus	139					
Potassium	512					

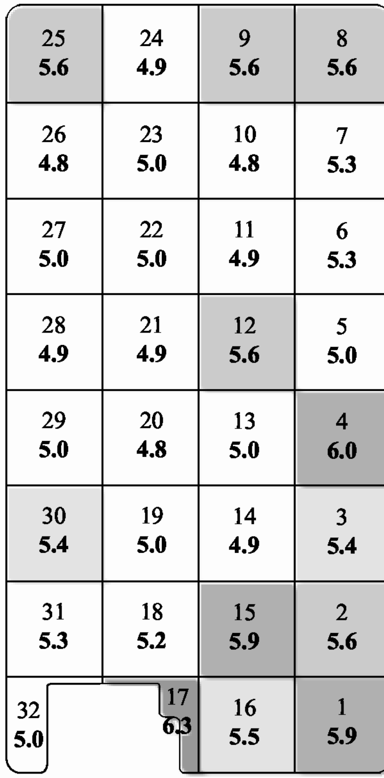
Soil Samples from 2004

	Field Median	Fertility Level				
		V Low	Low	Medium	High	V High
Water pH	5.7					
Phosphorus	150					
Potassium	588					

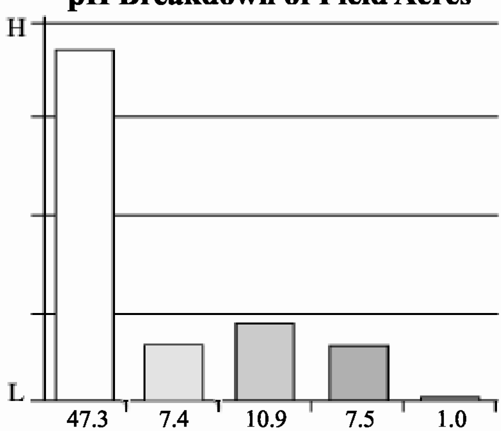
Kossuth County: Tested 07/09/1999

Field Average: 5.3
Total Map Acres: 74.1

Legend		Avg.
	Below 5.3	5.0
	5.3 – 5.5	5.4
	5.6 – 5.8	5.6
	5.9 – 6.2	6.0
	6.3 – 6.7	6.3
	Above 6.7	



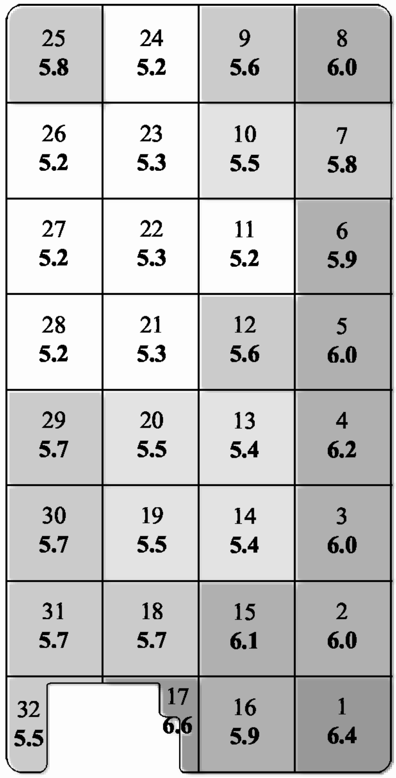
pH Breakdown of Field Acres



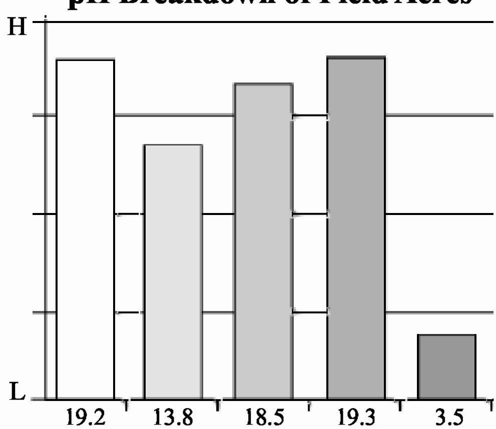
Kossuth County: Tested 06/21/2004

Field Average: 5.7
Total Map Acres: 74.3

	Legend	Avg.
	Below 5.3	5.2
	5.3 – 5.5	5.5
	5.6 – 5.8	5.7
	5.9 – 6.2	6.0
	6.3 – 6.7	6.5
	Above 6.7	



pH Breakdown of Field Acres



How to manage high pH soils (soil greater than pH 7.0)

High pH soils (above 7.0) can be managed for improved productivity by:

- Banding of fertilizer
- Using Acid forming fertilizer
- Applying gypsum annually

What is Gypsum?

$$CaSO_4 \longrightarrow Ca^{++} + SO_4^{=}$$

As soil pH rises above 7.0 calcium becomes less soluble and immobile and available for plant uptake, only soluble Ca^{++} and exchangeable Ca^{++} can be utilized by plants. Table 14 shows the amount of Ca^{++} and $SO_4^{=}$ used by 200 bu/A corn and 80 bu/A soybeans.

Table 14. Nutrient needs of corn and soybeans.

	200 bu/A Corn	80 bu/A Soybeans
Nutrients in seed and stover	• 42 lbs (0.21 lb/bu) **Calcium** (90% left in stover)	• 136 lbs (1.7 lb/bu) **Calcium** (88% left in stover)
	• 32 lbs (0.16 lb/bu) **Sulfur** (56% left in stover)	• 36 lbs (0.45 lb/bu) **Sulfur** (56% left in stover)

Soil pH and solubility of lime and gypsum

Limestone (calcium carbonate) becomes less soluble than gypsum between pH 7.0 to 8.3. This is when gypsum is really needed because:

- Gypsum can release free calcium up to soil pH of approximately 8.5
  - $CaSO_4 \longrightarrow Ca^{++} + SO_4^{=}$
- Only high sulfate and HCO_3^- concentration slows the dissolution of gypsum

As the pH of the soil rises above 7.0, bicarbonates (HCO_3^-) and carbonates ($CO_3^{=}$) increase, raising the soil pH. Free calcium from gypsum lowers the concentration of both and can drop the pH of the soil solution from 8.0 to 7.3. This helps drop the soil solution pH in the root zone, increases nutrient availability and reduces the toxic compounds (HCO_3^- and $CO_3^{=}$) that negatively impact plant growth, especially soybeans.

High soil pH and "Iron Deficiency Chlorosis (IDC)" in soybeans

In high pH or alkaline soils, yellow soybeans are often observed. This is often associated with Iron Deficiency Chlorosis (IDC). The following is what we know about IDC:

- Low iron content of the soil is seldom the cause. Availability of iron to the plant is usually the cause.
- Iron, as all plant nutrients, must be in soil solution for plants to be able to take it up. Iron solubility is at a minimum between pH 7.4 and 8.5.
- IDC symptoms are often seen on soils with high levels of free calcium carbonates. This further reduces the solubility of iron.
- Soil compaction can aggravate IDC, but it may also reduce its symptoms. This is likely attributable to the fact that compacted soil holds less oxygen, which can bind with iron, making it less available to the plant.
- Excessively wet or dry conditions can make IDC symptoms worse.
    - In wet soils, carbon dioxide accumulates in the soil, forming bicarbonate, reducing iron solubility.
    - In dry conditions, soluble salts tend to accumulate, or precipitate, near the surface of the soil through capillary action. Capillary action is the movement of water with other ions, such as calcium to the surface of the soil. This is readily observed in many areas of Minnesota.
- Root diseases, such as rhizoctonia and pythium, favored by wet soil conditions, may also interfere with the plant's ability to take up iron.

Managing Iron Chlorosis in soybeans with gypsum

- As the pH of the soil rises above 7.0, bicarbonates (HCO_3^-) and carbonates ($CO_3^=$) increase, raising the soil pH.
- Free calcium from gypsum lowers the concentration of bicarbonates and carbonates and can drop the pH of the soil solution from 8.0 to 7.3.

> - Gypsum can release free calcium up to soil pH of approximately 8.5
>
> $$CaSO_4 \longrightarrow Ca^{++} + SO_4^{=}$$
>
> - Ca^{++} ties up bicarbonate (HCO_3)
>   - Drops the pH of the soil solution
>   - Keeps HCO_3^- away from Fe
>   - Ensures better Fe solubility at root surface
> - $SO_4 + Fe^{++} = FeSO_4$
>   - $FeSO_4$ increases Fe uptake
>   - $SO_4^=$ also increases Zn and Mn uptake

- This helps drop the soil solution pH in the root zone, increase nutrient availability and reduce the toxic compounds (HCO_3 and $CO_3^=$) that negatively impact plant growth, especially soybeans.

Source: Agri-Growth, Inc.

Figure 12. Soybean plant at R2 stage

Benefits of Pelletized Gypsum

SuperCal SO_4 pelletized gypsum offers these benefits to corn and soybean growers:

- Improves plant health and productivity
- Is an excellent source of readily available calcium and sulfate for the plant at all soil pH levels
- Improves nitrogen utilization and fixation by legumes like soybeans
- Helps manage micronutrient deficiencies such as iron chlorosis in soybeans
- Improves soil structure, aeration, drainage, and rootability of plants in conventional and especially in no-till soils
- Reduces soil surface crusting and improves seedling emergence
- Will reduce the soil pH of sodic soils and help create the optimum calcium/magnesium ratio (4:1) in your soil
- Helps fight diseases caused by fungi, such as white mold

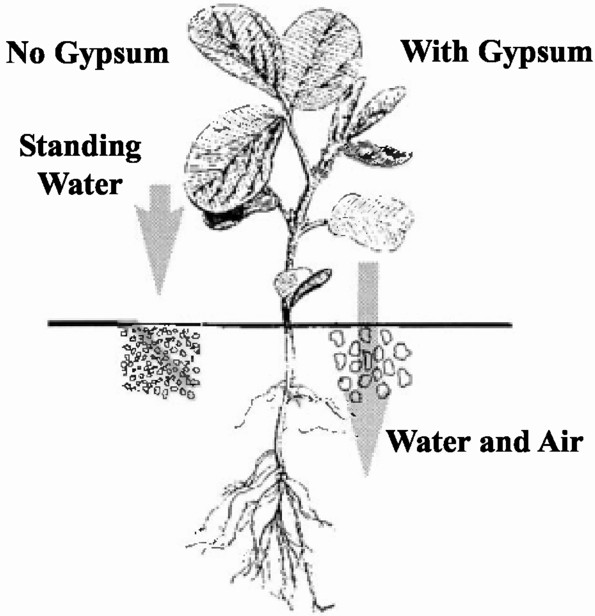


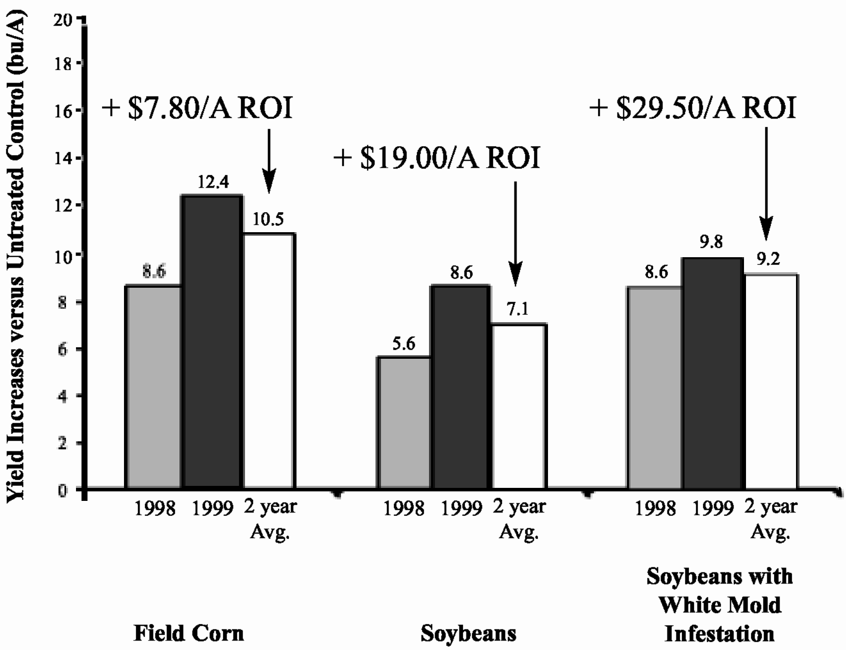
Figure 13. Gypsum helps soil drain and aerate.

Results from precision concept research

precision concept research is research in actual commercial field situations and uses precision farming technologies to examine product efficacy. Field-sized plots are planted and harvested with conventional farm equipment outfitted with GPS equipment. Results from precision concept research reflect the results growers can expect to see in their own fields.

The following are precision concept research studies conducted in 1998 and 1999 with pelletized SuperCal SO_4 on corn, soybeans, and alfalfa. The soil pH on these studies range from 7.5 to 7.9.

1998 and 1999 Summary of the Yield Advantage of Using SuperCal SO_4 on Corn and Soybeans[1,2,3]

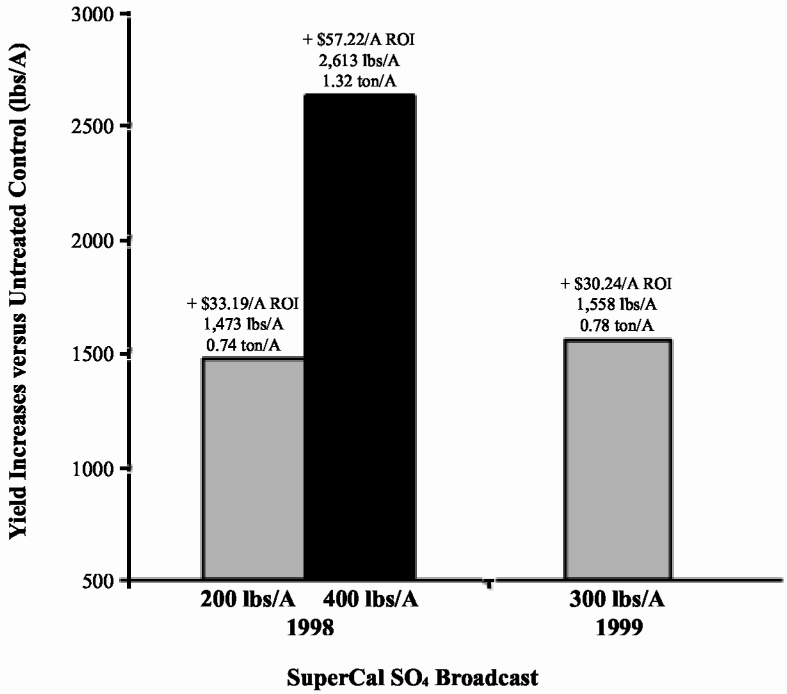


[1] SuperCal SO_4 was applied at 300 lbs/A broadcast

[2] ROI = corn at $2.25/bu, Soybeans at $5.50/bu and pelletized SuperCal SO_4 at $16.50/300 lbs.

[3] Location: Hollandale, MN

1998 and 1999 Summary of The Yield Advantage of Using SuperCal SO_4 on Alfalfa [1,2,3]



[1] Average total yield of three cuttings
[2] ROI = Alfalfa at $60.00/ton and pelletized SuperCal SO_4 at 200 lbs = $11.00, 300 lbs = $16.50, 400 lbs = $22.00
[3] Location: Hollandale, MN

Statistical Analysis of Yield
The Duncan's MRT indicates statistical separation between the treated and untreated for the studies above at the 95% confidence level.

Use of pelletized gypsum

Pelletized gypsum can be:

- Applied in the fall to provide the greatest impact on soil structure
- Spring broadcast to enhance early calcium and sulfer availability
- Placed in zones with N, P, & K to improve drainage and calcium availability
- Easily blended and spread with other dry fertilizer products
- Applied at moderate rates and still achieve significant yield responses (200 to 300 lbs/A)

Gypsum is not toxic to seeds or young plants when placed in seed furrow or banded over the top.

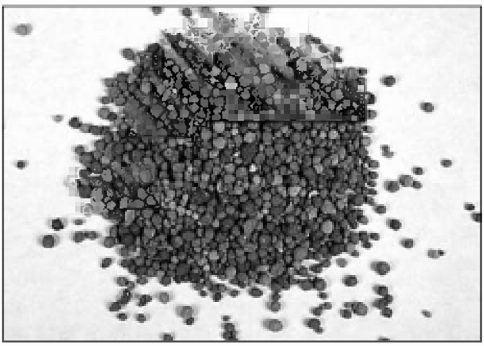


Figure 14. Pelletized gypsum

Application rates of pelletized gypsum

For best soil conditioning effects, gypsum should be broadcast after tillage in the fall or winter, or in the spring prior to the last tillage before planting. A pre-plant broadcast rate of 300 lbs/A of pelletized gypsum is adequate for corn or soybeans.

Some growers have used air seeders to apply pelletized gypsum at planting as a band over the row or in the seed furrow. They put seed in one tank and pelletized gypsum in the other tank. Because the gypsum is applied in narrow strips in the field, a reduced rate can be used:

- 70 to 100 lbs/A for 30 inch rows
- 140 lbs/A for 15 inch rows

Narrow rows require more gypsum to get the same amount per foot of row (one ounce of gypsum per $15^{1/2}$ feet of row).

Summary

- Controlling Soil pH is an important part of managing soil fertility.
- Even slight differences in pH can have a considerable effect on your yield and profitability.
- Calcium is a good balancing agent. It promotes uptake of some nutrients and tends to suppress uptake of trace elements that can be toxic.

Pelletized lime

- Gives the grower a way to "power up" soil pH
- Creates a "friendlier" environment for crop growth
- An annual maintenance application counters the acidifying effects of nitrogen (1.85 lbs pelletized lime/lb N)
- Remember these key points:
  - Lime helps to minimize the potential for reduced yields
  - Lime helps to optimize fertility amendments
- Annual application rates range from 100 to 200 lbs/A - refer to soil test for use rate

Pelletized gypsum

- Should be used in combination with pelletized lime in low pH soils
- Can be used on all soil types and pH ranges
- Improves plant health and productivity
- Helps fight diseases caused by fungi, such as white mold
- Is an excellent source of readily available calcium and sulfate for the plant at all soil pH levels
- Improves nitrogen utilization and fixation
- Helps manage micronutrient deficiencies such as iron chlorosis in soybeans
- Improves soil structure, aeration, drainage, and rootability of plants in conventional and especially no-till soils
- Reduces soil surface crusting and improves seedling emergence
- Will help create the optimum calcium/magnesium ratio (4:1) in your soil
- Annual application rates of 200 to 400 lbs/A broadcast and 75 lb/A (30" row) in a band

Notes

Notes

Notes

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