PRODUCT MANUAL

98G™

PELLETIZED LIMESTONE

The Science Behind 98G

CALCIUM PRODUCTS™

OMRI LISTED For Organic Use

calciumproducts.com

Nov 18

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KEY TERMS

Defining key terminology in liming

Before diving into the topics of soil pH, 98G and comparing liming materials, it's important to define a few key terms that will be used throughout the product manual and can be referred to at any time.

Individual state terminology for limestone ratings

IA: Effective Calcium Carbonate Equivalent (ECCE)
IL: Effective Neutralizing Value (ENV)
IN: Relative Neutralizing Value (RNV)
KS: Effective Calcium Carbonate Equivalent (ECCE)
KY: Relative Neutralizing Value (RNV)
MN: Effective Neutralizing Power (ENP)
MO: Effective Neutralizing Material (ENM)
NE: Effective Calcium Carbonate Equivalent (ECCE)
OH: Effective Neutralizing Power (ENP)
OK: Effective Calcium Carbonate Equivalent (ECCE)
WI: Neutralizing Index (NI) – ranges of 10 are applied to liming materials in Wisconsin, e.g. 80-89, 90-99, etc.

Terminology and definitions

Basic cations: Cations described as basic include Ca^{2+}, Mg^{2+}, K^{+} and Na^{+}. These ions are called base or non-acid cations because they are nonhydrolyzing and therefore do not create acidity in the form of hydrogen (H^{+}) ions. They generally do not produce hydroxide (OH^{-}) ions either and therefore have a neutral effect in the soil solution (Brady and Weil, 2008).

Calcite: A stable, crystalline form of calcium carbonate ($CaCO_3$). Pure calcite contains 100% calcium carbonate and has a calcium content of 40%. Although calcite occurs in nature, limestones of this purity are not commercially available.

Calcitic limestone: Term widely used by agronomists when referring to agricultural limestone with high calcium and low magnesium content. Mainly contains calcium carbonate but may also contain small amounts of magnesium. Term is not restrictive as in calcite, with which it is frequently confused.

Calcium carbonate: A compound consisting of calcium combined with carbonate. It occurs in nature as limestone, marble, chalk, marl, shells, and similar substances.

Calcium carbonate equivalent (CCE): The neutralizing potential or purity of a liming material determined by a standardized analytical procedure; scored in relation to 100% pure calcium carbonate.

Cation: An ion with a positive net charge. Some cations important to soil chemistry include hydrogen (H^{+}), potassium (K^{+}), ammonium (NH_4^{+}), sodium (Na^{+}), magnesium (Mg^{2+}), calcium (Ca^{2+}), zinc (Zn^{2+}), manganese (Mn^{2+}), copper (Cu^{2+}), iron (Fe^{2+}, Fe^{3+}), and aluminum (Al^{3+}).

Dolomite: A crystalline carbonate mineral composed of calcium magnesium carbonate, $CaMg(CO_3)$. Pure dolomite is 54.3% $CaCO_3$, and 45.7% $MgCO_3$.

Dolomitic limestone: In the production agriculture and limestone trades, there is no widely accepted definition; however, limestone containing 10% $MgCO_3$ concentration or more is often referred to as dolomitic limestone (Jones and Mallarino, 2018). The $MgCO_3$ content of dolomitic limestone may range from approximately 4.4 to 22.6%. Although $MgCO_3$ has a higher acid neutralizing potential than $CaCO_3$ because of the lower atomic weight of Mg, the reaction rate of dolomitic limestone is slower and typically requires more material to achieve the same pH results as calcitic limestone (Pagani and Mallarino, 2012).

Effective calcium carbonate equivalent (ECCE): The amount of material in a given quantity of liming material that will effectively change soil pH. It takes into account the CCE, the particle size analysis/fineness factor, and the moisture content of the material to determine the final ECCE score.

Ion: A charged atom or molecule that has a non-zero net charge.

Mesh size: The mesh size refers to the number of openings per linear inch on a screen. A higher mesh number indicates more openings per inch and a smaller particle size.

Particle size analysis: Particle size distribution is determined with a standardized protocol for wet or dry sieving, depending on the specific state. Particle size is very important when evaluating the reactivity of limestones. With all factors being equal, the finer a limestone is ground, the more rapidly it will react. Each state specifies the particle size requirements for scoring limestone, with 8-, 20-, 30- and 60-mesh sizing frequently utilized.

Reactivity: The reactiveness of a liming material describes its relative ability to neutralize soil acidity. This effect can be viewed by the combination of vinegar, which is acidic, with baking soda (basic) and the resulting effervescence or bubbles.

IMPORTANCE OF PROPER SOIL PH

Soil pH is the foundation of nutrient availability

Soil pH is critical to healthy plant growth and works as a master variable in the soil, governing chemical and biological processes such as nutrient availability.

The availability of all nutrients is impacted by varying pH levels. One of the primary concerns is that at low pH, particularly <5.5, the solubility of aluminum increases, allowing it to react with phosphorus and create insoluble compounds. Effectively, this means that the phosphorus is immobilized and cannot be utilized by plants. Phosphorous is the nutrient most affected by soil pH.

Table 1. Relative yield of selected crops at different pH levels.
(Adapted from USDA, 2011)

Crop	pH				
	4.7	5.0	5.7	6.8	7.5
	Relative Average Yield				
Corn	34	73	83	100	85
Wheat	68	78	89	100	99
Alfalfa	2	9	42	100	100
Soybean	65	79	80	100	93

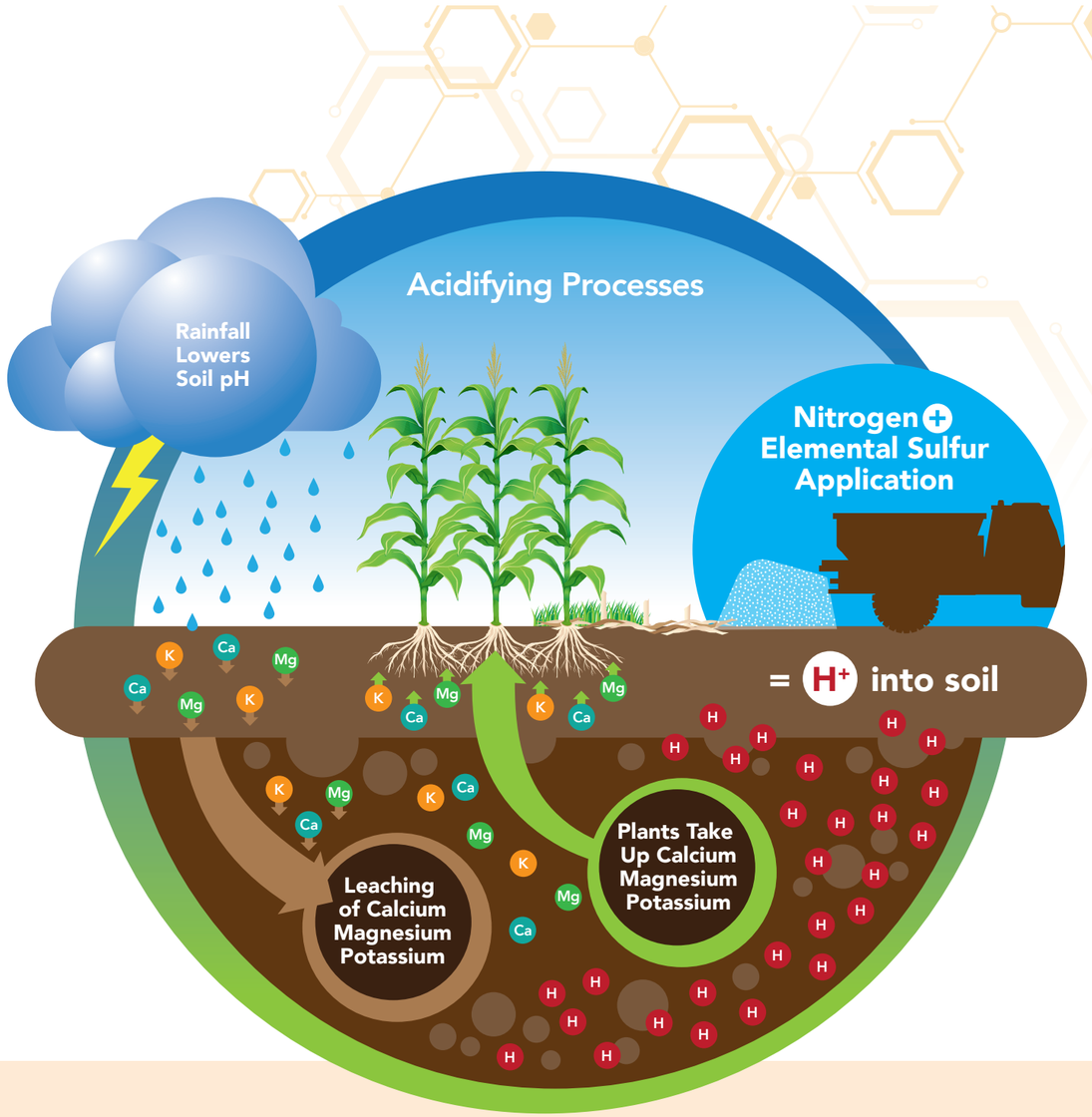
Soil pH impacts yield

Soils have a natural tendency to become more acidic with time. Because pH is a master variable in the soil, it is not surprising that soil pH below 6.0 can reduce crop yields by as much as 30% (USDA, 2011).

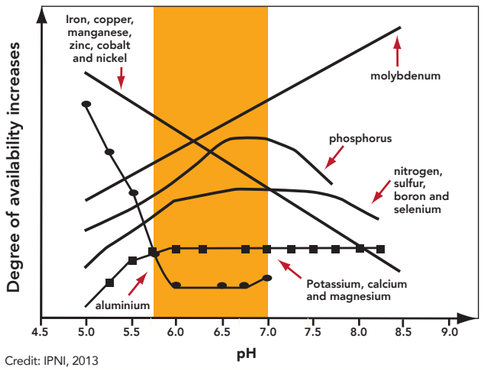
The negative effect of pH on crop yield is related to two primary factors. First, the availability of crop nutrients is significantly impacted by soil pH. Second, the solubility of harmful elements, such as aluminum, increases as soil pH decreases, leading to toxicity.

Causes of soil acidity

Low soil pH, or soil acidity, is one of the most prevalent problems in production agriculture. It is estimated that 40%-70% of the world's soils are acidic and represent some of the most important food-producing regions (Rengel, 2003).

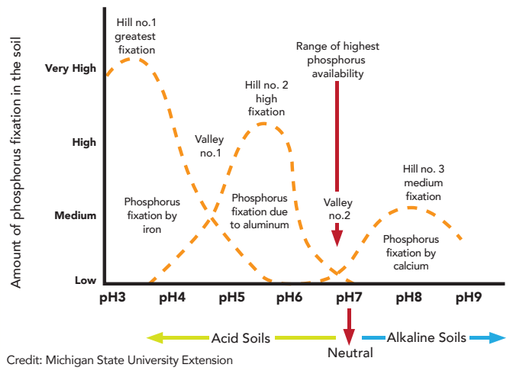


Nutrient availability



Credit: IPNI, 2013

Peaks and valleys of phosphorus fixation



Credit: Michigan State University Extension

Many factors, both naturally occurring, and management influenced, contribute to soil acidity. There are four primary reasons why soil becomes acidic.

1. **Oxidation of nitrogen**
   The conversion of nitrogen from ammonium to nitrate (nitrification) in several common fertilizers leaves behind free hydrogen, which acidifies the soil.

2. **Oxidation of elemental sulfur**
   The conversion of elemental sulfur to sulfate, the plant available form of sulfur, leaves behind free hydrogen that contributes to soil acidity.

3. **Rainfall**
   Rain can contribute to soil acidity in two ways. First, rain can cause the leaching of basic cations from the soil that help buffer against pH change. Second, rainfall itself can become acidic as atmospheric carbon dioxide is dissolved into the rain as it falls.

4. **Plant uptake of cations**
   Plants take up basic cations and release hydrogen that can result in further acidification. Cation removal is increased when higher amounts of dry matter are removed from the field, such as alfalfa or other forages and corn stover used for livestock feed or biomass production.

IMPORTANCE OF PROPER SOIL PH

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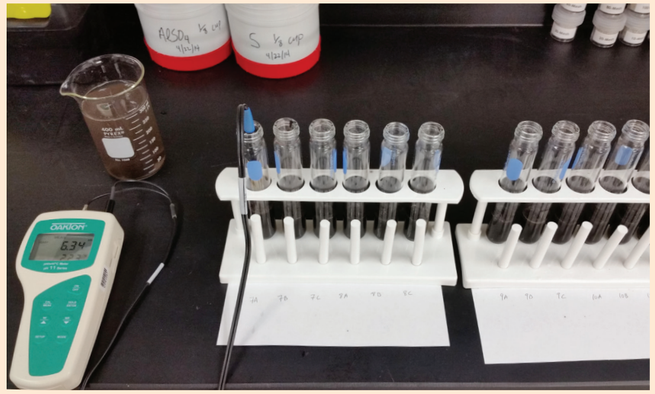
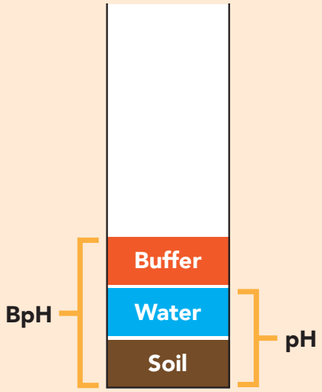




Measuring soil pH

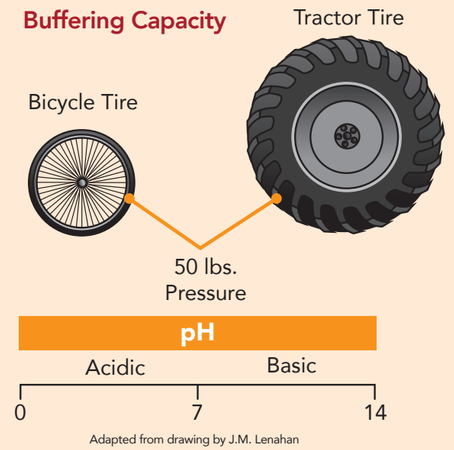
Soil pH is a measure of active acidity or alkalinity in the soil solution. The scientific definition of pH is the negative logarithm of the hydrogen ion (H^+) concentration. The scale is from 0-14 and values greater than 7 are basic or alkaline; values below 7 are acidic. It is important to recognize that because the pH scale is logarithmic, a change of one pH unit represents a 10x difference in H^+ concentration and can induce significant changes in the chemistry and biology of a soil system.

In most states, soil pH is measured with a pH meter in a 1:1 distilled water and soil slurry. In some states, a weak salt solution (0.01M $CaCl_2$) is used in place of distilled water to coax additional hydrogen from the soil sample; this method typically results in a pH reading approximately 0.5 units lower than pH measured with distilled water.

FOR THE PURPOSES OF THIS DOCUMENT, ALL PH REFERENCES ARE TO WATER PH MEASUREMENTS.

If the pH level is less than a threshold value (typically 7.0), a second pH measurement, called the buffer pH, is taken. Buffer solution is added in an equal volume directly to the 1:1 soil/water slurry; the buffer pH solution used depends on the type of soil and regional calibrations. Examples include Sikora, Shoemaker-McLean-Pratt (SMP), Wooduff, Adams-Evans, and Mehlich buffer pH tests.

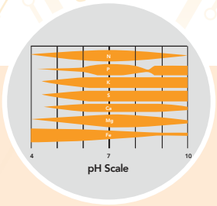
The buffer pH reading serves one purpose: to determine how resistant the soil is to pH change (buffering capacity) and therefore, how much liming material is needed to adjust the pH. In soils with a large amount of reserve acidity, bound in organic matter and clay, buffer pH measurements will typically be low or close to the initial pH measurement, indicating that the soil is very well buffered against pH change and therefore, needs a relatively large amount of liming material. Conversely, a lower organic matter, sandier soil will result in a buffer pH measurement well above the initial pH, indicating a lower amount of reserve acidity, lower buffering capacity, and a relatively small amount of liming material needed for neutralization. An analogy to better visualize the buffering capacity of a soil is comparing two pneumatic tires of different sizes, but at the same pressure. If one tire is significantly larger than the other, such as a tractor tire vs. a bicycle tire, and the pressure is changed by one psi, the larger tire will require a significantly larger volume of air compared to the smaller tire. The tractor tire would be similar to a soil with a high buffering capacity, such as found in organic soils with high clay content which require more liming material to achieve the desired change in soil pH. The bicycle tire would resemble soils with low organic matter and coarse texture, a low buffering capacity, and requiring a smaller volume of lime to achieve the desired pH change.



WHAT IS 98G?

Correct and maintain soil pH

98G is pelletized limestone – the most effective and consistent product to correct and maintain soil pH.



Improve Nutrient Availability

Consistently Maximize Yield

Precise Placement

- **Improves Nutrient Availability**
  98G increases and stabilizes soil pH levels, maximizing the investment in crop nutrients by making them readily available to the crop.

- **Consistently Maximizes Yield**
  Research shows that soil pH below 6.0 reduces crop yield by as much as 30 percent (USDA, 2011). 98G corrects soil pH faster and more completely than aglime, and maintenance application rates deliver consistent, yield maximizing soil pH levels over time.

- **Precise Placement**
  98G results in precise placement from flat-rate or variable-rate applications and won't blow away in the wind like aglime. It reacts quickly to effectively change soil pH and can be applied in the spring or fall.

98G is OMRI listed®

98G is approved for use in certified organic production by the Organic Materials Review Institute (OMRI).

OMRI LISTED For Organic Use

Product specifications

Guaranteed Analysis
Calcium: 36%
Magnesium: ..... <0.5%
Moisture (max):.....1.0%
Calcium carbonate equiv. (CCE): 94%

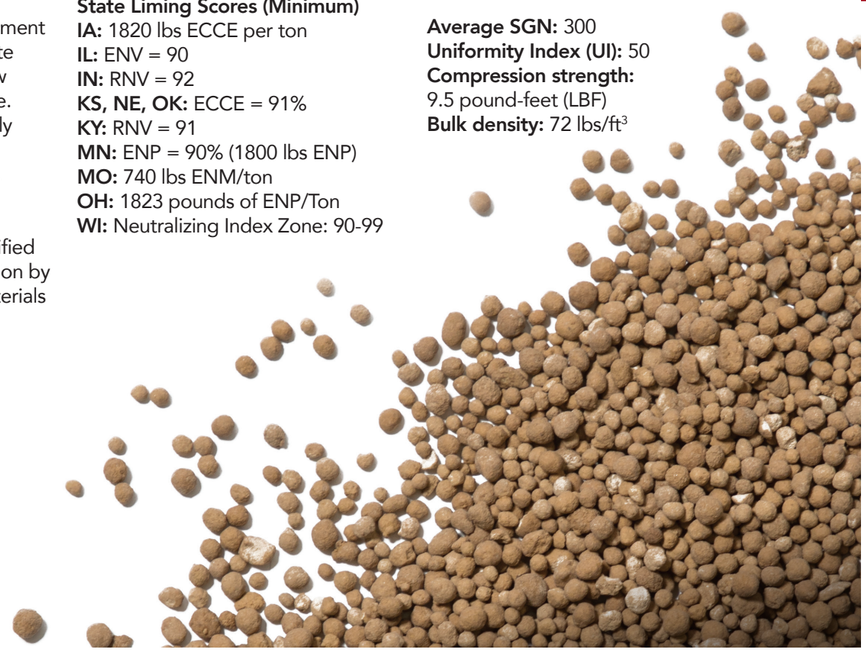
Average Particle Size Before Pelletizing
4-mesh: 100% passing
8-mesh: 100% passing
20-mesh: 100% passing
40-mesh: 98% passing
50-mesh: 97% passing
60-mesh: 95% passing
100-mesh: 90% passing
200-mesh: 70% passing

State Liming Scores (Minimum)
IA: 1820 lbs ECCE per ton
IL: ENV = 90
IN: RNV = 92
KS, NE, OK: ECCE = 91%
KY: RNV = 91
MN: ENP = 90% (1800 lbs ENP)
MO: 740 lbs ENM/ton
OH: 1823 pounds of ENP/Ton
WI: Neutralizing Index Zone: 90-99

Production Details
- 98G pelletized limestone is manufactured from mined limestone in Alden, Fort Dodge, and Gilmore City, IA. The same limestone vein is used in each location to supply the limestone.
- The binding agent used is calcium lignosulfonate and is a by-product of the paper milling industry.

Pellet Physical Characteristics
Size Guide Number (SGN) Averages:
< 200: 3%
200-280: 27%
280-400: 50%
> 400: 20%

Average SGN: 300
Uniformity Index (UI): 50
Compression strength:
9.5 pound-feet (LBF)
Bulk density: 72 lbs/ft^3



COMPARING LIMING MATERIALS

98G vs aglime

How does your aglime stack up?
Aglime is a commonly used liming material to correct soil pH. Its effectiveness is impacted by purity (CCE), chemical composition and particle size.

In the picture to the right, an aglime sample has been separated by particle size in a sieve machine and organized in stackable jars. The jars are stacked by mesh size and color coded with a traffic light analogy.

98G is manufactured by grinding 98% pure calcitic limestone to a very fine powder and then pelletizing it to balance pellet solubility and hardness. The pellets are sized for precise and uniform distribution out of application equipment and won't blow away in the wind like aglime.

98G's pure limestone material and manufacturing process in combination make it a highly reactive liming material allowing it to change soil pH faster than aglime.

The aglime in jars with a red sticker includes particles that are too coarse to effectively change soil pH.

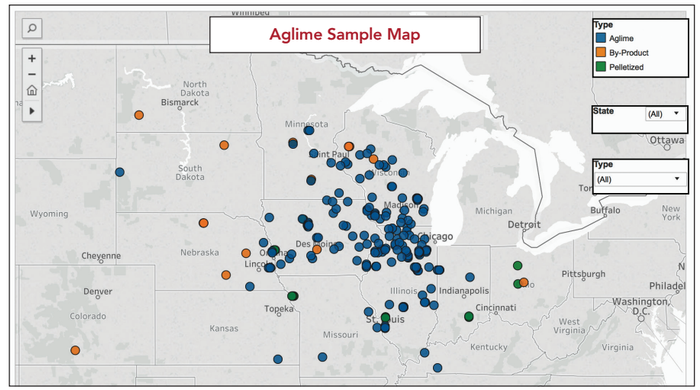
The aglime with a green sticker includes particles that are fine enough to react in soil, yet coarse enough to land where they are spread.

This aglime stack shows that 11% of the material (60-mesh) is a particle size that will be effective at changing soil pH.

The yellow sticker represents aglime with the finest particles. This aglime is more effective at changing soil pH, but it is also more subject to drift loss.

View our online map of aglime samples and stacks

We've collected and analyzed many aglime samples from across the Midwest.Visit calciumproducts.com/98gchallenge to view an interactive map that includes aglime stacks and chemical analyses.



COMPARING LIMING MATERIALS

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Particle size and drift loss

Drift loss describes the amount of finely ground material that can be lost from the desired application area due to being suspended in the air and movement from wind.

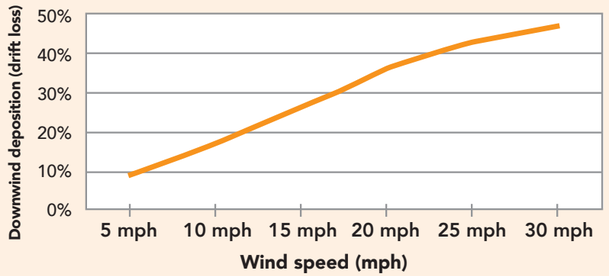
Unfortunately, aglime can have up to 25% of the most reactive, finest material lost to drift. This off-target effect is not accounted for in liming scores such as ECCE.

How effective is your aglime?

Take the 98G Challenge and put your aglime to the test.

Ask your territory sales manager about aglime stacks for your agronomy sales team to use as a conversation starter with growers.

Aglime drift loss with varying wind speed



**Results provided with AGDISP v. 8.28 from the USDA Forestry Service.*

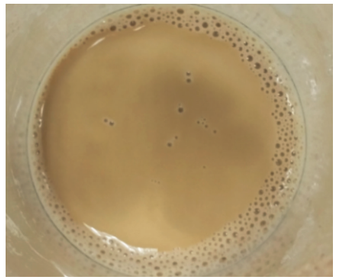
Quantifying the dramatic effect that wind can have on aglime drift loss is something that can be quite visible in many instances, but difficult to measure. This graph demonstrates that wind speed as low as 10 mph can result in more than 15% of particles drifting from the intended application area.

Limestone reactivity

The reactivity of different limestones ultimately describes their ability to change soil pH. While purity (CCE) and chemical composition are important, limestone is a relatively insoluble material, so the particle size distribution is extremely important in how reactive a liming material is. As particle size decreases, more surface area is exposed, leading to more rapid and complete reactivity. The carbonates in limestone are responsible for neutralizing soil pH, and if they are bound inside larger limestone particles, they will never be exposed to free hydrogen in the soil and won't change the pH.

Because 98G is made from 98% pure calcitic limestone and ground to an ultra-fine powder during the manufacturing process, it is highly reactive, making it more effective at changing soil pH.

This difference in reactivity and resulting efficacy at changing soil pH is what separates 98G from aglime as the most efficient and consistent product to correct and maintain soil pH.



98G: *Completely Reacted Particles*

Aglime: *Non-Reactive Particles Remaining*

Because aglime is slower to react and correct soil pH, yield is compromised at both the beginning and end of aglime's reactivity curve – shown at 6 months and 42 months after application in the chart below.

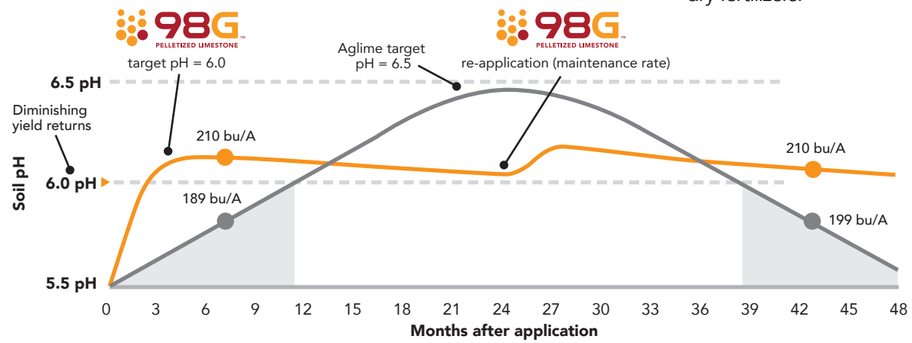
98G is fully reactive at about 3 months after application. A maintenance rate application can be made at 24 months to maintain proper soil pH and continue to maximize yield potential.

The chart below illustrates the impact a liming material's reactivity has on soil pH and potential crop yield.

Improve operational efficiencies with 98G

Not only is 98G more effective at changing soil pH, it can also improve operational efficiencies.

1. **Apply fall or spring –** don't limit pH correction to a small timing window. Broaden your application season by applying 98G in the spring or fall.
2. **No in-field piling –** unlike aglime, 98G is pelletized and does not require in-field piling.
3. **Handles like any dry fertilizer –** store, blend, transport and apply 98G with the same equipment you utilize for applying other dry fertilizers.



**Relative yield percentages from USDA Soil Quality Indicators: Soil pH (2011)*

COMPARING LIMING MATERIALS

(CONTINUED)

Efficiency of pH change with 98G vs. Aglime

Overview

- Research was performed by Iowa State University evaluating how 98G, calcitic and dolomitic agricultural limestone (aglime), and different particle sizes of both aglime sources increased soil pH.
- Three liming materials were used in the study. 98G from Calcium Products (ECCE = 91), calcitic aglime from Ames, IA (ECCE = 59), and dolomitic aglime from Cedar Rapids, IA (ECCE = 65; Mg = 15%).

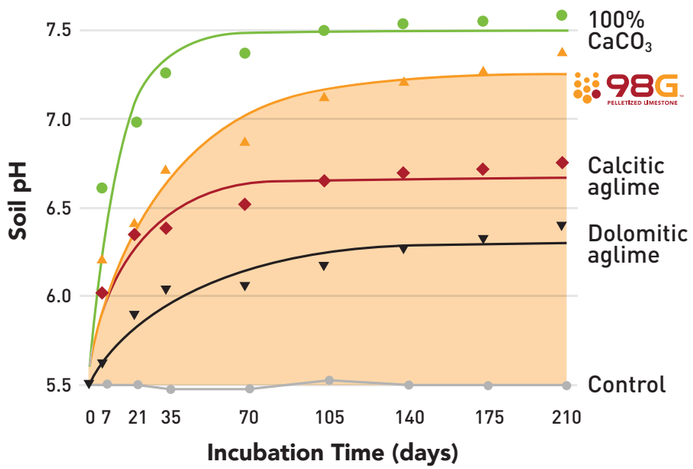
KEY STUDY FINDING

98G RAISED PH 0.7 AND 1.0 PH UNITS MORE THAN CALCITIC AND DOLOMITIC AGLIMES, RESPECTIVELY, AT EQUALIZED RATES.

Study Findings

- 98G resulted in a more complete and efficient pH correction than calcitic and dolomitic aglimes.
- This shows that 98G can be targeted to a lower pH and achieve a similar or better pH change than aglime. We recommend targeting a 98G rate 0.5 units lower than aglime (e.g. 6.0 vs 6.5).
- Overall performance was affected by particle size composition. The Iowa limestone scoring system (ECCE) doesn't differentiate particles finer than 60-mesh and therefore, did not account for the difference in performance of these liming materials.
- This study also showed the value of distinguishing between calcitic and dolomitic aglime in protocols for aglime assessments and recommendations. Calcitic aglime resulted in more rapid and complete pH change compared to dolomitic aglime despite a lower ECCE value.

Study Results



Study Results From: *Jones, J.D. and A.P Mallarino. 2018. Influence of source and particle size on agricultural limestone efficiency at increasing soil pH. Soil Sci. Soc. Am. J. 82:271-282.*

98G vs pell-lime

When comparing 98G to other pelletized limestone materials (pell-lime), there are several chemical and physical characteristics that distinguish 98G as the most efficient and consistent product to correct and maintain soil pH. The analyses of the products in the table were completed by Midwest Laboratories in Omaha, NE.

	98G PELLETIZED LIMESTONE	Eastern Corn Belt Pell-Lime	Iowa Pell-Lime	Kansas Pell-Lime
Calcium	36%	34%	33%	34%
Magnesium	0.4%	3%	0.5%	0.5%
CCE†	94%	89%	89%	83%
ECCE‡	91%	71%	72%	81%
Percent Passing 60-Mesh	97%	69%	67%	96%
Percent Passing 100-Mesh	95%	61%	57%	94%
Pounds Equivalent*	100	190	119	110
Analysis Date	Continual	10/15/2016	6/27/2016	10/15/2016

† = CCE; Calcium carbonate equivalent (purity)
‡ = ECCE; Effective calcium carbonate equivalent (purity + particle size + moisture)
* Pounds Equivalent combines ECCE and magnesium component of liming material to calculate equivalency.

Key differences:

- Because of 98G's purity and particle size, it requires the least amount of product to effectively change soil pH. Eastern corn belt pell-lime requires almost twice as much 98G for the same pH correction – for every 100 lbs of 98G, 190 lbs of eastern corn belt pell-lime is needed.
- 98G has the highest ECCE, which means it is the most effective in changing soil pH. For example, the ECCE of Iowa pell-lime requires 19% more material to achieve the same pH correction as 98G.
- The magnesium content in the eastern corn belt pell-lime results in more material and time to achieve the same pH correction as 98G. This is due to the decreased solubility and efficacy of dolomitic limestones.
- The Kansas pell-lime has shown consistently weaker pellet strength compared to 98G leading to pellet inconsistency, dust and handling concerns.

The Iowa pell-lime has larger particle sizes, which result in slower and poorer performance in the field.

98G APPLICATION, HANDLING AND STORAGE

Application programs and guidelines

pH correction

When soil pH is below 6.0, it can reduce crop yield by as much as 30% and a correction application is needed. Application rates to correct soil pH can vary widely depending on soil characteristics. Variable rate application is preferred in order to account for this variability. For accurate application rates:

1. Incorporate our variable rate (VR) equations into your precision software, or
2. Visit calciumproducts.com/98G to use our 98G application rate calculator.

When considering a pH correction application, it is common to compare aglime and 98G application maps side-by-side in a precision software program. This best demonstrates the product rates and overall cost for a liming program based on specific field conditions.

pH maintenance

Historically, liming applications occur every 3-5 years to correct soil pH, with peak reactivity not taking place until 18 to 24 months after the aglime application. Rather than create a pH roller coaster in the field with infrequent liming applications, we recommend a pH maintenance program that keeps pH above an economic and agronomic threshold of 6.0.

Once soil pH is at an optimum level, 98G can be utilized to neutralize the acidity resulting from application of nitrogen.

Below are general 98G application rate recommendations for a pH maintenance program.

When considering the impact a more rapid and complete pH change can have on yield in the first season of application, combined with maintaining pH in the optimal range, yields will be maintained. This often results in a more beneficial economic analysis for 98G vs. aglime when compared over a 4-5 year application regimen where aglime is applied once at a very high rate in year 1 and 98G is applied at a lower rate in year 1 with a maintenance application in year 3. Looking at increased grower profit due to consistent yield over this timeframe is a better way to compare the true costs and benefits associated with 98G vs. aglime.

Crop	Maintenance Application Rate
 Corn	1 to 2 lbs 98G per 1 unit of N applied
 Soybeans	100 to 200 lbs/A/year or every other year
 Alfalfa	

Application timing and tillage practices

98G can be applied fall or spring. After spreading 98G, some moisture combined with light incorporation into the soil to promote pellet breakdown is desired, but not required.

When used in no-till, 98G rates calculated for conventional tillage should be halved and vertical soil pH change should be expected to be slower than when used with tillage. Our VR recommendations automatically correct for no-till situations.

Strip-till and banding is appropriate where desired, although rates are typically in the range of 50-150 lbs/A and large scale changes in pH should not be expected. Rather, this application scenario is intended to modify pH in a small zone surrounding the nutrients to keep them available to the plant.

Handling and storage best practices

To best maintain the integrity of the 98G pellet, there are a few handling and storage best practices to keep in mind.

1. Handling equipment such as conveyor belts or bucket elevators (legs) are conducive to maintaining good product quality. Augers and drag conveyors are not ideal for product handling, as they create numerous opportunities for abrasion and wear between the material and handling equipment. Maintaining all handling equipment and keeping it in good repair will result in satisfaction with product quality and less downtime due to breakdown.
2. Product should be stored in facilities kept in good repair. Minimizing exposure to moisture from rain or snow will aid in maintaining product integrity. 98G does not absorb moisture from the atmosphere, unlike many other fertilizers such as urea, which are hygroscopic.
3. Product should be stored as close to the receiving location and equipment as practical. This will result in less interaction with the handling equipment due to shorter conveying distances and time.

Mixing best practices

For correction programs, 98G may be applied flat-rate or variable rate in a stand-alone application. For maintenance programs, 98G may be applied with other dry fertilizers or stand-alone.

To best maintain the integrity of the 98G pellet when mixing with other dry fertilizers, there are a few best practices to keep in mind.

1. 98G pellets will begin to break down or degrade after contact with water or other liquids. The amount of water needed to begin this process is minimal. Typically, 0.25" of rain is more than adequate. 98G is frequently used where pesticides are impregnated onto dry fertilizers. The addition of small amounts of 98G into the dry fertilizer blender will aid in removing the free liquid that may be present and can help in reducing the overall moisture content. Some nitrogen stabilizers for dry fertilizers may recommend pelletized limestone specifically for this purpose. When labeled rates, directions and mixing practices are followed, regardless of the products being utilized, problems should not arise. In cases where application volumes exceed labeled rates and carryover wetness contacts 98G pellets, breakdown can occur and cause gumming or build up on the application and/or blending equipment. If higher than normal rates are expected, we recommend a small scale blend test to determine how these rates will affect 98G breakdown and subsequent problems.
2. While no adverse or damaging effects have been noted between 98G and other pesticides, additives, etc., it is the responsibility of the end user to consult with the manufacturer of other products on any concerns or questions regarding product efficacy, product interactions, etc.

SELLING 98G TO GROWERS

Ask your Territory Sales Manager about our 98G sell sheet that can be used with growers!

Consistently Maximize Yield

Research shows that soil pH below 6.0 reduces crop yield by as much at 30 percent. 98G is a more reactive liming material than aglime and corrects soil pH faster keeping pH at a level where yield goals can be met and exceeded.

Improve Nutrient Availability

Soil pH is the foundation for nutrient availability. Increasing and stabilizing soil pH levels with 98G protects a grower's investment in crop nutrients by making them more readily available to the crop.

Precise Placement

98G results in precise placement from flat-rate or variable-rate applications and won't blow away in the wind like aglime. It reacts quickly to effectively change soil pH and can be applied in the spring or fall.

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