

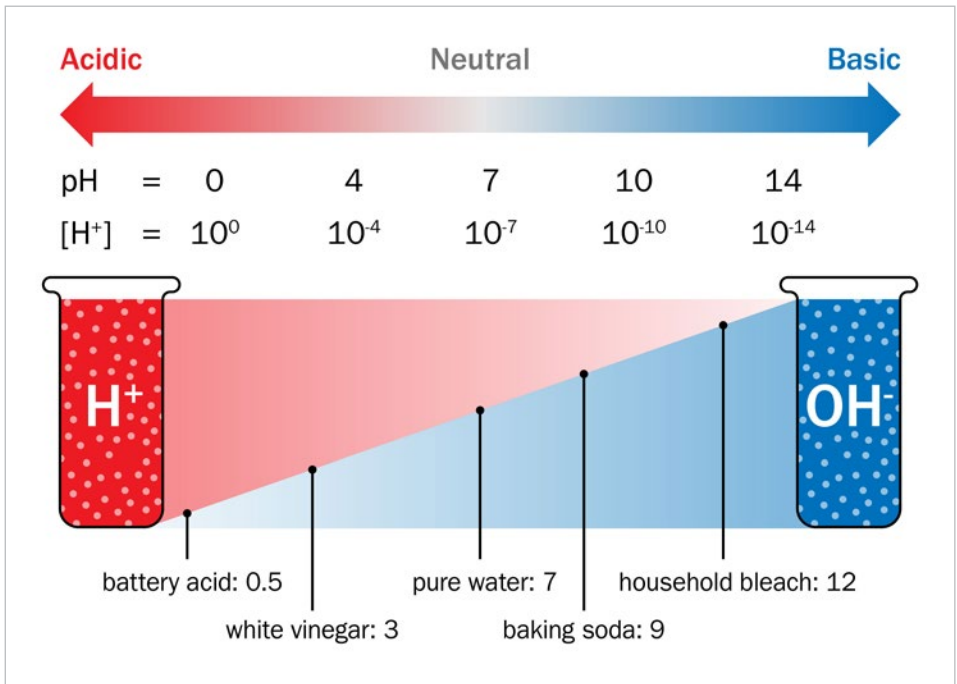
# 3. Soil pH, Liming and Acidification

## Soil pH

Soil pH is a measure of the hydrogen concentration of the soil solution. The pH scale runs from 0 to 14 with 7 being neutral, below 7 being increasingly acidic and above 7 increasingly basic. For every 1 unit of pH decrease, the hydrogen concentration increases 10 times. For instance, a soil that has a pH of 4 has 1,000 times more hydrogen in the soil solution than a soil with a pH of 7. For reference, the approximate pH of some common materials are: battery acid, 0.5; white vinegar, 3;

pure water, 7; baking soda, 9; and household bleach, 12 (see Figure 3–1).

At the pH levels typical in soils, the hydrogen concentration itself does not have an appreciable impact on a plant. However, pH can impact other elements, including plant nutrients in the soil, and can have direct and indirect impacts on the activity of soil organisms that build soil structure, cycle organic matter or fix nitrogen in the nodules on the roots of legumes. It also impacts the performance and breakdown of some pesticides.



**Figure 3–1.** pH scale showing relative hydrogen ion (H<sup>+</sup>) and hydroxide (OH<sup>-</sup>) concentrations and pH values of common materials

Generally, plants take up nutrients only if they are dissolved in water. Soil pH influences the solubility of plant nutrients and other elements. Some nutrients are more soluble at high pH, others at low pH, and still others at ranges in between (Figure 3–2). This increase in solubility can also result in some elements, like aluminum and manganese, becoming toxic to the plant at low pH levels. Plant species differ in their requirements and tolerance of soil conditions that result from different pH regimes; however, they all generally have specific pH ranges at which they perform best. As such, monitoring and managing soil pH is one of the first steps in good soil management.

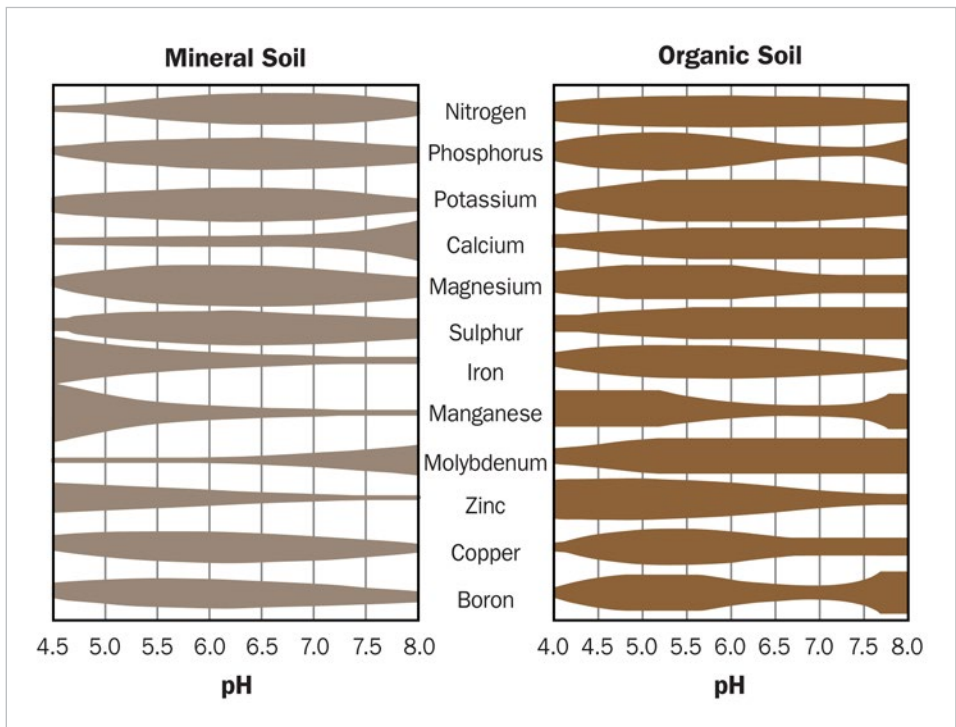
### **pH and metal solubility**

Aluminum is contained in large quantities in soil mineral materials (sand, silt and clay). As pH decreases, the solubility of metals in soil, including aluminum, generally increases. Although aluminum is not a plant nutrient, plants do take it up. Above pH 5.7, the chemical forms of aluminum in soils are not toxic to plants; however, as pH drops below 5.7, forms of aluminum that can be toxic to plants increase rapidly with decreasing pH level. These toxic forms of aluminum can impact the roots of plants by slowing root elongation. The plant will continue to provide carbohydrates to the roots to fuel growth, but since elongation slows, the roots get wider, resulting in short stubby roots that have limited capacity for water and nutrient uptake. These forms of aluminum also react with soil

phosphorus, resulting in phosphorus compounds with very low solubility that are unavailable for plant uptake. In addition, the forms of aluminum that exist at low pH can restrict the formation of nitrogen-fixing nodules on the roots of legumes.

The solubility of another metal, manganese, also increases rapidly as pH decreases (see Figure 3–2). As with all plant nutrients, insufficient quantity is a problem for plant growth; however, having too much can be toxic for the plant. The pH at which manganese starts to become toxic varies depending on the amount of manganese in the soil, but it generally is not an issue until the pH drops below 5.0. However, increasing pH will decrease the availability of manganese, along with most other micronutrients (see Chapter 2). As such, it is possible to induce a manganese deficiency in a field when lime has been used to increase pH.

Aluminum, manganese and iron compounds abound in mineral soils but not in organic soils (mucks and peats). This limits the ability of these elements to interfere with the solubility of other nutrients in organic soils. Lower soil pH is, therefore, more acceptable for organic soils than for mineral soils (Figure 3–2).



**Figure 3–2.** Impact of soil pH on nutrient availability in mineral and organic soils

## Factors influencing soil pH

### Parent material

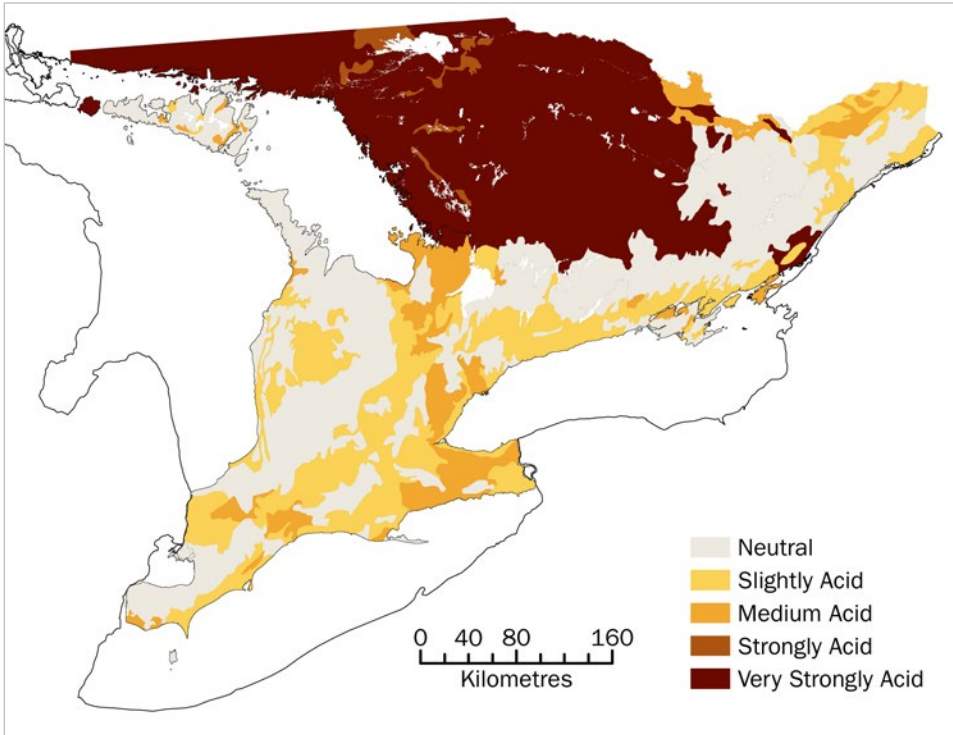
The primary factor influencing the natural pH of a soil is the geological materials (soil parent material) that the soil has formed from. When the glaciers retreated from Ontario 10,000–15,000 years ago, the materials left behind were uniform in pH from the surface to bedrock. These materials were either deposited directly by the glaciers, deposited by meltwaters running from the retreating ice front or settled from the waters of post-glacial lakes. The nature of these glacial environments resulted in differences in the textures (sand, silt and clay) that were left behind

and went on to form our soils. In areas like Tillsonburg, that had fast-moving water coming from the glacial melt, all but the coarser materials were washed away. In areas where the meltwater formed lakes, like a significant part of Essex, Lambton and Kent counties, the clay and silt settled to the bottom resulting in very clay rich soils. In large areas of Wellington and Waterloo counties, the contents of the glaciers were simply deposited on the ground with little sorting by water, resulting in mostly loam textured soils.

The soils on most of southern Ontario, the Ottawa valley and the northern clay belt have formed on primarily limestone-based parent

material. This material will result in a soil pH of approximately 8.2. However, natural and manmade processes have led to acidification, resulting in the soil pH decreasing over time to a point where there are some instances of acid soils in these areas (Figure 3–3). The processes that make soils more acidic work on the layers of soil closest to the surface. Over thousands of years since the glaciers left Ontario, the acidified surface layers thickened as the added acids reacted with

limestone contained in the soil. The soil horizons at depth are unchanged from what was deposited by the glaciers, and as such still contain high levels of limestone and have a slightly basic soil pH. This results in a typical soil profile that may be slightly acidic to neutral at the surface and more basic at depth. The parent material of most of Northern Ontario is largely acidic igneous geological materials (Canadian Shield), resulting in acidic soils predominating (Figure 3–3).



**Figure 3–3.** Surface soil reactivity in Southern Ontario. **Note:** Categories of acidity do not represent definite ranges of soil pH, but instead provide a general indication of variability as a reflection of parent material.

In addition to the geological materials that the soil formed from, the soil's cation exchange capacity gives soil buffering capacity (resistance to change in soil pH). The amount and type of clay and the amount of soil organic matter will impact how quickly a soil's pH may change. As such, a coarse-textured soil low in organic matter will have a relatively poor ability to resist pH change compared to clay soils with high organic matter.

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## How a soil becomes acidic

### Precipitation

Pure rainwater is slightly acidic because carbon dioxide is dissolved in the water, forming carbonic acid. The amount of carbonic acid in rainwater is directly related to the amount of carbon dioxide in the atmosphere. As the carbon dioxide levels of the atmosphere increase, the pH of rainwater will decrease slightly. The amount of other acids, like nitric and sulphuric acid, is dependent on the amount of air pollution. The last 40 years have seen a decrease in emission of sulphur from areas that impact the rainwater in Southern Ontario. This reduction in pollution means that rainwater in Southern Ontario has become less acidic. The addition of acids creates a gradual reduction in pH at the surface of the soil as they percolate down through the soil over thousands of years. This is a normal part of soil development in humid climates.

### Organic matter decay

As organic materials break down, decay releases organic acids into the soil. This also contributes to the reduction of soil pH in the surface layers of the soil, where most of the organic matter is present.

### Fertilizer application

The microbial conversion of the ammonium form of nitrogen to the nitrate form is one of the biological processes that releases acid into the soil. Adding large amounts of ammonium-containing fertilizers can accelerate the decline in pH, particularly in sandy soils low in organic matter.

Urea and anhydrous ammonia do not contain the ammonium form of nitrogen but are converted to ammonium nitrogen when in contact with the soil. When ammonium, ammonia or urea forms of nitrogen from fertilizers or manure are used on sandy soil, the soil pH should be monitored regularly.

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## How soil becomes basic (alkaline)

Many of Ontario's agricultural soils are alkaline (pH greater than 7) at depths of only 30 cm (12 in.) or more and have a pH as high as 8.2 at about 1 m (39 in.). As a result, most agricultural soils in Ontario provide plants with ample supplies of basic nutrients such as calcium and magnesium within the rooting zone.

If soil pH is increasing over a series of soil tests, the likely causes are the following:

- The depth at which soil samples are collected has changed. It is much easier to collect soil samples to greater depth when the soil is moist and friable than when it is dry or compacted.
- Tillage is mixing soil from deeper in the profile with the soil being sampled. Some farmers see this as a way of increasing pH without liming, but it is rarely effective in making desirable changes in pH. The detrimental effects on soil structure and the dilution of nutrient and organic matter of the surface soil with sub-soil must be considered.
- Ditching or tile drainage has exposed sub-soil that is now being included in the soil sample.
- Erosion is removing the most acid surface layers. Subsidence (oxidation, shrinkage and disappearance) of a layer of muck overlying mineral soil has the same effect.

In Ontario, precipitation exceeds the water lost through evaporation and transpiration. The net movement of water through the soil is downward, and the net movement of basic cations is downward (albeit very slowly through all but coarse-textured soils).

Alkali soils (sodium saturated) and deposits occur in dry regions such as the Prairies where evaporation and plant transpiration exceed precipitation. As a result, the net

movement of water is upward, which carries basic cations to the surface and makes the surface more alkaline.

### **Dealing with high-pH soils**

It is important to assess soil pH levels through soil testing. The optimum soil pH range for most crops is 6.0–7.5. Even above 7.5, the impact of pH on field crop production is minor in most cases. Phosphorus availability is reduced somewhat, but this is reflected in the phosphorus soil test. As long as the recommended quantities of nutrients are applied for the given soil test, it should not affect crop production.

Don't try to reduce the pH of alkaline soils. If the soil pH is very high (7.8–8.2) then the soil will contain a high concentration of free lime (calcium carbonate). The soil is extremely well buffered and will resist any attempts to bring the pH down. Adding sulphur to acidify the soil will not be effective, but it will be costly.

Monitor crops for any signs of nutrient deficiencies induced by high pH. The most common deficiencies are manganese on soybeans or cereals or zinc on corn. If you see evidence of manganese deficiency, consider foliar application. For zinc deficiency, add zinc to the starter fertilizer.

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## Symptoms of pH problems

One principle of good soil management is to adjust soil pH to the optimal range for the crops you are growing, and then tackle soil fertility issues.

Soil testing is the only reliable means to determine whether the pH needs adjusting.

However, some areas within a field may show symptoms of low pH, even though the average pH for the field is acceptable. These areas, which are often sandy knolls, should be tested separately.

### Soil pH in starter fertilizer bands

Placed in a band, different fertilizers have different pH reactions when they initially dissolve. Di-ammonium phosphate (DAP) and urea initially raise the pH — but only when concentrated in a band. The higher pH can result in ammonium being converted to ammonia. This ammonia can be lost from the soil to the atmosphere and can be very harmful to plants if seedlings or roots come in contact with it. Although DAP delivers less risk of ammonia injury than urea per nitrogen unit, placing either urea or DAP with corn seed is not recommended. Use of DAP or urea in a band near the seedlings (for example, 5 cm (2 in.) below and beside) should also be limited, particularly in conditions that create high risk for ammonia injury, such as dry soil conditions in coarser-textured soils of higher-than-neutral pH.

Acidity in a phosphorus band has theoretical advantages in improving P availability in soils where the pH is neutral or higher. The pH in any band containing ammonium nitrogen may decline temporarily within the first weeks after application. When a plant takes up ammonium (a positively charged ion) as its nitrogen source instead of negatively charged nitrate, it releases a positively charged hydrogen ion to balance the charge inside and outside of the root. This can result in a decrease in the soil pH in an area of about 1–2 mm around the root called the rhizosphere. Although small, this area represents the full distance that phosphorus may travel towards the root in a given year due to its very low mobility. The reduction in rhizosphere pH caused by this process has been found to greatly enhance phosphorous uptake. Acidification of the band can also take place because nitrification (conversion of the ammonium to nitrate) generates acidity. In addition to increasing P availability, the lower pH in the band can also increase the availability of several micronutrients (for example, zinc, manganese, iron and copper).

Symptoms that may indicate a soil pH problem include:

- short stubby roots
- poor nodulation of forage legumes even though the seed was inoculated (pale green colour results from the poor nodulation)
- only oats harvested, even though mixed grain was planted (barley is more sensitive to acid soil)
- poor persistence in perennial forages with adequate drainage and fertilization
- presence of mosses and weeds such as wild strawberry, devil's paintbrush and sheep sorrel
- poor performance of soil-applied triazine herbicides like atrazine and metribuzin
- longer-than-expected carryover of imazethapyr (Pursuit)

Do not make a diagnosis based only on symptoms. Always take a soil test to confirm pH problems.

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## Buffer pH

### **H<sup>+</sup> and cation exchange sites**

Soil pH is a measure of the hydrogen contained in the soil water, while buffer pH is a measure of the soil's ability to resist changes in pH. Since hydrogen is a cation, it can exist both in the soil water and on the soil's cation exchange sites. The negative charges of cation exchange sites are always fully occupied with positively charged cations like calcium, magnesium and hydrogen. In addition, all of these cations are constantly cycling

on and off of the cation exchange sites. This results in an equilibrium concentration between all cations in the soil solution and those on the exchanges sites. As such, when new hydrogen (acid) is added to the soil, the equilibrium between hydrogen in the soil solution and hydrogen on the exchange sites is offset and a new equilibrium forms. This results in some of the newly added hydrogen moving to the exchanges sites.

Since only the hydrogens in the soil solution are measured in soil pH, the fact that some of the newly added hydrogen ends up on the exchange sites reduces the extent to which the pH changes. In addition, although the cation exchange sites are always fully occupied, they cannot be filled beyond capacity. As such, a soil with a greater cation exchange capacity can hold more hydrogen ions, keeping them out of the soil solution and resulting in even less pH change when acid materials are added.

### **Reserve hydrogen**

This process also works in reverse. When you attempt to increase pH by using lime to react with hydrogen ions in solution, more hydrogen is released from the exchange sites to maintain the balance between hydrogen on the exchange sites and those in solution. These hydrogens are often called "reserve hydrogen," and the process by which the soil resists changes in pH is called the soil's buffering capacity.



## Differences in buffering capacity

Soils differ in their buffering capacity depending mostly on the amount and type of clay in the soil and the soil organic matter content, both of which contribute to the soil's cation exchange capacity. In general, the greater the cation exchange capacity, the greater the buffering capacity of the soil. A simple measurement of soil pH does not reflect its ability to resist changes in pH; it only measures those hydrogens that are in the soil solution.

## Buffer pH measurement

Buffer pH ( $pH_B$  or BpH on soil test reports) is a direct measure of the soil's ability to resist pH change. It is a pH measurement taken after the soil sample has been mixed with a buffered solution. The solution itself resists change in pH. See Chapter 5, *Soil, Plant Tissue and Manure Analysis*, for more detail.

The pH resulting when the soil is mixed with buffer solution is well correlated to the amount of limestone needed to adjust soil pH to a target level. Buffer pH is a simple, inexpensive and accurate means of determining lime requirements.

Recommendations from soil tests for crop nutrients are based on the relationship between soil test levels and crop response to the addition of nutrients. The buffer pH test differs in that it relates soil test levels to the soil response to the addition of lime.

The actual lime recommendation depends on the target soil pH that you would like to achieve for the crop, as well as the buffer pH. Different crops require different pH ranges as seen in Table 3–1.

**Table 3–1.** Guidelines for lime application to Ontario crops

Crops	Soil pH below which lime is beneficial	Target soil pH <sup>1</sup>
<b>Coarse and medium-textured mineral soils (sand, sandy loams, loams and silt loams)</b>		
perennial legumes, oats, barley, wheat, triticale, beans, peas, canola, flax, tomatoes, raspberries, strawberries, all other crops not listed below	6.1	6.5
corn, soybeans, rye, grass, hay, pasture, tobacco	5.6	6.0
potatoes	5.1	5.5
<b>Fine-textured mineral soils (clays and clay loams)</b>		
alfalfa, cole crops, rutabagas	6.1	6.5
other perennial legumes, oat, barley, wheat, triticale, soybeans, beans, peas, canola, flax, tomatoes, raspberries, all other crops not listed above or below	5.6	6.0
corn, rye, grass hay, pasture	5.1	5.5
<b>Organic soils (peats/mucks)</b>		
all field crops, all vegetable crops	5.1	5.5

<sup>1</sup> Where a crop is grown in rotation with other crops requiring a higher pH (for example, corn in rotation with wheat or alfalfa), lime the soil to the higher pH.

After determining the target pH and measuring your soil's buffer pH, the quantity of lime required can be determined using the information in Table 3–2. Note that the amounts of lime recommended in Table 3–2 are based on a standardized liming

material. Different liming materials differ in their ability to neutralize pH. Therefore, the amount of lime required needs to be adjusted for the specific properties of the lime to be used.

**Table 3–2.** Lime requirements to correct soil acidity based on soil pH and soil buffer pH  
Ground limestone required — t/ha (based on an Agricultural Index of 75)

Buffer pH	Target soil* pH = 7	Target soil pH = 6.5 (Lime if soil pH below 6.1)	Target soil pH = 6.0 (Lime if soil pH below 5.6)	Target soil pH = 5.5 (Lime if soil pH below 5.1)
7.0	2	2	1	1
6.9	3	2	1	1
6.8	3	2	1	1
6.7	4	2	2	1
6.6	5	3	2	1
6.5	6	3	2	1
6.4	7	4	3	2
6.3	8	5	3	2
6.2	10	6	4	2
6.1	11	7	5	2
6.0	13	9	6	3
5.9	14	10	7	4
5.8	16	12	8	4
5.7	18	13	9	5
5.6	20	15	11	6
5.5	20	17	12	8
5.4	20	19	14	9
5.3	20	20	15	10
5.2	20	20	17	11
5.1	20	20	19	13
5.0	20	20	20	15
4.9	20	20	20	16
4.8	20	20	20	18
4.7	20	20	20	20
4.6	20	20	20	20

\* Liming to pH 7.0 is recommended only for club-root control on cole crops.

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## Limestone quality

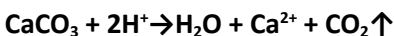
Two parameters are normally used when assessing the quality of agricultural limestone (i.e., its ability to neutralize pH). They are the neutralizing value and the fineness rating.

### Neutralizing value

Acidity is neutralized when hydrogen ions ( $H^+$ ) react with other compounds to form water ( $H_2O$ ).

Certain compounds that fall into the general categories of carbonates, hydroxides and oxides are normally used to neutralize acidity. Carbonates are most commonly used for agricultural purposes because they are readily available from the sedimentary limestone rocks found in many parts of the province and are relatively inexpensive.

When ground limestone is used, it is the carbonates in the lime that neutralize the acidity. The following reaction describes how calcium carbonate reacts with two hydrogen ions to produce water and carbon dioxide ( $CO_2$ ). The up arrow indicates that the carbon dioxide is given off as a gas. This helps to keep the reaction from reversing itself.



This reaction is essentially the same as when vinegar, an acid that releases hydrogen ions, is added to baking soda (sodium bicarbonate).

Hydroxides ( $OH^-$ ) combine directly with hydrogen ions ( $H^+$ ) to form water ( $H_2O$ ). Oxides of calcium, magnesium and potassium can combine with water to form hydroxides. Potential liming materials such as wood ash that contain oxides and hydroxides are normally the result of heat treatment or combustion. They tend to have high pH values and are more caustic to handle than limestone.

The neutralizing value of a material is its ability to neutralize acidity relative to the ability of pure calcium carbonate. Because it is a relative value, it is expressed as a per cent of calcium carbonate's ( $CaCO_3$ ) ability to neutralize acidity (see Table 3–3). Pure magnesium carbonate has a higher neutralizing value than calcium carbonate because magnesium atoms weigh less than calcium atoms. However, one magnesium carbonate molecule will neutralize as much acidity as one calcium carbonate molecule.

Pure compounds are never used for liming because they are too expensive. Normally, we use a source such as crushed limestone in which at least one of these compounds is found in relatively high proportions.

The pH of a material suspended in water is not a good indicator of its neutralizing ability. For example, the pH of a potassium hydroxide may be greater than 13 (basic and caustic). The pH of a solution of calcium carbonate may only be 8.2, yet the calcium carbonate is a more effective liming agent.

**Table 3–3.** Neutralizing values of some liming materials

Liming material	Formula	Neutralizing value relative to calcium carbonate
calcitic lime (calcium carbonate)	CaCO <sub>3</sub>	100
magnesium carbonate	MgCO <sub>3</sub>	119
dolomitic lime (calcium magnesium carbonate)	CaMg(CO <sub>3</sub> ) <sub>2</sub>	109
calcium hydroxide	Ca(OH) <sub>2</sub>	135
calcium oxide	CaO	179
magnesium hydroxide	Mg(OH) <sub>2</sub>	172
magnesium oxide	MgO	250
potassium hydroxide	KOH	90
gypsum (calcium sulphate)	CaSO <sub>4</sub> · 2H <sub>2</sub> O	0
wood ashes	n/a	40–80

Limestone is a sedimentary rock formed from corals in warm oceans. Limestone rock is not pure carbonate-minerals. Silts, clays, sand and other materials also accumulated in ocean bottoms. The degree of inclusion of these contaminants affects the purity of the limestone and therefore the neutralizing value.

### Fineness

To be effective, any liming material must dissolve. Limestone does not dissolve quickly like salt or sugar, and its rate of dissolution decreases as pH increases. The surface area of the limestone must be maximized to get satisfactory rates of dissolution. This is accomplished by having tiny particle sizes.

The fineness of liming materials is measured using sieves. The sieves are numbered according to the numbers of wires per inch and the size of the spaces between the wires. A #10 sieve has 10 wires per 25 mm (1 in.), with openings that measure 1.65 mm per side.

Any material passing through a #60 sieve (0.25 mm per side) is considered to be fully effective. Material that passes through a #10 sieve (1.65 mm per side) but not a #60 sieve is considered only 40% effective. Materials that do not pass through a #10 sieve are considered ineffective. Table 3–4 illustrates how the fineness rating for limestone is calculated.

**Table 3–4.** Determining a fineness rating for limestone

In this example, 75% of the sample passed through a #10 sieve and 40% passed through a #60 sieve.

Particle size	Percentage of sample (A)	Effectiveness factor (B)	(A) x (B)
coarser than #10	25	0.0	0
between #10 and #60	35	0.4	14
finer than #60	40	1.0	40
<b>Fineness rating</b>	<b>100</b>	<b>—</b>	<b>54</b>

Federal government standards dictate that liming materials be labelled with the percentages of the material that pass through a #10 and a #100 sieve (0.15 mm per side). In Ontario, we use the #10 and #60 sieves to help determine the quality of agricultural limestone. It should feel like finely ground flour.

It is usually not economical to crush materials to the fineness needed to make effective agricultural limestone. Estimated usage in Ontario is a modest 100,000–300,000 t/year. By comparison, retail sales of fertilizers in Ontario peaked in 1985 at 1,162,000 t. The limestone is usually crushed for other purposes such as aggregate for construction or to produce limestone fluxes for smelting. Fine material is not wanted for those purposes and is sieved out. This by-product may be sieved further to yield agricultural lime.

### **Dolomitic or calcitic lime**

Liming materials made of crushed limestone rock are generally divided into two groups, calcitic and dolomitic, based on their content of calcium and magnesium.

Pure calcium carbonate (calcite) contains 40% calcium. Pure dolomite contains 21.7% calcium and 13.1% magnesium.

The division between calcitic and dolomitic limestones is not absolutely defined. Any limestone that is dominated by calcium and contains very little magnesium is considered calcitic. A 2006 survey reported eight

sources of dolomitic lime and eight sources of calcitic lime in Ontario. (*Sources of Agricultural Limestone in 2006*. Ontario Ministry of Agriculture, Food and Rural Affairs, 2006)

When liming is recommended, dolomitic lime should be used on soils with a magnesium soil test of 100 ppm or less. When the magnesium soil test is greater than 100 ppm, either calcitic or dolomitic limestone can be used. Many Ontario soils contain lots of calcium or magnesium or both. High soil test values of either are not a concern and should not influence the choice of calcitic versus dolomitic limestone.

Anyone selling materials as an agricultural fertilizer source of calcium or magnesium must supply a guarantee of analysis. The calcium and magnesium content of the material are expressed as %Ca and %Mg.

### **Liquid lime**

Lime suspensions, liquid lime and fluid lime are all names for a system of suspending lime in a fluid. The limestone used in suspensions is usually very fine and suspended in water or liquid fertilizer. Typically, suspensions contain 50%–75% liming material, 0.5%–5.0% clay and a small amount of a dispersing agent. The remainder is water or liquid fertilizer.

Suspended lime is usually associated with a fineness rating of 100 (passes through a #100 sieve). Lime that passes through a #60 sieve is considered 100% effective. Anything finer is not any more effective.

There is no evidence that liquid lime is more effective than regular lime.

### **Granulated or pelletized lime**

Some companies are promoting the use of granulated lime. This material is a finely ground lime that is formed into granules similar in size to fertilizer granules. This helps overcome many of the difficulties handling and spreading regular lime because regular fertilizer equipment can handle it.

The pelletized lime is not more effective than regular lime, and the same quantity of material is required to neutralize pH.

The choice of liming materials must be based on the cost, availability and agricultural index of the product.

### **Alternative liming agents**

Many industrial by-products can be used as liming materials — wood ash, cement dust, beet lime, industrial precipitator sludges, slags and biosolids. Each must be evaluated for its ability to neutralize acidity, for metal content, and sometimes for organic compounds. A certificate of approval must be obtained from the Ministry of the Environment, Conservation and Parks (MOECP)

before spreading it on agricultural land. Guidelines for the Utilization of Biosolids and Other Wastes on Agricultural Land, available from offices of the MOECP or the Ontario Ministry of Agriculture, Food and Rural Affairs (OMAFRA), describe the criteria by which the material will be evaluated.

Agricultural limestone has a pH of about 8.2. Some alternative liming agents, such as wood ash, may have a much higher pH. Extra caution must be taken when handling high-pH materials. Seedling injury may occur if crops are seeded soon after a high-pH material has been mixed into the soil.

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### **Agricultural index**

The agricultural index is an indicator of limestone quality that combines the neutralizing value and the fineness rating into a single value (see Figure 3–4).

The agricultural index can be used to compare the ability of agricultural limestones to neutralize soil acidity. The higher the agricultural index, the more effective the limestone is on an equal weight basis.

$$\text{Agricultural index} = \frac{\text{Neutralizing value} \times \text{fineness rating}}{100}$$

**Figure 3–4.** Agricultural index

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$$\text{Amount of lime to apply} = \text{recommended amount} \times \frac{75}{\text{Agricultural index of lime used}}$$

**Figure 3–5.** Amount of lime to apply

The average agricultural index of limestones sold in Ontario has been around 75. Limestone recommendations based on Ontario-accredited soil tests in Table 3–2 are based on the assumption that the limestone used has an agricultural index of 75. Limestone recommendations should be adjusted according to the actual agricultural index of the limestone used. This calculation is illustrated in Figure 3–5.

The agricultural index of limestones sold in Ontario from 18 quarries in 2006 ranged from 36 to 102. The average was 74 (*Sources of Agricultural Limestone in 2006*. OMAFRA, 2006).

Transportation to the farm usually accounts for most of the cost of using agricultural limestone because of its weight and volume. In general, using lime from the closest quarry will be the most economical. The cost per hectare should be calculated by multiplying the cost of each source applied to the field by the amount of lime required per hectare. This allows a fair comparison of alternative sources.

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## Lime application

### Spreading

Conventional fertilizer spreaders are not designed to handle lime, and the material will bridge in the spreader

box. Commercial spreaders designed to handle lime are advised.

Check the distribution pattern by using the same method you would to check the distribution of manure from a manure spreader (laying 1 m x 1 m (39 in. x 39 in.) plastic sheets, collecting and weighing the amount of lime spread on each sheet, and comparing lime spread across the width of distribution).

Because lime is finely ground powder, wind affects distribution patterns. Spreading in calm conditions is advised. Operators should be protected against dust hazards. Lime will drift over considerable distances even in moderate winds.

If lime must be stored on the farm prior to spreading, protect it from the elements and from drifting away. Lime will consolidate into unusable clumps if it gets wet.

### Incorporation

As agricultural limestone does not dissolve quickly, it must be mixed uniformly with the soil to be effective. Tillage implements that mix the soil, such as the disc (offset disc-harrow), do the best job.

In no-till soils, correcting pH is a challenge. If the entire plow layer

(15 cm (6 in.)) is acid, then tillage to incorporate limestone is the only practical option.

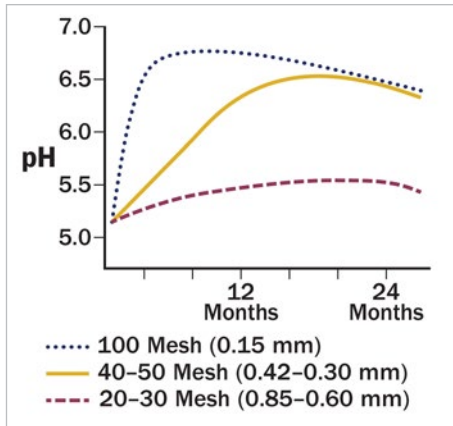
This does not mean that liming and no-till are completely incompatible. In no-till soils where nitrogen fertilizers have been surface-applied, a shallow layer of acid soil can develop. Sample the top 5 cm (2 in.) layer to check the surface pH. Frequent applications of low rates of limestone can neutralize the acidity in this zone.

Many farmers apply and incorporate a fraction of the total lime recommended over several years. This helps ensure the lime will be more uniformly distributed and mixed by tillage. This is an excellent preventive measure but will not correct severe acidity.

### Time to work

Agricultural limestone does not dissolve quickly. The rate at which each limestone particle dissolves depends on how finely the limestone is ground (see Figure 3–6). The rate of dissolution decreases as the pH of the soil increases (which is the desired result of liming). After dissolution, the lime must diffuse through the soil and interact with the acidity held in the soil solution and on the cation exchange sites. Dry or frozen soil conditions will increase the length of time required for this reaction to happen. As a result, it takes time for the full effects of liming to be realized. This may be up to 3 years.

For crops sensitive to low pH, like alfalfa, it is especially important to get the lime applied well in advance of seeding.



**Figure 3–6.** Reaction time for lime materials of different fineness

### What about gypsum?

Gypsum is not a liming material, even though it is widely promoted as a source of calcium or sulphur and as a soil conditioner. Gypsum is used as a conditioner for sodic soils (salt-affected soils), which are present on the Prairies but not in Ontario.

The chemical make-up of gypsum is calcium sulphate, which breaks down into calcium and sulphate ions when dissolved in the soil water. Although the calcium displaces hydrogen from the cation exchange sites, this hydrogen then combines with the sulphate in the soil solution to form sulphuric acid, leaving no net effect on soil pH.

Gypsum is promoted as a calcium source because it is more soluble than lime in alkaline soils. While this is true, the solubility is still quite low (gypsum is the main ingredient in wallboard), so that you need large amounts to provide a significant amount of calcium. It is also a good source of sulphur where the need has been documented.



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## Soil acidification

Occasionally, growers want to lower the pH of their soil. This is a requirement for most commercial blueberry sites in Ontario and for home gardeners who want to grow rhododendrons and azaleas. These plants thrive in soils of pH 4–5 and develop micronutrient deficiencies when the soil pH rises above these levels.

Growers with alkaline soils (i.e., pH 7 or higher) may think lowering the pH will improve nutrient availability. However, most crops thrive at soil pH levels from 6–8, and the negative effect of low soil pH is much greater than the penalty for high soil pH. In addition, it is much cheaper to add extra nutrients than to lower soil pH.

### Lowering soil pH

Soil pH is reduced by increasing the number of hydrogen ions in the soil, either directly by the addition of acids or by adding materials that will form acids when they react with the soil. Nitrogen fertilizers that contain ammonium will acidify the soil, as will elemental sulphur and iron or aluminum sulphate. Oxidized sulphur is available in the form of aluminum sulphate or iron (ferrous) sulphate, but these materials are required in much larger amounts than elemental sulphur (4 times and 8 times respectively).

For crops like blueberries, which enjoy a high level of organic matter, the addition of acidic peat moss will have the double effect of increasing organic matter and lowering soil pH.

Check that the pH of the peat is low, as several brands of peat moss raise the pH for use in potting mixes. For large areas, peat moss will be too expensive, and it is usually applied only in the rooting area of the plants.

Taking a soil test before the sulphur is applied and then 3 months after will provide baseline information on soil pH. Annual soil testing to monitor pH is important.

### Soils that can be acidified

The success of soil acidification will depend on the soil's buffering capacity. In general, it is easier to modify a sandy soil with low organic matter and low exchange capacity than a clay soil with high exchange capacity. On highly buffered soils, the reduction in soil pH may be short-lived. The other factor in soil acidification is the amount of free lime in the soil. Soils above a pH of 7 often contain undissolved calcium and magnesium carbonates, which react immediately with the acid produced by the sulphur, neutralizing it and preventing the desired drop in pH.

The natural soil pH also has an effect on the ease of lowering the pH. Remember that the pH scale is logarithmic: to move from 7 to 5 is 10 times more difficult than to move from 6 to 5. Soils with a natural pH of two units above the desired pH are almost impossible to alter. For example, if 750 kg/ha of sulphur is required to reduce the soil pH from 6 to 5, it could easily take 8,000 kg of sulphur or more to reduce the pH from 7 to 5, plus enough sulphur to neutralize any free lime that is in the soil at the higher pH.

For home gardens, replacing soil with acidic soil or building a raised bed of acidic peat may be more practical.

There are often patches in fields that show greater resistance to lowering pH. Symptoms of nutrient deficiency (e.g., nitrogen in blueberries) are a good indication of areas that need separate treatment. Test and treat these areas individually.

### Using sulphur

Sulphur (S) is the most economical way to lower soil pH, though still expensive. This involves a biological process where certain soil bacteria convert elemental sulphur to sulphate-sulphur. During this process, acid is formed. The drawbacks to using elemental sulphur are:

- A soil must have a viable population of the correct bacteria
- It is a slow process requiring time, as well as appropriate soil temperature and moisture conditions for microbial activity. It takes 3 months to 1 year for the reaction to be complete.
- Many soils need yearly applications of sulphur to maintain a lower pH

**Table 3–5.** Sulphur for soil acidification

Soil type	For each 1.0 pH unit	For each 0.1 pH unit
sand	350 kg/ha (313 lb/acre)	35 kg/ha (31 lb/acre)
sandy loam	750 kg/ha (670 lb/acre)	75 kg/ha (67 lb/acre)
loam	1,100 kg/ha (980 lb/acre)	110 kg/ha (98 lb/acre)

**Example:** The initial pH of a sandy loam soil is 6.2, and the desired pH for blueberries is 4.8. The soil pH must be lowered 6.2 to 4.8 = 1.4 units. Therefore, 1.4 x 750 = 1,050 kg/ha of sulphur must be applied.

Guidelines for the amount of sulphur that is required to lower soil pH are shown in Table 3–5. When treating the soil with sulphur to lower the soil pH, apply sulphur before the planting is established, and incorporate it throughout the soil. Powdered sulphur acts more quickly than granular sulphur but is also more expensive and unpleasant to spread. Sulphur can be applied in any season.

Alternatives to elemental sulphur are listed in Table 3–6, with conversions between the materials.

**Table 3–6.** Relative effectiveness of various materials for reducing soil pH

Material	Chemical formula	Per cent sulphur	Kg of material to neutralize 100 kg of calcium carbonate*
elemental sulphur	S	100	32
granular sulphur	S	90	36
sulphuric acid	H <sub>2</sub> SO <sub>4</sub>	32	98
iron sulphate	FeSO <sub>4</sub> · 7H <sub>2</sub> O	11.5	278
aluminum sulphate	Al <sub>2</sub> (SO <sub>4</sub> ) <sub>3</sub>	14.4	114
ammonium sulphate	(NH <sub>4</sub> ) <sub>2</sub> SO <sub>4</sub>	23.7	66

\* These are theoretical values, based on all the material reacting with the soil to produce acidity. Actual values will be less than this, often by as much as 50%, because of immobilization of the materials on soil surface, in soil microbes or by plant uptake.

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