Best Management Practices

pH EXTREMES

Soil pH extremes make conditions too acidic or alkaline (basic) for optimum nutrient availability and crop growth. They are the result of natural processes (e.g., soil formation), develop because of soil degradation (e.g., erosion) or occur over time due to the use of ammonium-based nitrogen fertilizers.

Soil pH is an indicator of the relative acidity or alkalinity of a soil solution. The scale of pH (0-14) is a logarithmic expression (inverse) of the concentration of hydrogen ions (H^+). A pH near 7 is considered neutral, while soils below 7 are acidic and those above 7 are alkaline.

This infosheet provides a set of diagnostic tools used to describe the nature and extent of pH extremes in Ontario cropland soils. Proper diagnosis is essential to identify the most suitable best management practices (BMPs) for a given field.

THE ROLE OF HEALTHY SOIL IN A CHANGING CLIMATE

Agriculture and climate are directly linked – anything that has a significant effect on our climate will influence farm production. Greenhouse gas (GHG) emissions and climate change are global concerns, and agriculture can be part of the solution.

BMPs that improve soil health can also help lower GHG emissions, reduce phosphorus loss from fields to surface water, and improve resilience to drought or excessively wet conditions. Healthy soil – an essential component of a healthy environment – is the foundation upon which a sustainable agriculture production system is built.

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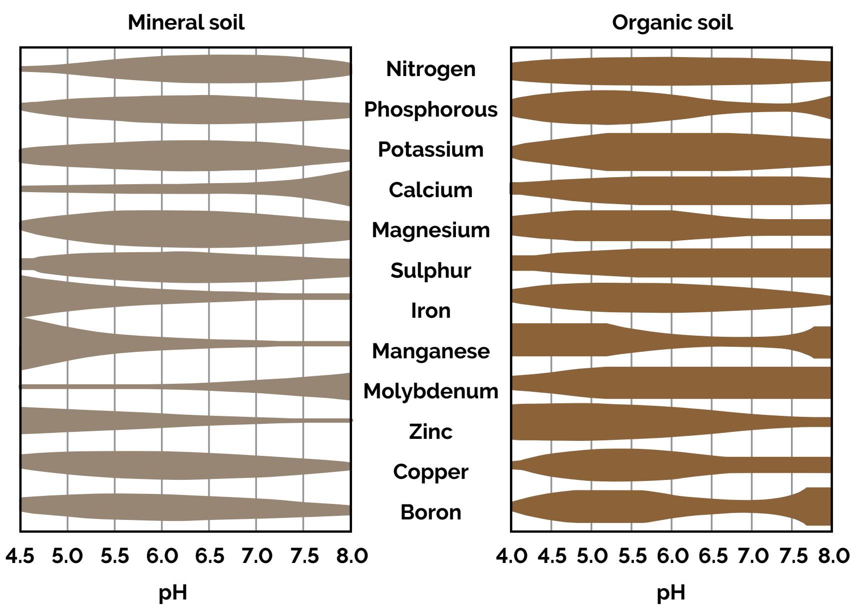
pH Extremes: Risks and Impact

The table below shows the various soil pH classes, ranging from extremely acid to strongly alkaline. While this infosheet is entitled *pH Extremes,* its focus is on soils in the moderately alkaline and moderately to very strongly acid categories.

Soil pH is directly related to nutrient availability for plant growth in both mineral and organic (muck) soils. For example, nitrogen (N) is most available to plants when soil pH is between 6.0 to 8.0, as the processes of N mineralization are driven by soil micro-organisms with pH preferences. Cycling and availability of other nutrients, including phosphorus (P), sulphur (S) and micronutrients, is also favoured by a pH within this range.

pH CLASS	pH RANGE
Extremely acid	4.4 or lower
Very strongly acid	4.5–5.0
Strongly acid	5.1–5.5
Moderately acid	5.6–6.0
Slightly acid	6.1–6.5
Slightly alkaline	7.4–7.8
Moderately alkaline	7.9–8.4
Strongly alkaline	8.5–9.0

Source: USDA Natural Resources Conservation Service
www.nrcs.usda.gov/wps/portal/nrcs/site/national/home.



Plant nutrients can be present in the soil but not necessarily in a form that is available for plant uptake. Soil pH greatly influences whether a nutrient is available for plant use.

RISKS ASSOCIATED WITH pH EXTREMES

- Nutrient availability:
  - Low pH – reduced availability of macronutrients, calcium and magnesium and some micronutrients
  - High pH – reduced phosphorus, iron, manganese, boron, copper and zinc availability
- Crop tolerance:
  - Most crops prefer neutral to slightly acidic soil conditions (pH 6.0-7.0).
  - Some horticultural crops (e.g., blueberries) thrive in moderate to strongly acidic conditions (pH 5.0-6.0).
  - Most crops tolerate basic (alkaline) conditions with pH ranges up to 7.9.
  - Few crops can tolerate pH extremes of < 5.0 and > 7.9.
- Changes in microbial activity:
  - The population and activity of certain soil organisms change with pH (e.g., reduced N_{2-} fixation within the nodules of legumes under acidic conditions).
- Solubility of heavy metals depends on pH:
  - Certain heavy metals (e.g., aluminum and manganese) become more water soluble under acid conditions.
  - Increased solubility of metals increases the risk of plant uptake and toxicity.
- Effectiveness and degradation of herbicides and insecticides:
  - Most pesticides are labeled for specific soil conditions. If soils have a pH outside the specified range, the pesticides may become ineffective, change to an undesirable form or not degrade as expected, resulting in problems for the next crop.

Sugar beets showing stunted growth and some chlorosis due to Imazethapyr (active ingredient in Pursuit) carryover from the prior year. Low pH conditions slow the breakdown of this herbicide.
Source: Darren Robinson, Ph.D., University of Guelph, Ontario.

pH Extremes: The Basics

NATURAL SOIL PROCESSES AND pH

Originally, most of the nutrients in soil (except nitrogen) were part of the chemical structure of rock. Over many thousands of years, natural forces (known as weathering) have broken down the rock and its minerals, releasing some of their nutrient content in forms that plants can use. Weathering continues to slowly release small amounts of nutrients from these sources.

Many of the chemical reactions that occur in soil remove nutrients from soil solution. Some of these reactions produce compounds that are insoluble in water and require other reactions to break the components apart and make nutrients available for plant uptake.

Soil pH has a major influence on which chemical reactions occur and which compounds are produced. pH also affects the solubility of the compounds. Therefore, the availability of most nutrients changes if the soil pH is altered.

The natural fertility of the soil on your farm was determined by two key factors: the type of rock and minerals from which the soil was derived and the conditions under which the soil was formed.

THE ROLE OF SUBSOIL AND SOIL PARENT MATERIALS

Subsoil is much lower in fertility and contributes a much smaller proportion of the nutrients taken up by plants than does topsoil. Several factors contribute to this:

- most of the plant root system is in the topsoil
- nutrients have not been added to the subsoil
- there is less organic matter in the subsoil
- fewer nutrients have been released into the subsoil because it is less subject to weathering than topsoil

Ontario's soils have developed from various types of parent material. Soil parent materials can range in pH from acidic to basic, depending on their origin, mineralogy and chemistry. For example, soil parent materials in areas near calcitic and dolomitic limestone bedrock are usually calcareous and alkaline. Soil parent materials located on or near the Canadian Shield are often acidic and reflect the mineralogy of the Shield bedrock (e.g., granites, gneisses, etc.).

The type of parent material affects how much a soil resists changes in pH or its buffering capacity. Soils with greater amounts of clay and organic matter have a higher buffering capacity and their pH changes slowly. Coarse-textured, low organic matter soils are susceptible to becoming acidic or alkaline more easily, depending on how they are managed.

Most weathered soils will reflect the general pH of the soil parent material. For example, topsoil developed on calcareous, alkaline soils is usually neutral to mildly alkaline, whereas sandy outwash soils developed near the Canadian Shield usually have slightly acidic topsoil (pH 6.1–6.5).

In extreme cases, the composition of the parent material is so basic or acidic that the entire soil remains strongly calcareous or acidic – even after more than 10,000 years of weathering! Examples include soils in Peterborough, Grey and Huron counties.

DEGRADED SOILS AND SOIL pH

Severely eroded soils are those with parent material exposed at the soil surface; a condition that reflects the loss of at least 60 cm (2 ft) of topsoil and subsoil. In such cases, surface pH reflects the pH ranges normally associated with the parent material. pH extremes due to erosion can be verified by examining the soil profile and, in the case of soils formed from calcareous parent material, by using 10% hydrochloric acid (HCl) to check for effervescence or bubbling. Whether the exposed parent material is acidic or basic, there are likely to be crop nutrient deficiencies normally associated with either extreme.

Eroded soils formed atop of calcareous parent materials will react with dilute hydrochloric acid right up to the soil surface. Normal, non-eroded topsoil in Ontario will not do this.

Soybeans growing on an eroded, high pH knoll show nutrient deficiencies and overall stunted growth.

OTHER FACTORS LEADING TO CHANGES IN pH

- Rainfall is a natural source of acidity. Rain mixes with carbon dioxide in the atmosphere and forms carbonic acid. Acidic rainwater creates a pH reduction at the soil surface over many years and is a normal part of soil development in Ontario.
- Crop uptake and excess removal of basic cations (e.g., calcium, Ca^{2+}; magnesium, Mg^{2+}; potassium, K^{+}), particularly by perennial legumes such as alfalfa, can contribute to soil acidification.
- Release of organic acids from root exudation and the decay of plant residues can acidify soil over time.
- Application of ammonium-containing nitrogen fertilizers – as well as urea, an ammonium-forming material – contribute to soil acidification. Soil bacteria convert ammonium (NH_4^{+}) to nitrate (NO_3^{+}) through a biochemical process called nitrification. Hydrogen (H^{+}) is released from this process and free hydrogen ions cause an increase in acidity. Plant uptake of nitrate results in a partial neutralization of acidity, which is why efficient application of N fertilizers, in ways that maximize uptake, is important to reduce acidifying effects.
- Loss of organic matter reduces a soil's buffering capacity. Soil organic matter offers many binding sites that help neutralize changes in soil pH. When organic matter levels decline – due to erosion, poor crop rotation or regular residue removal – soil becomes more vulnerable to pH extremes.
- Erosion of topsoil by water, wind or tillage can expose acidic or basic subsoil or parent material.

Erosion can expose acidic subsoils in some cases. This low pH, sandy knoll has a pH of 4.9 which has contributed to a poor corn stand compared to the rest of the field.

Tillage erosion can cause the exposure of parent material. On calcareous soils in this degraded condition, surface pH levels can exceed 8.0.

DIAGNOSTICS for pH Extremes

FIELD OBSERVATIONS:

High pH

- Tillage and water erosion
- Light coloured knoll or upper slope positions
- Reduced crop growth and vigour on knolls – particularly visible in early summer

Low pH

- Crop symptoms visible on knolls or in pockets across a field
- Delayed crop residue breakdown (less microbial activity under pH 6)
- Reduction in efficacy of triazine herbicides
- Longer than expected carryover of Imazethapyr (active ingredient in Pursuit)

When using aerial photography or other forms of aerial-based remote sensing information, look for evidence of eroded knolls. Noticeably lighter conditions indicate parent materials and subsoils at the surface. These are the places where pH extremes are most likely found.

CROP OBSERVATIONS:

- Stunted growth and decreased yield
- Nutrient deficiency or toxicity symptoms

High pH:

- Phosphorus deficiency
- Manganese deficiency in soybeans and cereals
- Boron deficiency in alfalfa (short internodes), zinc deficiency in corn (interveinal chlorosis)

Low pH:

- Poor nodulation of forage legumes, in particular alfalfa
- Poor persistence of perennial forages (assuming adequate drainage and fertilization)
- Aluminum (or manganese) toxicity – look for stunted growth and poor plant stand
- Magnesium deficiency
- Poor barley crop or no barley in mixed grain

Twisted, short and stubby corn roots in extremely acidic conditions can be an indicator of aluminum toxicity.

Manganese deficiency in soybeans is common in some high pH soils. It shows up as interveinal chlorosis on the younger leaves.

Magnesium-deficient corn on a sandy, low pH knoll. Magnesium deficiency is more common under acidic soil conditions.

SOIL OBSERVATIONS:

SOIL TEST is best!

A soil test will tell you the pH of your soil as well as the buffer pH, which helps determine lime application rates, if required.

High pH

- High pH conditions are usually associated with high levels of lime. The presence of carbonates can be detected by using dilute HCl. Bubbles indicate a carbonate content of 5–20%; extreme foaming indicates 20%+ free carbonates – a range normally associated with levels found in parent materials.

Low pH

- Light coloured or pale-yellow sandy subsoils exposed at surface
- Poor soil structure and poor tilth

Beige to pale-yellow colours at the surface of coarse-textured soils are indicators of acidic parent material. The soil profile on the right side of the soil box was from an eroded, acidic sandy knoll in Kent County that did not support a strong corn crop. The soil profile on the left was taken from the same field, a short distance away, off the knoll, and was neutral pH.

Best Management Practices (BMPs)

Choose the most suitable suite of BMPs from the list below to resolve soil problems associated with pH:

- Lime low pH soils based on soil test results. Use the soil buffer pH and a target soil pH based on crop tolerances to determine the amount of lime needed. Mix uniformly with a tillage implement that mixes the soil (e.g., offset disk-harrow). The full effects of liming may take up to 3 years.
- In low pH and poorly buffered soils, select nitrogen sources with lower acidification potential. Match nitrogen application rates with crop demand as closely as possible to avoid acidification caused by excess nitrogen.
- Use no-till, reduced tillage and residue management practices to keep topsoil in place and minimize erosion of knolls.
- Grow cover crops to scavenge nitrogen, reduce leaching and protect soil from erosion.
- Grow crops that tolerate acidic or alkaline soils (see table - Guidelines for lime application to Ontario crops).
- In general, it is not recommended to reduce the pH of alkaline soils. If the soil pH is very high (pH 7.8–8.2), the soil contains 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 elemental sulphur to acidify the soil will not be effective and it will be costly.

GUIDELINES FOR LIME APPLICATION TO ONTARIO CROPS

CROPS	SOIL pH BELOW WHICH LIME IS BENEFICIAL	TARGET SOIL pH[1]
COARSE AND MEDIUM-TEXTURED MINERAL SOILS (SAND, SANDY LOAMS, LOAMS AND SILT LOAMS)		
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
FINE-TEXTURED MINERAL SOILS (CLAYS AND CLAY LOAMS)		
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
ORGANIC SOILS (PEATS/MUCKS)		
all field crops all vegetable crops	5.1	5.5

[1] Where a crop is grown in rotation with other crops requiring a higher pH (e.g., corn in rotation with wheat or alfalfa), lime the soil to the higher pH.

Source: OMAFRA Soil Fertility Handbook (Publication 611), ontario.ca

Soil test is best! Review soil test results for pH and buffer pH values and apply lime at recommended rates if required.

For more information

ONTARIO MINISTRY OF AGRICULTURE, FOOD AND RURAL AFFAIRS

Many sources of supplementary information are available. Most can be found online at ontario.ca/omafra or ordered through ServiceOntario.

- *Soil Fertility Handbook*, Publication 611

Best Management Practices Series

- *Managing Crop Nutrients*
- *Soil Management*
- *Low Fertility*

Environmental Farm Plan (4th ed.) and EFP Infosheets

- Worksheet #15, *Soil Management*

Purdue University. Soil Acidity and Liming of Indiana Soils. http://www.agry.purdue.edu/ext/forages/publications/ay267.htm

Soil Acidity: A guide for WA farmers and consultants. Gazey, C, Davies, S, and Master, R. (2014), Department of Agriculture and Food, Western Australia, Perth. Bulletin 4858.

USDA. Soil Quality Indicators: pH. http://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcs142p2_052208.pdf

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