USDA Natural Resources Conservation Service

Indicator	Test	Function
C	F	F/N

Soil Quality Indicators

Soil pH

Soil pH generally refers to the degree of soil acidity or alkalinity. Chemically, it is defined as the $\log_{10}$ hydrogen ions (H^+) in the soil solution. The pH scale ranges from 0 to 14; a pH of 7 is considered neutral. If pH values are greater than 7, the solution is considered basic or alkaline; if they are below 7, the solution is acidic. It is important to recognize that because the pH scale is in logarithmic units, a change of just a few pH units can induce significant changes in the chemical environment and sensitive biological processes. For example, a soil with pH 5 is 10 or 100 times more acidic than a soil with pH 6 or 7, respectively. Sources of H^+ ions in soil solution include carbonic acid produced when carbon dioxide (CO_2) from decomposing organic matter, root respiration, and the soil atmosphere is dissolved in the soil water. Other sources of H^+ ions are root release, reaction of aluminum ions (Al^{+3}) with water, nitrification of ammonium from fertilizers and organic matter mineralization, reaction of sulfur compounds, rainwater, and acid rain. Certain soils are more resistant to a drop or rise in pH (buffering capacity). Therefore, the lime requirement, which is the quantity of limestone ($CaCO_3$) required to raise the pH of an acid soil to a desired pH, must be determined specifically for each field before amending the soil.

Phosphorus deficiency in corn. Source: R.L. Croissant, Bugwood.org

Factors Affecting

Inherent - The natural soil pH reflects the combined effects of the soil-forming factors. Weathering and associated chemical reactions release cations (Ca^{+2}, Mg^{+2}, K^{+1}, Na^{+1}) that remain freely in soil solution, form complexes with dissolved organic carbon compounds, or are adsorbed at the surface of clay minerals and humus. Over time, the leaching of free cations, basic oxides, and carbonates, as well as the removal of cations by plant uptake and harvesting, and the continuous formation of carbonic acid result in soil acidification. When cations are lost, H^+ ions replace them in the soil solution and on the surface of clay minerals and humus. In very acid soils (where pH is less than 5), aluminum becomes soluble and its ions (Al^{+3}) tend to react with water to produce H^+ ions, which further exacerbate acidification. In arid climates, soil weathering and leaching are less intense, cations accumulate, and OH^- ions offset H^+ ions. As a result, the soil becomes neutral or alkaline. Soils with coarse textures may acidify easily compared to clay soils, because they have low organic matter content, a low buffering capacity, a low cation-exchange capacity (poor cation retention), and high rates of water percolation and infiltration. Clay and organic matter in mineral soils act as buffers to resist pH variations. Soil parent material influences soil properties including pH as shown by the contrasting pHs of soil formed in calcareous and granitic materials. The effect of vegetation on soil pH is due partly to the type of humus produced as certain types of humus are soil acidifying. Water erosion removes surface horizons, which can be rich in organic matter, creating a pH gradient along the slope.

Dynamic - The conversion of uncultivated land into cultivated soils can result in drastic pH changes after a few years. These changes are caused by the removal of cations by crops, the acceleration of leaching, the effect of fertilizers and amendments, and the variations in organic matter content and soil buffering capacity. Inorganic amendments (lime and gypsum) and organic amendments rich in cations increase soil pH. Ammonium from organic matter mineralization (nitrification), ammonium-based fertilizers, and sulfur compounds lower the pH. High rates of water percolation and infiltration increases leaching of cations and accelerate soil acidification.

Relationship to Soil Function

Soil pH affects the soil's physical, chemical, and biological properties and processes, as well as plant growth. The nutrition, growth, and yields of most crops decrease where pH is low and increase as pH rises to an optimum level (see table 1). Many crops grow best if pH is close to neutral (pH 6 to 7.5) although a few crops prefer acid or alkaline soils. In acid soils, calcium and magnesium, nitrate-nitrogen, phosphorus, boron, and molybdenum are deficient, whereas aluminum and manganese are abundant, sometimes at levels toxic to some plants. Phosphorus, iron, copper, zinc, and boron are frequently deficient in very alkaline soils. Bacterial populations and activity decline at low pH levels, whereas fungi adapt to a large range of pH (acidic and alkaline). Most microorganisms have an optimum pH range for survival and function (see table 2). At very acid or alkaline pH levels, organic matter mineralization is slowed down or stopped because of poor microbial activity linked to bacteria. Nitrification and nitrogen fixation are also inhibited by low pH. The mobility and degradation of herbicides and insecticides, and the solubility of heavy metals are pH dependent. The effects of soil pH on cation availability influence aggregate stability since multivalent cations, such as calcium ions, act as bridges between organic colloids and clays. Some diseases thrive when the soil is alkaline or acidic. Take-all, which is caused by the fungus *Gaeumannomyces graminis*, is favored by alkaline pH and infects wheat, barley, rye, and several grasses.

Problems with Poor Soil pH Levels

Deficiencies of many nutrients, decline of microbial activity and crop yield, and deterioration of environmental conditions are associated with pH levels as discussed in the previous section.

Improving Soil pH

Liming, addition of organic residues rich in basic cations, and crop rotation to interrupt the acidifying effect of leguminous crops increase soil pH. Applying ammonium based fertilizers, urea, sulfur/ferrous sulfate, irrigating with acidifying fertilizers, or using acidifying residues (acid moss, pine needles, sawdust) decrease soil pH. Increasing organic matter increases buffering capacity.

Measuring Soil pH

Soil pH is measured in the field using a portable pH pocket meter as described in the Soil Quality Test Kit Guide, section I, chapter 6, page 15. See also section II, chapter 5, pages 63 to 66 for interpretation of results.

Specialized equipment, shortcuts, tips:

Always calibrate the pH meter with the appropriate buffer solution before using it and report the soil to water ratio used to take the reading. Wait 10 to 15 minutes after measuring electrical conductivity to allow soil particles to settle.

Time needed: 10 minutes

References:

Brady CN and RR Weil. 2002. The Nature and Properties of Soils, 13th Edition. Prentice-Hall.

Karlen D, Andrews S, Wienhold B, and Zobeck T. 2008. Soil quality assessment: Past, present and future. Journal of Integrated Biosciences 6(1):3-14.

Smith JL and JW Doran. 1996. Measurement and use of pH and electrical conductivity for soil quality analysis. In Methods for assessing soil quality. Soil Science Society of America Special Publication 49: 169-182.

Table 1. Relative yield of selected crops grown in a corn, small grain, legumes or timothy rotation at different pH levels. (adapted from Smith and Doran 1996)

	pH				
	4.7	**5**	**5.7**	**6.8**	**7.5**
Crop	**Relative Average Yield**				
Corn	34	73	83	100	85
Wheat	68	78	89	100	99
Oats	77	93	99	98	100
Barley	0	23	80	95	100
Alfalfa	2	9	42	100	100
Soybean	65	79	80	100	93
Timothy	31	47	66	100	95

Table 2: Maximum, minimum, and optimum pH values for microbial groups. (adapted from Smith and Doran 1996)

Microorganisms	**Range**	**Optimum**
Bacteria	5 - 9	7
Actinomycetes	6.5 - 9.5	8
Fungi	2 - 7	5
Blue green bacteria	6 - 9	> 7
Protozoa	5 - 8	> 7