

Site-Specific Nutrient Management

For Nutrient Management Planning To Improve Crop Production, Environmental Quality, and Economic Return

Presentation Script: Soil pH and Lime - Chapter 8

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Funding provided by the USDA-NRCS and TFI.

... and justice for all

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Soil pH and Lime Management

Slide 1.

This module will cover important concepts of soil pH and lime management in agronomic systems for profitable crop production. General concepts and some management practices will be presented. Even though these principles apply for most regions of the U.S., viewers are encouraged to review locally developed information and nutrient management recommendations.

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Soil pH is a measure of the soil solution's acidity and alkalinity. By definition, pH is the negative logarithm of the hydrogen ion concentration. Soils are referred to as being acidic, neutral, or alkaline, depending on their pH values on a scale from 0 to 14. A pH of 7 is neutral, less than 7 is acidic, and greater than 7 is alkaline. Because pH is a logarithmic function, each unit on the pH scale is ten times less acidic or basic than the unit above or below it. For example, a solution with a pH of 6 has a 10 times greater concentration of hydrogen ions than a pH of 7, and 100 times higher concentration than pH 8. Soil pH is influenced by both acidic- and basic-influencing ions in the soil. Common acidic cations, positively charged ions, are hydrogen, aluminum, and iron; whereas common basic cations include calcium, magnesium, potassium, ammonium, and sodium.

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Many factors influence the pH of a surface soil or subsoil. These include parent material the soil was derived from, length of weathering and soil formation, climate, organic matter mineralization, ammonium fertilizer rate and nitrification to nitrate, cropping system and crop harvest, and land use and management. Of the management practices for crop production, application of fertilizers or organic sources that contain ammonium or compounds that transform into ammonium once applied to the soil have the largest influence on increasing soil acidity. Nitrification of ammonium to nitrate from any fertilizer or manure source, or mineralization and subsequent nitrification of organic-nitrogen compounds, such as from manure, produces hydrogen ions, thus lowering soil pH. Frequency of crops in a rotation that require nitrogen application, and frequency of crops with high nitrogen fertilization requirement, will affect acidification rate. Most agricultural soils in dry climates have alkaline conditions with average pH values ranging from 7 to 8.5. This is primarily due to the presence of basic cations associated

with carbonates and bicarbonates found naturally in those soils and irrigation water. When sodium is abundant, which sometimes is the case in dry climate areas, soil pH can be as high as pH 10. Due to relatively low precipitation, often less than evapotranspiration, there is little leaching of basic cations resulting in pH values greater than 7 and a relatively high degree of base saturation which is the percentage of the cation exchange complex occupied by basic cations. In contrast, acidic conditions occur in soil derived from parent material high in minerals such as silica, for example rhyolite, granite, and sandstone, in soils with high levels of sand with low buffering capacities defined as the ability to resist pH change, and in regions with high precipitation and a long period of weathering and soil formation.

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Soil pH is important because it affects plant growth directly and also indirectly by affecting availability of essential nutrients, levels of phytotoxic elements, and microbial activity. The figure shows relatively how nutrient availability and microbial activity are affected by soil pH. The availability of iron and zinc, for example, is severely reduced in high-pH soils. Even though iron is present in large quantities in soils, its availability in a form the plant can use is limited by reactions that form insoluble compounds at high pH.

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Knowing the soil pH helps identify the chemical reactions likely to be occurring. In general, important reactions from the standpoint of crop production are those dealing with solubility of essential and non-essential elements. As indicated previously, the relative availability of several essential nutrients is greatly reduced at low pH, for example phosphorus. Toxicity from aluminum, manganese, and hydrogen is a major cause for crop failure in very acidic soils. Aluminum and manganese are a problem in acidic soils because they are more soluble at low pH. As a component of clay, large quantities of aluminum are present in soils. When the soil pH is greater than 5.0 to 5.5, soluble aluminum is low and aluminum remains in a solid combination within clays and other elements, and therefore is not harmful to plants. However, as the pH drops below 5.0, aluminum containing materials began to dissolve and aluminum increases in soil solution and on the soil cation exchange complex. Because of its nature as a cation, the amount of dissolved aluminum is 1,000 times greater at pH 4.5 than at 5.5. Toxic levels of aluminum harm the crop by negatively affecting root activity. As a result, plants are unable to absorb water and nutrients normally and will appear stunted and exhibit nutrient deficiency symptoms, like

that for phosphorus. Often the field will also appear to be under greater stress from pests, such as weeds, because of the poor crop growth and inability to compete. In addition to effects on solubility, microorganisms have varying optimal pH ranges, just like plants. Therefore, if pH is too low or too high, microbial activity will diminish. This can affect important process such as mineralization, nitrification, and breakdown of herbicides.

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Soil pH is best measured in soil-water slurries, with soil to water ratios of 1:1 (most common in most of the U.S.), 1:2, or in a saturated soil paste. Soil pH values are measured with a pH electrode placed into either the slurry or paste. This pH is designated as the water pH and is an indication of what is called the active acidity or acidity in soil solution. Though most soil testing laboratories utilize water for pH determination, some will use a dilute salt solution (such as potassium chloride or calcium chloride). The dilute salt is used to mask the effects of naturally occurring soluble salts or recent fertilizer application on pH measurement. By adding a slight concentration of salts, more exchangeable hydrogen ions are brought into solution from the exchange complex, with the measured pH generally 0.5 to 1.0 units lower than measured using a water slurry. Also, differing soil-water ratios produce slightly different pH values; a reading obtained from a 1:1 soil:water ratio is generally 0.15 to 0.25 pH units higher than that of a saturated paste extract, but lower than a 1:2 ratio. Therefore, it is important to be aware of the soil pH test being used and to be consistent with sample analyses to ensure comparable data over time. Soil testing laboratories typically denote the pH test method used on their soil test reports.

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Most plants have a wide range of pH where they can grow and survive, but have optimal growth and production in a fairly narrow range. For example, a legume crop like alfalfa can grow and survive in soil pH's ranging from 5.0 to 8.1, however, forage yield will be greatly reduced in low-pH soils (less than 6.0) and is optimized with soil pH only slightly acidic to neutral. Other crops, cranberries, for example, are adapted to acidic soils and will not grow well in soils with a pH above 6.0. Therefore, soil pH modification must be tailored to the crop or cropping rotation. Optimum soil pH ranges dependent on the crop and geographic region have been established for crops. More examples are given in this table.

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Collecting an appropriate soil sample for pH determination is the first and most critical step in determining liming needs. Improper sample collection and handling can lead to incorrect recommendations. While there is some regional variability, it is generally suggested to collect at least 12 cores from the recommended depth at random locations across the area of interest and to place them in a clean, plastic container for shipment to the lab. Timely soil sampling is important because limestone requires time to neutralize soil acidity. Sampling and limestone application should be completed several months in advance of crop growth to provide time for pH adjustment. In addition, soil pH fluctuates during the year, thus soil sampling should be conducted at the same time during the season.

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The frequency of soil sampling to determine lime requirement will depend on soil properties, crop, the source and amount of nitrogen applied, and the quality and type of liming material used. Under intense cereal production with high rates of nitrogen fertilizer, acidity will increase rapidly, especially in coarse textured, low cation exchange capacity soils. Finely ground liming materials will result in a more rapid increase in pH, but also a more rapid decrease in pH over time. Sampling at least every three to five years is recommended. There is increased interest in within-field site-specific pH measurement and variable rate lime application due to the often large variation in soil pH. This is especially true in fields with variable soils, for example, fields where acidic soils are intermixed with carbonate containing soils with a higher, more basic pH. Dense grid soil sampling approaches and variable rate technologies are being adopted at a rapid rate by producers. Results from samples collected from producer's fields and field-scale research have shown very high pH variation within fields and even within soil map units.

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This figure shows soil pH spatial variability from a very dense grid sampling for a field having several soil types in central Iowa. Taking into account the degree of spatial variability for most agriculture soils in the U.S. along with the cost of sampling, soil analysis, and limestone, the 2.5-acre soil sampling approach is the one most frequently recommended for making prescription maps for variable rate liming. However, less dense grid sampling schemes or zone sampling, for example by soil type, are also used in areas where soil property variation dominates soil pH spatial variability. Also, remote sensing can sometimes be used to establish sampling zones for

pH. For example, soybean iron deficiency chlorosis in high-pH, calcareous soils can be used to verify the pH is calcareous and map those areas within fields.

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Alkaline soils have pH above 7.0, which means the exchange complex is saturated with basic cations. In soils with pH 7.2 to 8.5, pH is controlled by dissolution of calcium and magnesium carbonates, referred to as free lime. In soils with pH 8.5 to 10.5, pH is controlled by exchangeable sodium and dissolution of sodium carbonate. Therefore, decreasing the pH of alkaline soils is difficult due to the need to neutralize free lime or sodium salts and to reduce base saturation. Except perhaps for high-value horticultural crops, this is impractical for in-field situations due to the high cost for large applications of acidifying amendments and potential salt buildup from those applications. For example, a soil containing 1% free lime in the top 7 inches of soil would require 68 tons per acre of concentrated sulfuric acid to neutralize the carbonates before alkalinity could be reduced to neutral. In most cropping situations, alkaline soil pH is not modified, instead crop, nutrient sources, and production practice decisions are based on knowledge of field conditions.

Soil pH reduction can be achieved in localized (small areas); for example garden or landscape areas for plants that require low pH. In such cases, a common amendment to acidify soil is elemental sulfur. Elemental sulfur is oxidized by microbes to sulfate, with production of hydrogen ions which then neutralize free lime or lower base saturation on the exchange complex. Ferrous sulfate and aluminum sulfate can also be used to lower pH by contributing acidic cations. The amount of an acidifying material required depends on the volume of soil to be treated, free lime content, soil cation exchange capacity, desired pH, and acidifying effect of the material applied. Salt issues can develop if the amount of acidifying material applied is large, and element toxicity is possible when materials containing aluminum are used.

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Acidic soils are the most common agronomic problems in humid and highly productive areas of the U.S. In non-alkaline soils, application of nitrogen fertilizers and many manure sources continually cause a steady increase in soil acidity. The most common method for neutralizing soil acidity and increasing soil pH is to apply limestone. Liming materials are most often carbonate containing materials, such as calcium carbonate and magnesium carbonate. Limestone, and other liming materials, react with carbon dioxide and water in the soil to yield bicarbonate,

which reacts with hydrogen to form water and aluminum to form insoluble compounds. These reactions remove acidic cations from the exchange complex and from solution, thereby increasing base saturation and raising soil pH. The amount of limestone material to apply depends on the amount of reserve soil acidity to be neutralized and the quality of the liming material. The quality of liming materials is determined by two factors. One factor is the ability to neutralize acid (purity), called the calcium carbonate equivalent. As this index increases, the material purity increases and the acid neutralizing ability increases. The second factor is the particle size analysis. Finer limestone particles react faster due to increased surface area. The combination of these two factors is the effective neutralizing value. This quality factor has different names in different states, but in all cases is providing the ability of liming materials to be effective in neutralizing acidity and raising soil pH. Most agricultural limestones are ground calcium and magnesium carbonates, and have a mix of particle sizes from small to large. The quality measure is then a combination of the fineness efficiency from the percent of material passing each mesh size, the calcium carbonate equivalent, and moisture content. The mix of particle sizes is important so there are adequate fine materials and coarser materials to ensure rapid pH improvement and stabilization of pH for several years.

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The amount of limestone needed to adjust soil pH depends on the desired level for a particular crop, the initial soil pH, and the soil cation exchange capacity. The cation exchange capacity is the soil clay and organic matter content which determine the soil buffer capacity or resistance to pH change. While soil pH is used to determine whether or not soil acidity limits crop growth and liming is needed, it does not directly estimate lime requirement. Several analytical methods have been developed to determine lime requirement. These methods include soil incubation, direct titration, and use of buffer solutions. Long-term soil incubations with calcium carbonate have been used for research studies and to calibrate other lime requirement methods; however, these are impractical for use by routine testing laboratories. Direct titrations are laborious and may require days to complete, so they are not practical for use in routine soil testing. Buffer pH methods were developed to provide a faster assessment of lime requirement in a routine lab setting. A buffer solution resists pH change when exposed to acidity, and provides a linear decrease in pH when the soil's potential acidity reacts with the buffer. The decrease in pH of the buffer solution is what is measured after mixing the buffer with soil and provides an estimate of

the amount of lime required to neutralize the acidity of the soil in order to reach a desired pH. There are several buffer pH solutions in use. In the Midwest U.S., the Shoemaker-McLean-Pratt or SMP buffer has been the method used in many states. However, that buffer solution contains hazardous chemicals and needs special and expensive disposal by soil testing laboratories. Therefore, new buffers, such as the Mehlich and Sikora buffers, were developed and are currently being used because they do not contain hazardous chemicals and are more environmentally friendly. In some states, instead of using a buffer pH method, the lime requirement is calibrated from measured soil pH and the soil cation exchange capacity. CEC can be determined by lab measurement or knowledge of the soil's textural class and color, both reflect the soil clay and organic matter content. In addition to these methods, some states, especially in the southeast U.S., have developed fast direct titration methods that use a single addition of a strong base to determine lime requirement.

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Although limestone can be applied at any time, several factors should be considered when planning an application. Most importantly is the length of time required for pH change to take place. Crops with more sensitivity to low pH, such as forage legumes, should have pH corrected well in advance of seeding. Soil moisture is critical for the reaction of limestone with soil acidity, thus rainfall patterns should also be used as a guide for application timing. Soils should be sufficiently firm to support heavy equipment and minimize compaction. If subsoil pH is low, a long period will be required for the limestone to effect a change in the soil pH with depth. Coarse limestone particles react more slowly and may take several months to correct pH. Incorporation into the soil will provide faster reaction and pH adjustment within the tillage zone. Surface application, for example in no-tillage, will have the greatest impact on pH near the soil surface. When a more rapid pH correction is needed, the use of finely ground limestone or an agricultural ground limestone containing considerable fine particles should be considered.

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Application of lime using variable rate technology has recently grown in popularity. Variable rate applications help growers avoid under-applying liming products in field areas having lower-than-optimum pH and reduces or avoids application in areas with high pH that do not need lime application. This methodology can greatly aid in correct field placement and application rate of

lime materials, especially in highly spatial variable fields, which increases liming efficiency and therefore profitability.

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A variety of agricultural liming materials, most frequently calcitic and dolomitic limestone, are readily available in the U.S., as shown in the table. Agricultural liming materials (limestone) are defined as products whose constituents are capable of neutralizing soil acidity, typically calcium and magnesium carbonates. Although the terms are not well defined, calcitic limestone means a material consisting mainly of calcium carbonates or high in calcium carbonate and low in magnesium carbonates, while dolomitic limestone means a material with approximately sixteen percent or more of the neutralizing value is derived from magnesium carbonate. Other liming materials can come from a variety of by-products or other sources. Some are very reactive, and not commonly used for liming soils, such as burnt or hydrated lime, due to handling issues. Application rates need to be adjusted for the particle size and high reactivity. Liquid, fluid, or suspension lime is a combination of very fine limestone, 100 mesh or smaller, in water with 1 to 2% clay to form a suspension that is about 50 to 60% solids. Some drinking water treatment byproducts are similar as they result from rapid throughput of water treated with finely ground calcium oxides. Fluid lime does not react differently than finely ground dry limestone, but because of the fineness of grind the rate of application should be adjusted to avoid over-liming and resulting too-high pH.

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Soil pH is considered the single most important chemical property of soil because it affects plant growth, microbial activity, and nutrient availability in many different and complex ways. Limited solutions exist for reducing pH in high pH soils because they are impractical or uneconomical. Soil acidity is a common problem in many agricultural soils. It reduces plant nutrient availability, affects microbial activity, and with low pH increases toxicity of some elements. Therefore, neutralization of soil acidity has many positive effects and greatly enhances crop productivity. Lime application is the most common way to neutralize acidity in soils and there are many lime sources that vary in type, neutralization capacity or purity, and particle size. Agricultural ground limestone is the most commonly used liming material. Although several methods can be used to determine liming rates to achieve optimum pH for crop growth, buffer solutions, single titrations with a base, and indexes that include soil characteristics such as soil

pH and organic matter, clay, or CEC, are the most widely used approaches. The large within-field spatial variability in soil pH and lime requirement commonly found in many U.S. regions greatly justifies dense soil sampling and variable rate technology for limestone application. No matter the method to determine soil pH or liming rate requirement, or the method to apply liming materials, monitoring and improving soil pH is often most important consideration for sound soil fertility management in many soils.