WHY TURFGRASS RESPONDS TO PROPER USE OF LIME AND SULFUR COMPOUNDS

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What does pH really mean?

WE know a soil may be either acid, neutral or alkaline, and that the degree of acidity or alkalinity is expressed as pH. Technically pH is defined as the reciprocal of the hydrogen ion concentration of the soil solution. pH is always expressed as a numerical exponent (a logarithm) to the base 10.

In the instance of 10^6, the 6 is the numerical exponent or logarithm (pH) and 10 is the base. These pH numbers form a scale which extends from 0 to 14 and the numbers are so arranged that at the point where the concentration of hydrogen ions equals the concentration of hydroxide ions a condition of neutrality exists. At this point the solution is neither acid nor alkaline. One liter (1 gallon = 3.78 liters) of any neutral solution will contain a concentration of hydrogen ions equal to 10^{-7} or 0.0000001 gram (1 pound = 454 grams) of hydrogen ions per liter. The reciprocal of this is 1/0.0000001 or 10,000,000 or 10^7 and the logarithm of this is 7.0. An acid solution with a pH of 6.0 will contain 10^{-6} or 0.000001 gram of hydrogen ions per liter. The reciprocal of this is 1/0.000001 or 1,000,000 or 10^6 and the logarithm is 6.0. An alkaline solution with a pH of 8.0 will contain 10^{-8} or 0.00000001 gram of hydrogen ions per liter. The reciprocal of this is 1/0.00000001 or 100,000,000 or 10^8 and the logarithm is 8.0. It can be seen that an acid solution contains a higher concentration of hydrogen ions than an alkaline solution (0.000001 gram is greater than 0.00000001 gram).

In comparison with common units of weight these amounts are extremely small. It also may be noted that the pH as a whole number is the same as the number of zeros in the reciprocal of the hydrogen ion concentration or it is the same as the exponent in that expression of the hydrogen ion concentration. It is evident that the hydrogen ion concentration at each pH unit is 10 times greater than the next higher unit or 10 times smaller than the next lower unit. For example, as pH levels increase from 1 to 2 to 3 to 4 the hydrogen ion concentration decreases 10 times from 1 to 2, 10 times more from 2 to 3, and 10 times more from 3 to 4 or the hydrogen ion concentration decreases 100 times from 1 to 3 or 1,000 times from 1 to 4. This indicates that a small change in pH actually represents a rather large change in hydrogen ion concentration (See Table 1). In addition, as hydrogen ion concentration increases, hydroxide ion concentration decreases.

How do Soils become Acid?

Factors which influence soil acidity may be classified in three groups:

1. Soil Properties
2. Biological influences.
3. Climatic influences.

Soil Properties

Soils composed of minerals high in calcium and magnesium resist tendencies to become acid. The same acid forming processes go on in these soils that take place in other soils. However, these calcium soils have a built-in supply of lime which is effective in neutralising acidity as it forms. In general, processes of weathering, decomposition of organic matter, exchange of bases on colloidal soil systems, cropping, accumulation of fertilizer residues and leaching influence soil pH. These processes result in the formation of acid silicates, mineral acids, acid salts and organic acids which tend to increase soil acidity.

Biological influences

Plant roots release hydrogen in their respiratory processes. Since respiration is an essential feature of all living matter, the release of hydrogen in the soil is particularly large where organic matter levels are high and the soil is active biologically (contains a large number of microorganisms). Calcium, magnesium potassium, and sodium, all plus charged ions, are obsorbed by plant roots and by microorganisms and thus removed from the soil while hydrogen ions are left behind to increase soil acidity.

Climatic influences

The plus charged ions; calcium, magnesium, potassium, and sodium are subject to leaching from soils where rainfall or irrigation practices result in excesses in soil moisture at various periods throughout the year. In such instances these ions are washed out of the topsoil into the subsoil where they are drained away and lost. Hydrogen ions accumulate in these situations and soils tend to increase gradually in acidity. Where rainfall is in excess of 20 inches a year and where calcium and magnesium contents of the soil are low, soil acidity is likely to be a major problem. Putting greens and tees which are watered regularly are particularly susceptible to development of acid conditions.

In areas where the total yearly rainfall is light and where large amounts of precipitation seldom occur these basic elements (calcium, magnesium, potassium, and sodium) do not leach away but accumulate in both the topsoil and the subsoil. Often in these locations irrigation water is relatively high in basic ions and the use of such water increases further the concentration of these elements. Under such conditions, soils gradually increase in alkalinity.

Table 1. — The pH Scale

pH Reading	Hydrogen Ion Concentration*		Hydroxide Ion Concentration*	
0 Acid	10^{-0}	1.0	10^{-14}	0.00000000000001
1	10^{-1}	0.1	10^{-13}	0.0000000000001
2	10^{-2}	0.01	10^{-12}	0.000000000001
3	10^{-3}	0.001	10^{-11}	0.00000000001
4	10^{-4}	0.0001	10^{-10}	0.0000000001
5	10^{-5}	0.00001	10^{-9}	0.000000001
6	10^{-6}	0.000001	10^{-8}	0.00000001
7 (Neutral)	10^{-7}	0.0000001	10^{-7}	0.0000001
8	10^{-8}	0.00000001	10^{-6}	0.000001
9	10^{-9}	0.000000001	10^{-5}	0.00001
10	10^{-10}	0.0000000001	10^{-4}	0.0001
11	10^{-11}	0.00000000001	10^{-3}	0.001
12	10^{-12}	0.000000000001	10^{-2}	0.01
13	10^{-13}	0.0000000000001	10^{-1}	0.1
14 Alkaline	10^{-14}	0.00000000000001	10^{-0}	1.0

*Moles per liter (1 mole of hydrogen = 1 gram per liter; 1 mole of hydroxide = 17 grams per liter).

How Soil Acidity and Alkalinity Affect Turfgrass Growth

Turfgrass species and strains differ in their tolerance of acid soil conditions. In general, of the cool season grasses, the bentgrasses are most tolerant, the bluegrasses least tolerant and the red fescues are intermediate. The optimum pH for all these grasses, however, lies between 6.0 and 7.5 Applications of ground limestone to correct acid soil conditions are recommended any time the pH drops below 5.8.

It is important to note the effects of soil acidity and alkalinity on turfgrass production. Plant response often provides the first indication of poor growth conditions in the soil. The following observations have been associated with acid soils.

First, Plant Vigor. Turf grown on acid soil is often more free of weeds, particularly clover than turf grown under neutral or slightly alkaline conditions. Where soils are acid, bentgrasses are often darker green in color and turf is more dense. Not all weeds do better at higher soil pH levels. For example, sheep sorrel and field horse-

Continued: *Page* 10

from page 5

tail grow best on acid soils; also bentgrasses and fine leafed fescues grown under non-irrigated conditions perform best under acid soil environments.

Second, Injuries. Turf grown on acid soil has been found more susceptible to winter kill, more prone to injury from applications of chemicals such as arsenic and less reliable under adverse climatic conditions. These growth responses are believed to be primarily due to a weakened condition within the plant when grown on acid soils.

Third, Thatch. Turf is more likely to develop thatch and to become root bound on acid soils. Soil microorganisms are affected by the pH of their environment. Decomposition of organic matter, ammonification, nitrification and nitrogen fixation are carried out more effectively where soils are properly limed. For example, the activity of nitrifying organisms declines with pH much below 5.5. It is known that earthworms and bacteria are less active under acid conditions while fungi are more active. Since bacteria activity is reduced in acid soils and these microorganisms are effective in the breakdown of organic residues, thatch accumulates where soils are acid. In addition, the normal decomposition of thatch results in the production of organic acids which as they accumulate may further suppress the rate of organic matter breakdown. Applications of two to five lb. of fine ground limestone or of hydrated lime per 1,000 square feet are of value in correcting soil acidity so that these processes may continue.

Fourth, Disease. Acid soils have been correlated with increased incidence of dollar spot, brown patch and snow mould diseases. It is likely that increased fungal activity under acid soil conditions is responsible for these observations.

Fifth, Drought. Drought tolerance of turf is less where soils are acid. This may be related to decreases in depth and distribution of root systems in acid soils.

It has been concluded that soils may readily become too acid for the best growth of fine turf and that in the long run maintenance of soil pH levels between 6.0 and 7.5 is most desirable.

Why Soil Acidity and Alkalinity Affect Turfgrass Growth

Acid soils may be detrimental to plant growth directly by presenting hydrogen ion concentrations which are too high. Since the pH of cell sap in roots of plants varies from 4 to 6 it is not believed that this effect is of great importance. It is more likely that aluminium and manganese toxicity or calcium and magnesium deficiency are responsible for most acid effects on plant growth. Aluminum hydroxides may form in the conductive tissues thus clogging them to the detriment of plant function. Calcium is recognised as essential for the production of strong vigorous roots, for cell wall construction, to promote translocation of carbohydrates and mineral elements, to control absorption rates of minerals by roots and to bring about balances in the chemical acidity within cell fluids. Magnesium functions in similar processes and in addition is an essential component of the chlorophyll molecule. The use of lime to correct deficiencies of calcium and magnesium may be important on some soils. It should be remembered that the over use of lime may aggravate deficiencies of other elements such as boron.

In addition, soil acidity affects availability of essential nutrients and is related to the development of physical soil conditions which may be detrimental to plant growth.

Soil Variability. It is often noted that soil acidity varies considerably from location to location on turfgrass areas of various sizes. This results in a spotty or patched growth response which is characteristic of pH related causes of poor turf production. In this regard it has been found that from 550 to 1,000 lb. of limestone per acre may be removed annually in drainage water. Pockets which are excessively well drained may be large in area or restricted in size and become more acid than surrounding locations.

Seasonal Effects. Variations in pH are likely to occur with time of year.

In general soils are more acid in mid-summer than in early spring or late fall. As much as 0.5 pH unit difference may be observed in mid-summer when organic matter decomposition rates are high and soil moisture levels may be lower. Also fertilizer action at that time of year often assists in lowering pH levels.

Excess Moisture. The notation that wet areas and the presence of moss always indicate acid soil conditions is false although moss and wet spots are often associated with acid soils.

Acidity and Alkalinity Effects on Soil Structure

Soil is composed of a mineral fraction of sand, silt, and clay. Under acid soil conditions the silt and clay particles tend to exist as individual units. Under more alkaline soil conditions where calcium and magnesium are more plentiful the clay and silt particles group together to form granules. These granules provide improved soil structure which results in more favourable balances of air and water in the soil. It has been observed that where soils are acid and have poor structure, water peneration is very slow. Under these conditions the growth of fine turf becomes increasingly difficult.

The precise value of favourable conditions for improved soil structure under a turf which is subjected to active play is uncertain. Use of a turfgrass stand makes it virtually impossible to maintain good soil structures, for resulting compaction is a constant threat to granulation and aggregation processes. It is recognised; however, that aerification, wetting and drying, freezing and thawing of soil are less likely to have beneficial effects on soil structure under acid conditions than where lime has been used properly.

The Effect of Fertilizers on Soil pH

Such nitrogen sources as ammonium sulfate, ammonium nitrate, diammonium phosphate and Ammo-Phos are commonly used as fertilizers for turf. These materials have an effect on soil pH. In the soil the ammonia of these compounds oxidizes to nitric acid. Also, where the ammonium compound is accompanied by a sulfate there is a certain amount of sulfuric acid formed. Sulfuric and nitric acids are strong mineral acids which have a cumulative effect in exhausting the lime content of a soil. These acids react with the lime to form gypsum (calcium nitrate). Both of these materials may be leached from the soil and lost to plants.

About 100 lb. of ammonium sulfate will develop sufficient acid to neutralize 150 lb. of calcium carbonate (ground limestone). About 100 lb. of ammonium nitrate would require 125 lb. of ground limestone and about 100 lb. of diammonium phosphate would require 185 lb. of ground limestone to neutralize the acid effect.

Urea also has a slight acid reaction in soils.

Cyanamid, sodium nitrate and calcium nitrate are alkaline reacting and will tend to increase soil pH levels over a period of time.

Organic fertilizers have little effect on the pH of most soils. Superphosphate may eventually make soils slightly less acid. Muriate and sulfate of potash tend to make soils slightly more acid at first and then later reverse this trend and make them less acid. The overall effect of superphosphate and potash on soil pH is limited.

The Effect of Soil pH on Nutrient Availability

Nitrogen

Nitrate nitrogen does not change much in availability over the normal pH range for plant growth. Organic forms of nitrogen, however, must be converted to simpler inorganic forms before they can be absorbed by plants. This process is carried out by micro-organisms in the soil and consequently is affected by the pH of the soil environment. It would be expected that nitrate formation from such fertilizers as processed tankage, activated sewerage sludge and ureaform or from soil organic residues would be reduced at pH levels below 5.5. From 5.5 to about 8.0 microbiological activity is favourable for breakdown of organic matter and nitrogen availability is about the same throughout this pH range. Above pH 8.0 an over-supply of lime, may reduce

Table 2.
Suggested Lime Application to Adjust Soils to Various pH Levels[1] Based on Use of Limestone, Broadcast and Worked into Soil to Plow Depth. Tons per acre.

pH of soil as tested*	Soil Group 1 Sandy Soils Low OM**	Soil Group 2 Sandy Soils Med. OM** Loamy Soils Low OM**	Soil Group 3 Sandy Soils High OM** Loamy Soils Med. OM** Clay Soils Low OM**	Soil Group 4 Loamy Soils High OM** Clay Soils Med. OM**
Desired pH 6.6				
6.0	0.4	0.7	1.0	1.3
5.8	0.6	1.1	1.4	1.9
5.6	0.8	1.3	1.8	2.5
5.4	1.0	1.6	2.2	3.1
5.2	1.2	1.9	2.6	3.7
5.0	1.4	2.1	2.9	4.2
4.6	1.6	2.3	3.2	4.6
4.8	1.8	2.5	3.5	5.0
Desired pH 6.0				
5.6	0.3	0.6	0.9	1.2
5.4	0.5	0.9	1.3	1.8
5.2	0.7	1.2	1.7	2.4
5.0	0.9	1.5	2.1	3.0
4.6	1.1	1.8	2.5	3.6
4.8	1.3	2.1	2.8	4.1
4.4	1.5	2.2	3.1	4.5
4.2	1.7	2.4	3.4	4.9
Desired pH 5.4				
5.0	0.2	0.5	0.8	1.1
4.8	0.4	0.8	1.2	1.7
4.6	0.6	1.1	1.6	2.3
4.4	0.8	1.4	2.0	2.9
4 2	1.0	1.7	2.4	3.5
4.0	1.2	1.9	2.7	4.0
3.8	1.4	2.1	3.0	4.4

*Based on pH in early spring or late fall. For summer tests, add
0.5 pH for Soil Group 1 — to pH as tested before using table.
0.4 pH for Soil Group 2
0.3 pH for Soil Group 3
0.2 pH for Soil Group 4
**OM — Organic matter content.
[1]The Fertiliser Review, May-June 1937.

the rate of organic matter decomposition and cause nitrogen to become less available for plant growth. Under conditions in the cool humid regions of the country excessive amounts of lime are seldom found.

As far as most plants are concerned, nitrates are more readily absorbed under extremely acid conditions than is ammonia nitrogen. Under acid conditions the abundance of plus charged hydrogen ions causes the root membranes to be predominantly electropositive and thus the electronegative nitrate is attracted to the root surface and absorbed. Under these conditions plants often fail to respond to applications of ammonium nitrogen. Under extremely alkaline conditions ammonia nitrogen is absorbed more readily than nitrate. In this case an abundance of negative charged hydroxyl ions causes the root membranes to be predominantly electronegative and thus the electropositive ammonium ions are attracted to the root surface and absorbed.

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To be continued