# The damaging effects of high soil pH: urban legend or reality?

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**Bottom line: Alkaline soils (pH above 7.0) are typically regarded as "problem soils" that require amendment with materials such as sulfur or ammonium sulfate in order to support good plant health. But this belief may be much more of an urban legend, correct perhaps in some aspects, but generally unsupported by the facts. A study of over 750 soils from high performance greens, tees and fairways reveals that high quality turf is routinely produced on alkaline soils that range from a pH of 7.0 - 8.25, without the use of acidifying amendments. High performance turf can be achieved by the much simpler, less phytotoxic and more effective approach of targeting the appropriate concentrations of key nutrients such as nitrogen, potassium, phosphorous, calcium, magnesium, iron and manganese.**

## True or False?

1. Your soil tests consistently show that greens have pH's that run between 7.8 and 8.0. In other words, you have alkaline, or basic soils and you're in big trouble! It is necessary to take immediate action to lower soil pHs to below 7.0, or else turf health will suffer. Lowering pH can be accomplished easily and safely through reliance on ammonium sulfate as your main source of nitrogen fertilizer. **True or False?**

2. Good turf health is possible only if the soil pH is between 6.0 and 7.0. Any value that is higher than 7.0 requires an aggressive soil amendment program. **True or False?**

By now you may have guessed that the answer to both questions is "**False**".

Our point, in this issue of *PACE Insights,* is that although an understanding of your soil pH is important in developing management programs, turf can actually survive -- and survive well -- at a much wider range of pH's than most people believe. This argument is based on data from the scientific literature, from PACE's soil chemistry database, and from our involvement with superintendents as they develop improved soil fertility programs.

## The lowdown on pH

Fertilizer and soil amendment sales pitches are heavily based on it. It's placement at the top of most soil reports indicates its importance to soil scientists and agronomists. And almost everybody knows what theirs is -- down to the decimal point.

We're talking about pH, of course -- but despite its ubiquity in the lives of anyone who grows plants for a living, it requires a major stretch of memory back to high school chemistry classes to remember exactly what pH measurements represent.

Starting with a general definition, pH is a measurement of the concentration of positively charged hydrogen ions ($H^+$) in a liquid solution. The more hydrogen ions present, the more acidic the solution. The lower the concentration of hydrogen ions, the more basic the solution. For reasons that will be explained below, the pH scale is unfortunately an inverse one where high values represent low concentrations of hydrogen ions, and low pH values represent high concentrations of hydrogen ions. The pHs of some familiar liquids are listed in Table 1.

**Table 1.** The pH of some common liquids. Note that the pH scale is inverse: bleach, with the lowest concentration of $H^+$ (hydrogen ions) ($10^{-12}$ molar [M]) has the highest pH value, while highly acidic gastric juice, with the highest concentration of $H^+$ ($10^{-1.2}$ M) has the lowest pH value. For an explanation of the use of molarity, see page 4.

↑ More basic (fewer hydrogen ions)

| Liquid | pH | $H^+$ conc |
|---|---|---|
| Bleach | 12 | $10^{-12}$ |
| Antacids | 9 | $10^{-9}$ |
| Baking soda | 8 | $10^{-8}$ |
| Blood plasma | 7.4 | $10^{-7.4}$ |
| **Pure water: pH = 7** | | $10^{-7}$ |
| Milk | 6.6 | $10^{-6.6}$ |
| Saliva | 6.4 | $10^{-6.4}$ |
| Rain | 5.5-6.0 | $10^{-5.5}$ - $10^{-6}$ |
| Coffee | 4.0 | $10^{-4}$ |
| Vinegar | 3.0 | $10^{-3}$ |
| Cola | 2.8 | $10^{-2.8}$ |
| Gastric juice | 1.2 | $10^{-1.2}$ |

↓ More acidic (more hydrogen ions)

Let's start by looking at water -- the substance that makes up 70 - 90% of the weight of most forms of life, and represents about 25% of the volume of a soil that is at field capacity. At any given time, the majority of water is present as a molecule: $H_20$. However, a very small percentage of pure water is present in a dissociated form, where it is broken down into two ions: the negatively charged hydroxide ion ($OH^-$) and a positively charged hydrogen ion ($H^+$):

$$H_20 \leftleftharpoons H^+ + OH^-$$

In pure distilled water, there are equal, but extremely small concentrations of hydrogen ions and hydroxide ions -- a concentration of $10^{-7}$ (0.0000007) M of each, to be exact. This amounts roughly to one hydrogen and one hydroxide ion for every 555 million molecules of pure water.

To avoid having to work with these difficult numbers, the pH scale is frequently used. This allows us to speak about pure water as having a pH of 7, rather than as having a concentration of $10^{-7}$ M (molar) hydrogen ions, or a pH of 5, rathern than $10^{-5}$ M hydrogen ions. The pH scale is based on the **negative $\log_{10}$ of the $H^+$ concentration.** Because the pH scale is a log scale, a change of just one pH unit -- for example, from pH 5 to pH 6 -- means that the pH 5 solution has 10 times the hydrogen ion concentration of the pH 6 solution. A change in two units will result in 100 times the hydrogen ion concentration, and so on. For a more in-depth discussion on the derivation of pH values, see the box at the end of this article labeled "More on Moles".

## Soil pH: the good, the bad and the ugly

At soil pHs of 7.0 and higher (alkaline soils), soil particles are surrounded by cations such as calcium, magnesium, potassium and sodium, as illustrated in Figure 1. Under these conditions, there are two chief concerns:

1) Avoiding the build-up of sodium on the soil cation exchange sites. High levels of sodium (greater than 10%) may occur in high pH soils, and can damage plants and negatively affect the soil's physical structure. Amendments such as gypsum, lime or calcium chloride can be used to correct high soil sodium levels, but managing high sodium can be a complex matter. We hope to delve more into this topic in an upcoming *Insights.*

2) Deficiencies in phosphorous and in micronutrients such as iron, manganese, copper, zinc and boron. In high pH soils, these elements form complexes with other materials in the soil, making it more difficult for the plant to take them up. This situation can be addressed in two ways -- by lowering the pH of the soil, thus possibly freeing up the micronutrients. However, it is not always possible to effectively lower soil pH, especially if soils are heavily buffered. And the amendments that are used to lower soil pH have their own set of disadvantages -- potential ammonia toxicity if ammonium sulfate is used, and potential phytotoxicity if sulfur if used, for example. An alternative strategy that has produced good results is to add micronutrients to the turf, if testing indicates that a deficiency exists. Micronutrients such as iron are available in chelated form, a conformation that helps protect the nutrient from forming an insoluble, unavailable complex in high pH soil. To further avoid complexing, chelated micronutrients can be applied to the foliage, rather than to the soil. Once the micronutrients are absorbed by the plant foliage, they are transported to the areas where they are needed.

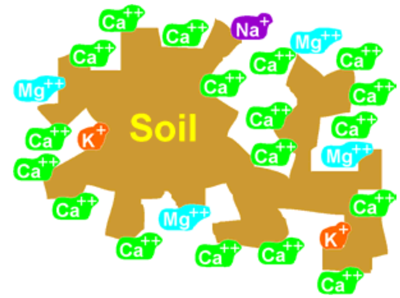



**Figure 1. Typical cation arrangement around a soil particle from an alkaline (pH 7) soil.** Cation concentrations are roughly: 76% calcium, 17% magnesium, 4% potassium, 2% sodium and no hydrogen. Although alkaline soils have their share of problems, the data presented in Figures 4-6 illustrates that high performance greens, tees and fairways are frequently grown on alkaline soils that range from pH 7 - 8.25.

Acid soils (lower than pH 7) usually occur in areas with higher rainfall, where nutrients such as calcium, magnesium and potassium are leached out of the soil and are replaced by hydrogen ions (see Figure 2).

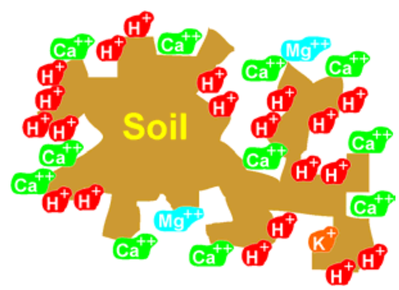



**Figure 2. Typical cation arrangement around a soil particle from an acid (pH 5) soil.** Note that over 40% of the exchange sites are occupied by hydrogen ions ($H^+$), thus displacing important nutrients such as calcium and magnesium. Rough cation percentages are: 47% calcium, 43% hydrogen, 9% magnesium, 2% potassium and no sodium.

Without amendment, soils that are acidic can present serious problems for turf in the form of aluminum toxicity, and insufficient quantities of calcium, magnesium and potassium. Luckily, application of lime, if used at the correct rates and frequencies, is an excellent tool for overcoming low pH-related problems.

## Understanding the data in Figures 4-6

Alkaline soils are common on golf course greens, tees and fairways. They are frequently encountered in the arid and semi-arid regions of the Western U.S. where frequent irrigation with mineral bearing water is responsible for the build-up of basic cations (such as calcium, magnesium, potassium and sodium) in the soil. Soils that are high in calcium carbonate -- calcareous soils -- are another type of alkaline soil that can be found throughout the U.S.

The data shown in Figures 4-6 illustrates our main message: that good performing greens, tees and fairways are are very possible on alkaline soils that range from pH 7 - 8.25 (at soil pHs of greater than 8.5, performance usually begins to suffer, however). To illustrate this, the data from the PACE soil chemistry database (which includes over 6,000 soil samples taken over the past 10 years) is represented in a special type of graph known as a **frequency distribution.**

**Figure 3. Percent hydrogen ions on soil cation exchange sites at different pHs**. The concepts illustrated in Figures 1 and 2 are illustrated here again, but in a different form. Note that as soil pH increases from pH 5 to pH 7, there are fewer and fewer hydrogen ions (H+) on the outside of soil particles. At pH 7 and higher, there are no hydrogen ions. They have all been replaced by other cations, such as calcium, magnesium, potassium and sodium.

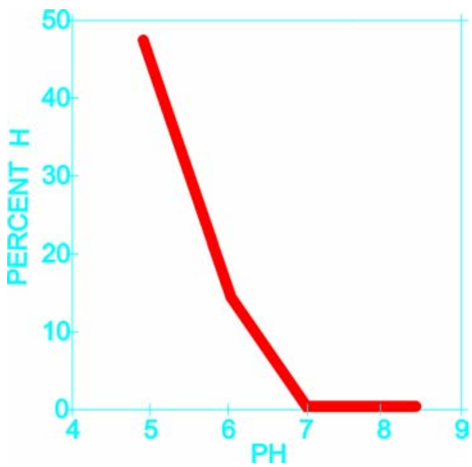
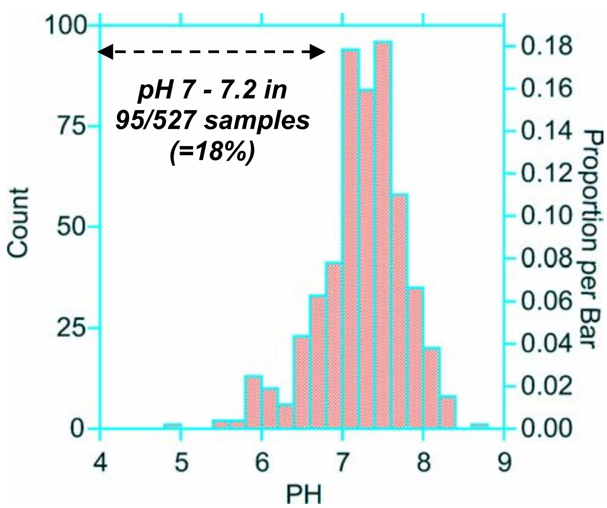



**Figure 4. Soil pH values for good performing greens**. Data is based on 527 soil samples taken from greens across the U.S. that superintendents rated as "good performers".




In the frequency distribution shown Figure 4, note that the horizonal, or "X" axis, tracks a range of soil pHs from 4 to 9. However, almost none of the soils we tested occurred at these two extremes, as indicated by the lack of red, vertical bars associated with these pHs. This is what we would expect from good performing greens, since a pH of either 4 (highly acid) or 9 (highly basic) would be damaging to most turf plants. The soil pHs that we found most frequently are represented by the tallest of the vertical bars. Therefore, the most common pHs for the good performing greens in Figure 4 are represented by the 3 tallest bars -- 95 samples at pH 7-7.2, 80 samples at pH 7.2-7.4, and 98 samples at pH 7.4 - 7.6. Figures 5 and 6 can be interpreted using the same logic.

**Figure 5. Soil pH values for good performing tees**. Data is based on 49 soil samples taken from tees across the U.S. that superintendents rated as "good performers". For these tees, the number of samples at pHs below 7 was roughly equivalent to those above 7. The broader range of pHs exhibited by tee samples is due to the use of a spectrum of materials -- from native soil to sand -- in tee construction.

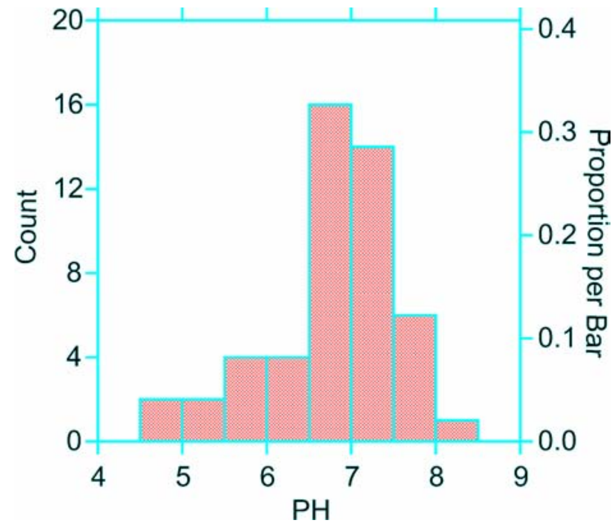
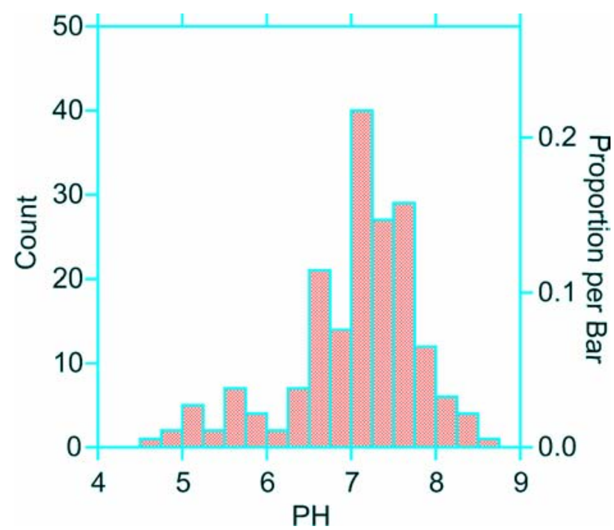
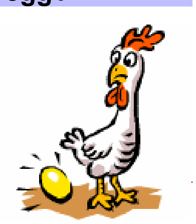



**Figure 6. Soil pH values for good performing fairways**. Based on 184 soil samples taken from fairways across the U.S. that superintendents rated as "good performers". Note that the majority of samples tested were alkaline, ranging in pH from 7 - 8.5.




**Soil pH: The chicken or the egg?**

There are two approaches towards the use of soil pH values in making turf management decisions. In the first approach, soil pH dictates the nutritional quality of the soil, and of



the plants growing in it. As a result, it is critical that pH be adjusted to an optimal level -- usually between 6 and 7 -- so that the proper conditions for plant growth and nutrient availability are achieved. To increase a low, acidic pH soil, lime is most frequently applied, while sulfur or ammonium sulfate are typically recommended to decrease high, alkaline pHs.

While the first viewpoint sees pH as the **cause** of a soil's nutritional status, an alternative view sees soil pH as the **result** of many interacting physical and biological factors. In this second approach, pH is just one of about 20 important measurements that are typically made on soils (see PACE Reference 7:7). If the major nutrient levels are adjusted to fall within guidelines such as those in the PACE Reference, soil pH and other nutrients should be sufficient for plant growth.

We tend to think more along the lines of the second approach, and the soil guidelines presented in PACE Reference 7:7 reflect this.

### A word on words: defining "micronutrients"

The "micro" in micronutrients can be misleading, erroneously suggesting that the elements are tiny, or are not important. In reality, micronutrients such as iron, manganese, magnesium, copper, zinc and boron are extremely important to plant health -- but the plant requires only very small amounts, as compared to major nutrients such as nitrogen, phosphorous, and potassium.

The availability of micronutrients, especially in alkaline soils, can be compromised -- but not necessarily. Many factors in the soil -- from pH, to naturally produced chelators that protect micronutrients, to microorganisms that help dissolve insoluble micronutrient and phosphorous complexes - interact to influence the availability of these important nutrients. In other words, it's hard to predict just how available micronutrients will be in a soil, just based on the pH. Because of this lack of predictability, most soil amendment recommendations (including those listed in PACE Reference 7:7) err on the slightly high side to prevent deficits from becoming a problem. Fortunately, toxicities are seldom a problem and micronutrients such as zinc and manganese frequently exceed generally accepted maximum desired levels without causing plant stress. This does not mean that you can pour on the micronutrients without fear. Soil nutrient levels should always be based on guidelines if possible.

### References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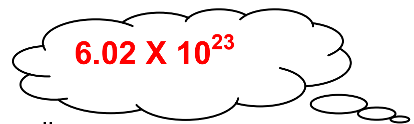
### More on moles




You don't really need to understand what a **mole** is in order to understand the impact of soil pH on turf health, but you'll get a more solid picture in your mind by reviewing this fundamental concept. We have defined pH as the concentration of hydrogen ions ($H^+$) in a liquid solution. These concentrations are expressed in terms of **molarity**, so that 1 mole of hydrogen ions per liter of water is a 1 molar (1M) solution. And 0.001 (which = 1/1000 = $10^{-3}$ = pH 3) of a mole of hydrogen ions per liter of water is a 0.001M solution.

So, what is a mole, and why is it so important? For chemists, it is frequently useful to describe, as precisely as possible, how many atoms of a given element -- be it hydrogen, nitrogen, oxygen or over 100 others -- are present. If you look at the periodic table of the elements in the REFERENCES section of your PACE Info-Pak notebook, you'll note that each element has an **atomic weight** (the number in red print that appears at the upper right hand corner of the rectangle that surrounds each element). With an atomic weight of 55.8, iron (Fe) is of middling weight, while uranium (U), with a weight of 238, is one of the heaviest elements. Hydrogen (H), with an atomic weight of 1, is the lightest of all elements.

A mole of any element is made up of 6.02 X $10^{23}$ atoms (this is known as Avogadro's number -- the nightmare of many a high school chemistry student). As you might expect, a mole of a light element such as hydrogen will weigh less than a mole of a heavier element. In fact, a mole of any element is equal ot its atomic weight when measured in grams. Thus, a mole of hydrogen atoms weighs 1 gram. A mole of lead will weigh 207 grams. But both will have exactly the same number of atoms -- 1 mole, or 6.02 X $10^{23}$.