THE CURIOUS CASE OF SOIL PH:

A DYNAMIC VIEW OF ACIDITY MANAGEMENT IN FARMING

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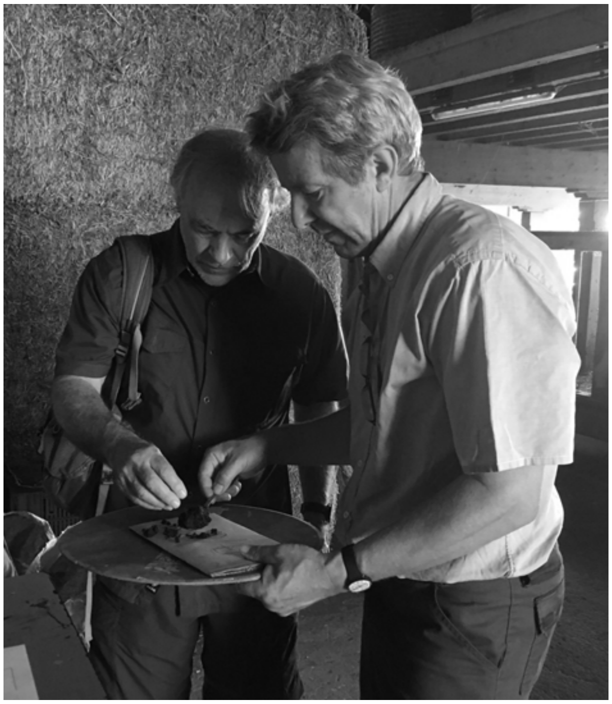
A review of the origin of pH and how it came to be applied to soils raises some challenging questions about popular assumptions.

The importance of testing the acidity of soil, often referred to as soil pH, is virtually taken for granted today in farming and gardening circles. What is it, exactly, and how, if at all, does it apply as a management tool in biological farming and, in particular, biodynamics?

The concept of pH is part of the scientific discipline of chemistry, and it appears to be used in the conventional and organic farming movements to almost an equal extent. This suggests a more or less universally accepted applicability. In addition, the most widely-used remedy for an acid soil is limestone, which is considered a "natural" soil amendment without any restrictions in either organic or biodynamic farming, and therefore managing around it is taken for granted. (This does not forestall concerns about limestone as a source to the atmosphere of fossil carbon as CO_2 is released upon use, similar to burning fossil fuel.)


Will Brinton and Ueli Hurter discuss quality testing of preparations. In early research, Brinton found that BD preparation 500 naturally acidifies itself while buried bringing the high pH and ammonia content of fresh manure under control without any outside actions.
(Photo credit: Woods End Lab)

Popular farming and gardening charts in virtually all the literature show us that plants are sensitive to a wide range of pH values. Nutrient tables widely published show solubility and availability of plant nutrients significantly affected by soil pH reaction. This information is used to inform recommendations for corrective actions such as the addition of limestone, the change of plant selection, the adjustment of soil mineral balances, and more. It is difficult to imagine ignoring these precautions, so pervasive is the literature.

Yet, a review of the origin of pH and how it came to be applied to soils raises some challenging questions about popular assumptions. If we balance this against the organic and biodynamic premise of enabling soil self-regulation and working with native soil biodiversity, the concept of needing to adjust pH according to some abstract principle deepens the mystery.

Curiosity about soil pH increased recently as a result of a farm soil study our laboratory conducted comparing variability of soil chemistry tests on eighteen different dairy farms in three New England states.[1] We chose dairy farms because they mostly re-use all their manures and possess, to a high degree, a nutrient sustainability groundwork, even if not organic. The comparison of differing soil tests concluded that pH appeared to be the least variable soil test between fields and across all farms in three states, compared to nutrients like calcium, magnesium, and especially phosphorus, which were the most variable. Soil health tests were also evaluated which were less variable than the nutrient tests. Curiously, pH stood out as showing very little variability from a point of view of reliability of lab testing. Another recent study looking at variability between labs when conducting soil tests went so far as to propose that pH, being so reliable, should be considered the "the gold standard" of tests.[2]

THE BACKGROUND OF PH

It was the Danish physiologist and mathematician Sorensen who first developed the concept of pH around 1909, based on extensive studies on how body fluid enzymes are affected by soluble hydrogen ions, the cause of acidity.[3] Living organisms possess an extraordinary pH control system, such as in the blood, and this metabolic process bathes all the supported interconnected organs in a remarkable buffered stream that resists change. However, since the concentration of dissolved hydrogen which could be measured was so extremely low and varied over such a vast range, Sorensen proposed compressing it to report it logarithmically, such as by 10^{-6}, 10^{-7}, and so forth. This could be compared to the practice in microbiology of reporting bacteria and fungi in log terms like 2.5×10^6 instead of the same quantity expressed in simple numeric terms of "2,500,000 cells."

As a result of this variance, the sheer range and the extremely tiny numbers—like 0.000013 for the hydrogen concentration being measured—Sorensen came up with the concept of "pH," meaning "potenz Hydrogen." He then created a standardized scale for it, where, coincidentally, the mid-point meant a solution neither acid nor alkaline. To create this pH scale, he dropped the base (10) notations altogether and instead just used the mantissa portion of the logarithm [i.e., the numbers *following* the decimal point.— ed.]. Then, to further simplify this, and perhaps to appease lay audiences, he also removed the negative exponent sign which any scientist would not ignore.

In other words, from Sorensen's work, an acidity of 10^{-7} became simply "pH 7.0." At one point, Sorensen expressed concern that people should not misunderstand that the acidity scale "goes in reverse," meaning that higher numbers indicate lower acidity. Today, this does not seem to concern us as we have been taught that low pH means more acidity. In effect, Sorensen's acidity scale has become the opposite: an alkalinity scale.

More revealing is the implication of the logarithmic compression. What does this mean? In effect, a pH of 7 is 10-times less acid than pH 6. This is understood as the difference between 10^{-7} vs 10^{-6}. Moreover, a pH of 6.0 is twice as acid as 6.25, indicating the hugeness of this compression. This means that small differences in reported pH represent potentially huge differences in actual real acidity.

To compare a nutrient or a soil health value in actual concentration (e.g. ppm or %) to a pH value as a log-compressed number is extremely problematic. In fact, in view of this huge compression involved in pH, it is difficult to interpret popular literature today, which tells us that nutrients and plants are "pH sensitive."[4]

The use of pH measurement applied to soils, first proven for physiologic fluids with blood and enzymes as the quintessential case, does not appear until sometime in the late 1930s, just prior to the outbreak of WWII, and after Sorensen's time. In fact, Sorenson did not anticipate that pH would be applied to soil. When asked what other systems on earth for which the concept and measurement of pH was applicable, he commented that it would be the oceans. This extraordinary and insightful remark has been proven over and over again, as the metabolic regulation that ocean buffering bathes all oceanic organisms becomes threatened as excessive atmospheric CO_2 dissolves in the seas a natural acid.

This adaption of pH to soil posed a significant

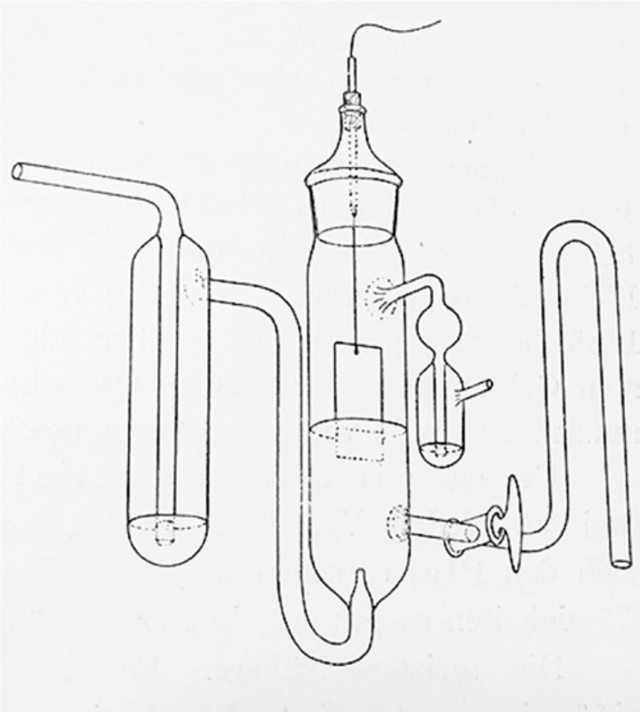
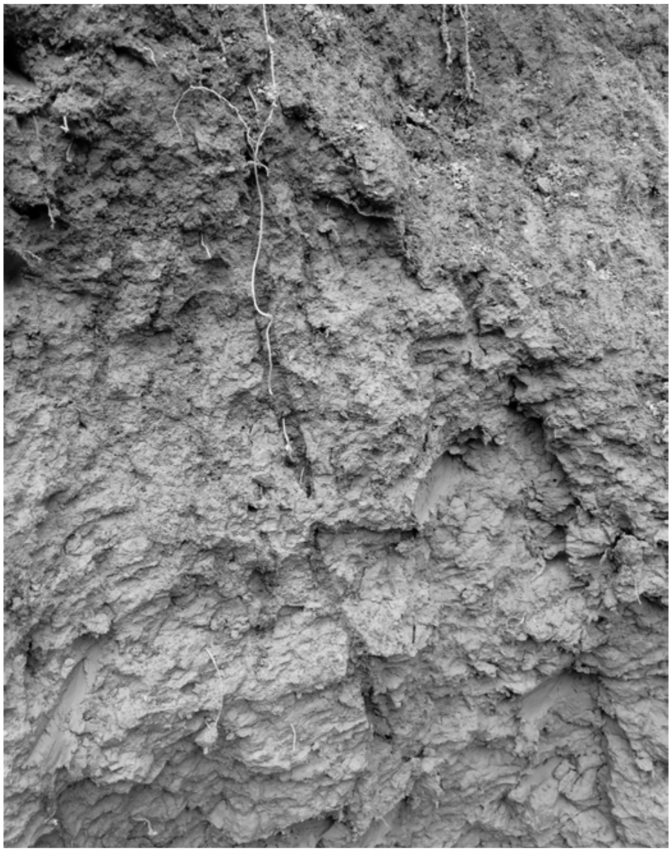


Figure 1. *Sorensen's Platinum-Hydrogen Electrode, from 1912, enabled the first measurements of extremely small quantities of free hydrogen present as acidity in living systems. (Source:* Ergebnisse der Physiologie. *Verlag Von J.F. Bergmann, 1912.)*

challenge since soils are not liquid and testing them violated Sorensen's basic rule that acidity must be soluble to be accurately reported.[5] This became a challenge to be first tackled in the post WWII years, with the huge expansion of mining of soil minerals, especially limestone, for concrete and other purposes.

Whereas the actual pH of a physiologic fluid such as blood can be well known, since it is always in solution, the real pH of soil cannot be known, and may in fact be significantly lower than is apparent from an ordinary soil test, using only water and extracting only a portion of the real amount.

The basic soil explanation goes something like this: Hydrogen ion (the source of acidity) carries a positive charge (this is why it can be measured electrometrically). Soil particles, especially clays, carry negative charges and so hydrogen adheres to soil particles to a degree. Water, the most common solute for soil pH testing has a poor ability to release the acidity present. This dilemma became the soil pH measurement challenge (which would undoubtedly have disturbed Sorensen enormously).



Plants and animals in active soil systems interact at all soil depths to influence soil chemistry. The exudate from roots and especially earth-worm castings reaching down into soil cause natural pH buffering without any outside intervention.
Photo: Woods End Lab

Soil scientists in Europe have long been aware of this problem and therefore prefer extraction methods such as very dilute calcium chloride ($CaCl_2$) or potassium chloride (KCl) solutions to test soil pH. Why? The reason for this is that these natural compounds displace the hydrogen ions from their attachment to soil particles fairly completely, so that they are actually being measured in the soil solution, Sorensen's requirement.[6]

Whereas the actual pH of a physiologic fluid such as blood can be well known, since it is always in solution, the real pH of soil cannot be known, and may in fact be significantly lower than is apparent from an ordinary soil test, using only water and extracting only a portion of the real amount. In fact, the actual pH of soil is now known to be ½ - to 1 log digit lower than measured in water; i.e. the acidity that plants are actually experiencing is 7 – 10 times stronger than supposed, making the common pH-sensitivity tables even more problematic.

Early warnings about this dilemma in attempting to measure soil pH indicated that pH measurements must be carried out using an electrolyte solution of known composition, otherwise soil tests cannot be compared.[7] In most respects, this debacle was never resolved pro or con, and instead, the debate just got dropped over time. This follows a basic principle in science and chemistry, namely, errors that persist for long enough become accepted, requiring a huge effort later to overthrow.

What this meant in the soil pH world is that in order to obtain comparable results from different soils, the exact method needed to be published. For a variety of industry and science reasons, as above suggested, this also never happened, and discussion and debate around this theme simply was dropped.

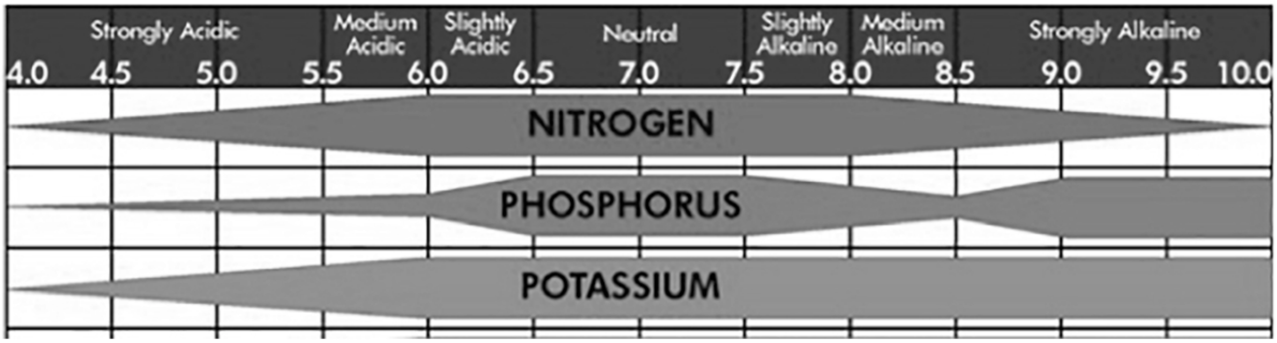


Figure 2. *Popular representation of dependency of soil nutrients on pH. The information is not practical.*

If there was any resistance to changing this requirement, namely that methods be published and measurement be based on real, complete release of active hydrogen in soil, it may have been due to the fact that modern charts and tables for "pH preferences" became, over time, based on the simpler but much less accurate soil-water method of testing acidity. This is hardly an organic or biodynamic approach, and even by itself is somewhat unsatisfactory.

If we take these facts alone, it should make it obvious that from a biology perspective, plants (and nutrients) are actually pH-insensitive. In fact, unlike our knowledge of acidity in bodily fluids, we really don't know what the real plant and nutrient thresholds are. They exist across a wide range of conditions. There is, in fact, no proper soil-water solution and therefore no ideal soil pH to be obtained, and, in nature, there is no ecological balancing system in soils comparable to ocean-buffering or physiologic fluid homeostasis.

Ultimately, the healthiest farms were the ones that had not overly altered native soil-mineral composition and especially not applied lime to significantly alter pH balances outside of what was geologically indicated by the local soil origin.

The fact that plants are fairly insensitive to a wide range of soil acidity should not be a surprise, and is ecologically of huge significance. We have only to consider the wide range of environments within which plants have evolved and adapted-to over millennia. Furthermore, as more becomes known, it turns out that plant species diversity, such as at the pasture level, is nearly inversely proportional to pH as acidity. Moreover, it is not really pH connected at all, as the plant diversity relates to and reflects the geologic substratum that went into making the soils on which native plant associations developed. It is that soil which became the native species diversity at a given location, and to which resident animal populations also adapted to over time.

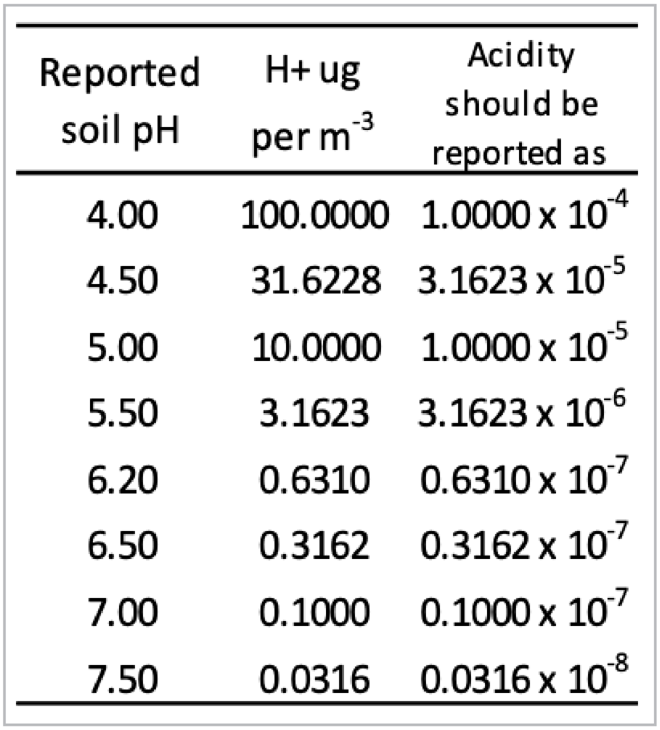
This linkage of native soil mineral-balance and natural pH to diversity and animal health *in situ*, was substantiated in the famously comprehensive studies conducted out of Linz, Austria, in the late 1960s. These examined soil-mineral-plant-animal conditions in four agricultural regions of the country and measured dairy herd health against biotic and mineral diversity. Ultimately, the healthiest farms were the ones that had not overly altered native soil-mineral composition and especially not applied lime to significantly alter pH balances outside of what was geologically indicated by the local soil origin.[8]

An increasing amount of ecological studies, to the extent they can penetrate the chemistry-dominated world of agronomy, are anticipated to show that plant biodiversity leading to forage quality and good nutrition will generally depend on not significantly manipulating soil pH (and other nutrient factors). In any event, the continued emphasis in popular guides on the pH sensitivity of plants and nutrient availability based on pH, is arbitrary if not misleading, particularly so for organic and especially biodynamic farming.

MEASURING ACIDITY

Acidity can be evaluated by two means: as "pH," the logarithmic compressed value, and as actual concentration, by decompressing the logarithm. For vague reasons, no one anymore reports the actual concentration of acidity, but only the logarithm, programmed into pH electrodes or designed into litmus paper by using strong buffer chemicals to resist pH change over the huge range that is present, enabling a semblance of accuracy in the result.

In our recent study on New England farms, whereas reporting acidity as pH made replicated test results across all farms appear remarkably robust, and not variable, when reporting it as actual acidity, the variability turned out to be 25 times greater, and significantly more variable than all other ordinary soil tests, including biology tests. What this means is that acidity is a tremendously variable trait of soils and extremely unreliable to measure. Why use it at all as a management tool? It would be like car speedometers not being able to accurately distinguish 10 from 100 miles per hour, compressing it logarithmically to speed limits signs of "1," "2," etc.



Reported soil pH	H+ ug per m^{-3}	Acidity should be reported as
4.00	100.0000	1.0000×10^{-4}
4.50	31.6228	3.1623×10^{-5}
5.00	10.0000	1.0000×10^{-5}
5.50	3.1623	3.1623×10^{-6}
6.20	0.6310	0.6310×10^{-7}
6.50	0.3162	0.3162×10^{-7}
7.00	0.1000	0.1000×10^{-7}
7.50	0.0316	0.0316×10^{-8}

Figure 3. *What is actual acidity in soil vs the representation of pH?* [9]

To put this in more practical terms, we asked statistically how many soil samples would be required to obtain a given accuracy, such as 20% of the mean. That's not terribly accurate, but, as it turns out, probably the best any lab can do. One soil sample was defined as 12-cores composited. The results showed that if reporting pH, it appeared that only one sample would suffice to reach and surpass ± 20% precision. In terms of the real acidity concentration of hydrogen ion, 100-samples per field would be required to measure this accurately—an impossible amount. (100 soil samples composited from 12-cores each means 1,200 individual cores per field would be needed to measure acidity with any accuracy.) This underscores the fact that making management decisions based on the compressed acidity scale of pH, often rounded to only one significant digit, is grossly haphazard,and has no place in biological farming.

GOING FORWARD

There are several conclusions that can be drawn. First, to be accurate, soil acidity as pH should be measured to 2 decimal precision, which most labs are not capable of. This may sound like an odd comment given our emerging view that pH management is not central to a soil program. But it is an important question whether the accuracy—or lack of—is meaningful. Popular charts on pH preferences for plants and minerals provide virtually meaningless information and should rarely be used.

An early "lesson" received was when the author interviewed Scott Nearing, around 1973, in reference to growing blueberries organically. When asked if he controlled soil pH, since all the popular literature tells us that blueberries "require low soil pH," Mr. Nearing responded that this was "totally unnecessary." Why would that be? Curiously, we don't have a good chemistry theory yet as to why organic and biodynamic farms evolve to become virtually pH insensitive, but this exercise may suggest the answer. Living systems exercise pH management internally and "share" it with surrounding environments. Obviously, soil pH manipulation by technological means is not practical compared to nature's skills at overcoming pH restrictions. In organic management, it is hardly necessary, with the rarer cases of counteracting elements that in some weathered soils—prevalent in New England—become phytotoxic, such as aluminum ion. Aluminum can interact harshly with phosphorus, for example. The point is not to control the pH, but to reduce the aluminum activity which is the cause of deficiencies in phosphorus and, to some extent, calcium.

The good news for the biodynamic garden, and especially at the farm scale, is that soil pH adjustment may be less important than previously believed, but also more intrinsic to biology than recognized. In many ways, the very early work and insights of Sorensen and his failure to see pH as relevant to soils, has cast a long, questioning shadow over a century from which we are now recovering.

TABLE 1. TRADITIONAL AND PROPOSED MANAGEMENT PRACTICES

• TRADITIONAL APPROACH TO SOIL PH •		
OBJECTIVE	**STEPS TO MANAGE**	**ACTIONS**
Identify plant choice and decide on ideal pH	Have soil pH tested, then determine lime requirement by “buffer pH test”	Apply $CaCO_3$ limestone to soil, in tons per acre to reach desired result in topsoil
• EMERGENT APPROACH •		
Identify plant diversity and establish desired yield and quality of forages	Are plants limited by a pH-mediated factor? Example Ca deficiency or excess aluminum	Treat soil sparingly not to target pH but to alleviate symptoms of plant stress without significantly reducing plant diversity

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9 This chart depicts the popular test pH value as commonly reported by soil labs (Column 1). This is compared to the actual hydrogen ion concentration, such as ions per cubic meter of soil (Column 2). In the third column (Col. 3) the real numerical concentration with mantissa and exponent is listed. The Danish scientist Sorensen wished to avoid the form of reporting as shown in Column 3, and so society ultimately ended up with the simplified measure of soil quality.