THE CAUSE AND SOME EFFECTS OF SOIL ACIDITY

H. J. SNIDER
University of Illinois, Urbana.

Since ancient times, soil acidity has been considered a factor in the production of crops, and it is generally recognized that this acid condition has an unfavorable influence upon soil fertility. It has long been known that lime has a beneficial influence upon cultivated lands, because of its ability to correct acidity and otherwise improve the condition of the soil. Hence, we have the saying by Hillgard (4), "A limestone country is a rich country."

Soil acidity in certain respects is not unlike many other forms of acidity. The definitions by Clark (2) apply equally well in the case of soil acids: "Acid still means sour, like vinegar. This common meaning preserves the ancient flavor of the word. An acid is any substance which is capable of supplying to its solution or to other substances, hydrogen ions bearing a positive electric charge. A base in any substance which is capable of supplying to its solution or to other substances the electronegative OH group."

The cause and nature of soil acidity have not been fully understood until recently and there has been considerable confusion as to its origin. At an earlier time, it was supposed that this acidity was due to acids originating from the organic matter that might be in the soil. This supposition was not well founded, as was pointed out by Hopkins (5) and others, because the acidity of upland well areated soils usually increased very markedly as the organic matter decreased, consequently, while some of the acidity might be due to organic acids, there are acid silicates which probably account for most of the acidity.

As soil science developed, there were evolved two outstanding theories regarding the cause and origin of soil acidity. One of these is known as the adsorption theory and the other the mineral acid theory. The justification for these two theories is discussed fully by Truog (11). Soil material presents an enormous surface and, hence, should exhibit an appreciable adsorptive phenomenon. The definition given by Holmes (7) is "that adsorption is a surface holding and depends largely, not wholly, on extent of surface."

The adsorption theory of soil acidity is based on the principle that the colloids of the soil have the power of selective adsorption for certain ions. Thus, the taking up of anion in preference to a cation or vice versa of a neutral salt was held to be the cause of the acid reaction of soils.

Truog (11) showed by experiments that when side reactions were eliminated, acid soils took up nearly chemical equivalent amounts of bases, thus indicating that soil acidity involved a chemical reaction which followed the laws of pure chemistry. However, adsorption is regarded as a physical phenomenon and maximum adsorption has no relation to chemical equivalents between adsorbent and adsorbed substance. The fact that the soil acidity reaction followed the stoichiometry laws of pure chemistry indicated that it was due to true acids in the soil and not selective adsorption of the colloids.

A more exact knowledge of soil acidity was arrived at when there was obtained a better understanding of the base exchange capacity of soils. This capacity of soils was demonstrated by Way (14) first in 1850, and the significance of this work seems to have been generally forgotten or overlooked until more recent years, when it was revived by Van Bemmelen (13), Gedroiz (3), Hissink (5), Kelley and Brown (8), Truog (12), and many others who worked on this phase of soil investigation.

The work of Kerr (9, 10) in which was used base exchange methods and an application of equilibrium equations to the results showing definitely that soil acidity involved a base exchange reaction which followed stoichiometric laws (the weight relationship that obtains when chemical changes take place) of pure chemistry. Kerr (10) also showed that alumino-silicic acids are the active inorganic compounds which function in the acidity of mineral soils. These alumino-silicic acids are in the solid phase of the clay or colloidal fraction of soils. Regarding colloids, Bancroft (1) states, "We now call a phase colloidal when it is sufficiently divided." Colloidal refers to the very finely divided portion of soils which contains the soil acidity or base exchange complex. Kerr (10) shows considerable evidence that indicates the formula H_2O $(Al_2O_3-6SiO_2)$ $:8H_2O$ as the active inorganic compound which functions in acid mineral soils.

There are then two general phases of soil acidity. The solid phase composed of the alumino-silicic acids and humic acids and the liquid phase or acids in the soil solution usually composed of sulphuric hydrochloric, nitric, carbonic and small amounts of many other acids. The acidity in the soil solution is infinitely small compared to that of the solid phase. There exists, however, an equilibrium between the acidity of the solid phase and that of the liquid phase of soils. A pH determination, which is the hydrogen ion concentration of the soil solution, represents in a degree the basis for determining the total acidity of the soil because of the equilibrium between the two phases.

The effects of soil acidity, which influences mainly plant growth, may be classified by the direct and indirect injury exerted on plants. Among some of the direct influences is that of too high a ratio of acids to bases in the soil solution which enter the plant and prove harmful to its growth. In an acid soil, the low supply of calcium is likely to be directly harmful to the plant. There is a possibility of a direct effect of acidity on plant roots providing the acidity goes as low as pH 4, which is unlikely.

The indirect influences of soil acidity are numerous. Acidity affects the availability of phosphorous, nitrogen and potassium in the order named. In an acid soil the phosphorous goes over to a more insoluble form and becomes less available to plants.

Toxic agents such as Al, Cu, Zn, Pb, B, and As, are likely to be more active under acid conditions.

Bacteria in the soil are dependent on the soil solution for certain minerals and if acidity removes the essential minerals the bacterial life suffers. This affects nitrogen fixing, symbiotic, nonsymbiotic nitrifiers and bacteria in general which flourish in soils.

Acidity influences the physical condition of soils. For example, calcium coagulates or flocculates colloidal material which improves the general physical makeup. If calcium is removed by acids, the colloidal material becomes deflocculated and the soil is compact and has an undesirable physical condition.

Some plant diseases are favored by an acid soil, however, potato scab flourishes on a soil rich in lime but does not do so well on an acid soil.

The competitive powers of different species of plants differ under acid conditions. An example is red sorrel (rumex acetosella) which flourishes on either an acid or non-acid soil, however, on a soil rich in lime, competing vegetation usually crowds out red sorrel while on an acid soil, this plant often predominates.

Using soils from two Illinois experiment fields and considering the cause and nature of soil acidity and its influence on plant growth, there may be made a direct comparison of soil composition and its productive capacity. The comparison of composition is found in Table I.

TABLE I—COMPOSITION OF SOILS FROM TWO EXPERIMENT FIELDS.

Location of field	pH	Organic matter	Nitrogen	Phosphorous	Total bases milli-equiv.
		Per cent	Per cent	Per cent	
Hartsburg	6.1	5.04	0.252	0.064	3.80
Toledo	5.1	2.76	0.138	0.027	0.61

In Table I the two soils represented are normal, well drained farm lands, typical of certain areas of Illinois. The Hartsburg soil is classified as black clay loam, and the Toledo soil is gray silt loam on tight clay. Both are of the surface layer or A_1 horizon. The Hartsburg soil with the higher pH or more nearly neutral soil, also has a correspondingly higher percentage of organic matter, nitrogen phosphorous and milligram equivalents of total bases, (milligram equivalents indicate chemical equivalents expressed in milligrams per 100 grams of soil). The Toledo soil having a pH of 5.1 is ten times as acid as the Hartsburg soil with a pH of 6.1 and contains considerably less of the essential plant food elements as indicated by the data in Table I.

Taking next the productiveness of these two soils, there are the same wide differences when the crop yields are considered on the respective fields.

TABLE II—CROP YIELDS PER ACRE FROM TWO EXPERIMENT FIELDS.

Location of field.	Wheat	Corn	Oats	Legume hay
	Bushels	Bushels	Bushels	Pounds
Hartsburg	28.1	54.0	45.8	3,740
Toledo	7.8	17.0	13.8	420

In Table II is given a ten-year average crop yield, except hay eight years, for the two experiment fields. This data shows that there is a positive correlation between the composition including acidity and the productivity of these two soils. On the very acid soil of the Toledo field the crop yields are much lower than on the less acid soil of the Hartsburg field. These two fields are located in near enough proximity to each other so that seasonal variations are of no great consequence. The very acid soil is less than one-third as productive as is the less acid soil. As soils become older, there is a loss of mineral elements and organic matter, soil acidity develops with all of its accompanying ills, and the productiveness of the land gradually declines.

REFERENCES

1. Bancroft, W. D. The theory of colloidal chemistry. Jour. Phy. Chem. 18:549–558. 1914.
2. Clark, W. M. Determination of hydrogen ions. 3rd ed., p. 1–3. 1928.
3. Gedroiz, K. K. Papers in Zur. Opt. Agron. English translation by S. A. Waksman. Copies by Schofield, U. S. D. A. 1912–24.
4. Hillgard, E. W. Soils. p. 365. 1905.
5. Hissink, D. J. Methods of estimating adsorbed bases in soils and the importance of these bases in soil economy. Soil Sci., 15: 269–276. 1923.
6. Hopkins, C. G. Soil fertility and permanent agriculture. p. 176–177. 1910.
7. Holmes, H. N. General chemistry. p. 283. 1923.
8. Kelley, W. P., and Brown, S. M. Replaceable bases in soils. 1924. Calif. Exp. Sta. Tech. paper, No. 15.
9. Kerr, H. W. Nature of base exchange and soil acidity. Jour. Amer. Soc. Agron. 20:309–335. 1928.
10. ——— Identification and composition of the soil aluminosilicate active in base exchange and soil acidity. Soil Sci. 26:385–398. 1928.
11. Truog, E. The cause and nature of soil acidity with special regard to colloids and adsorption. Jour. Phy. Chem. 20:457–484. 1916.
12. ——— Origin, nature and isolation of the inorganic base exchange compound of soils. Jour. Amer. Soc. Agron. 21, 1929.
13. Van Bemmelen, J. M. The adsorptionsverbinugen und das adsorptionsvermogen der ackeresde Tandw. vers. Sta. 35:69–139. 1888.
14. Way, J. T. On the power of soils to absorb manure. Jour. Royal Agr. Soc. 13:123–143. 1850.