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ACID SOILS

S. B. Weed[1]

Acid soils predominate wherever precipitation has been adequate to leach soluble salts from the surface horizons and to bring about a degree of base unsaturation of the permanent charge component of the exchange complex. Consequently, acid soils comprise a major part of the arable land in the United States, and especially in the eastern states. In North Carolina, soils of the Coastal Plain are, in general, more acid than those of the mountains or Piedmont, and Piedmont soils are less acid than mountain soils (Table 1).

Table 1. Common pH ranges of North Carolina soils under native vegetation[a]

Location	pH range
Coastal Plain	
Well-drained	4.7-5.1
Poorly drained	4.1-4.8
Piedmont	5.0-5.8
Mountain	4.8-5.4

[a] (Lee, 1955. N. C. Agric. Expt. Sta. Tech. Bull. 115)

Soils become acid because of the replacement of basic metal cations from the exchange complex by hydrogen ions in solution or possibly by aluminum ions released during the chemical weathering of other soil minerals, and their subsequent uptake by plant roots or leaching to lower horizons in the profile. Hydrogen ions active in this process may come from a variety of sources, including organic acids from decomposing organic matter; mineral acids, such as HNO_3 and H_2SO_4, which may originate from microbial transformation of nitrogen and sulfur compounds; carbonic acid, from solution of CO_2 in soil water; plant root surfaces; and from water itself, involving hydrolysis of adsorbed metal cations.

A number of studies have demonstrated that hydrogen adsorbed by certain exchange sites is very transient as an exchangeable ion. Apparently the hydrogen ion attacks the clay structure and brings about the release of certain metal cations, noteably aluminum and magnesium, which are part of the clay lattice itself. These cations then become

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[1] Department of Soil Science, N. C. State of the University of North Carolina at Raleigh, Raleigh, N. C.

exchangeable, so that the over-all process may be thought of as a replacement of exchangeable hydrogen ions by aluminum and magnesium. The relative amounts of aluminum and magnesium released from the lattice depend, of course, on the nature and composition of the clay. Once released to exchange positions, magnesium is more or less rapidly lost by leaching, being less tightly held to the clay than is aluminum. Thus, if both magnesium and aluminum are released by this process, the clay will still ultimately become aluminum saturated.

Soil Exchange Complex

Before pursuing the question of aluminum as an exchange ion it is desirable to review briefly the components of soil exchange capacity generally recognized.

The soil exchange complex consists of two classes of exchange sites, generally termed permanent and pH dependent. The permanent component remains constant with change in pH and is thought to be determinable by neutral salt leaching. This charge arises from within the clay crystal lattice, due to isomorphous substitution of ions lower in charge than that required for internal neutralization of lattice charge; for example, Al^{+3} may have substituted for Si^{+4}, or Mg^{+2} for Al^{+3}, when the clay was formed. The excess structural charge is balanced by cations held on the surface of the clay particle. Three-layer clays in general, e.g., montmorillonite, vermiculite and illite, exhibit this type of charge; there is good evidence that even the two-layer or kaolin clays may possess a small component of permanent charge (7, 10). The magnitude of permanent charge for a number of common clay minerals is included in Table 2.

Table 2. Some characteristics of the soil cation exchange complex

	Inorganic	Organic
Material:	Clay minerals	Humus
Permanent charge:	Vermiculite (100-150 meq/100 g) Montmorillonite (80-120 meq/100 g) Kaolinite (< 10 meq/100 g)	None
pH-dependent charge:	Broken bonds (edge - SiOH) Begins near pH 6. Some anion absorption at low pH	Mainly carboxyl (RCOOH) below pH 7. 100-200 meq/100 g air dry organic matter

The magnitude of the pH-dependent component of exchange capacity varies with soil acidity, as the term implies. One source of this component in pure clay minerals is thought to be weak acid groups or broken bonds (e.g. -SiOH) on clay crystal edges, which begin to ionize at about pH 6 and contribute an increasing amount to the exchange capacity with increasing pH of the system (Table 3). The exchange capacities of montmorillonite and kaolinite remain nearly constant up to about pH 6, and then increase with pH. In many inorganic soil colloidal systems, there appears to be a pH-dependent component of the measured CEC operative below pH 6. This is thought to be due to development of positive charge in some mineral components of the clay fraction with reduction in pH (9, 10). Soil organic matter, which in its hydrogen-saturated state behaves like a weak acid, provides a good example of pH dependent charge. The active sites on soil organic matter contributing to CEC below pH 7 are thought to be mainly carboxyl groups (1). The strength of these groups varies with the organic unit with which they are associated; consequently, the capacity to adsorb and exchange metal cations, which depends on the number of these groups ionized, varies continuously with pH. Amounts of these carboxyl groups vary with the type of organic matter but may contribute about 100 to 200 me/100 g of air-dry organic matter.

Table 3. Cation exchange capacity of several clay minerals and soils as related to pH[a]

	pH_2	pH_7	ΔCEC
Kaolinite	5.7	6.7	1.0
Montmorillonite	85	109	24
Cecil	1.4	3.5	2.1
Davidson	4.0	8.6	4.6
White Store	17.4	21.0 (pH 8)	3.6

[a] (Lin, Clara. Unpub. Ph.D. thesis, North Carolina State College, Raleigh, N. C. 1959)

Under acid conditions, i.e. below pH 6, the pH-dependent charge on the clay minerals is saturated with hydrogen; these ions are not replaceable by leaching the soil with neutral salt solution, e.g. KCl. The ionized and, therefore, charged sites on soil organic matter may be satisfied by both metal ions and by hydrogen ions, whereas the non-ionized sites would, of course, be satisfied by hydrogen. This is effectively demonstrated by the data in Table 4. At about pH 7, the permanent charge exchange capacity is completely saturated with basic metal cations, but with decreasing pH it becomes decreasingly base-saturated. The data in Table 4 indicate that aluminum ions, rather than hydrogen ions, occupy the major part of the permanent charge exchange capacity not countered by the basic metal cations, e.g. calcium, magnesium, potassium. Careful consideration of data from numerous sources describing ion populations on the permanent charge component of exchange capacity of acid soils suggests that this is generally true. Relatively very few exchangeable hydrogen ions seem to remain associated with the permanent charge.

Table 4. Exchange characteristics of the B horizons of some North Carolina soils[a]

Soil	pH	Exchangeable cations (me/100 g) Al	Ca + Mg	CECp[b]	% Saturation	CEC[c] (pH 8.2)	% Saturation
White Store	4.6	17.9	4.5	22.4	20	29.7	15
Durham	5.0	1.85	1.10	2.95	37	7.8	19
Appling	5.2	1.47	1.72	3.19	54	7.4	23
Alamance	5.4	1.41	1.87	3.28	57	7.08	26
Cecil	5.6	0.51	2.22	2.73	81	7.73	29
Mecklenburg	5.8	0.45	9.30	9.75	95	18.05	51
Davidson	5.9	0.26	4.40	4.66	95	12.26	36
Iredell	6.3	0.21	16.00	16.21	99	23.71	67

a/ Data from Coleman, N. T., Weed, S. B., and McCracken, R. J. Soil Sci. Soc. Amer. Proc. 23:146-149 (1959)

b/ CECp = permanent charge exchange capacity
= sum of exchangeable metal cations

c/ CEC (pH 8.2) = CEC determined at pH 8.2
= sum of permanent and pH-variable charges

Aluminum in Acid Clay Systems

As indicated above, initially hydrogen ion saturated clays change more or less rapidly to hydrogen-aluminum or aluminum-ion saturated systems. Realization of this phenomenon has been important in explaining many of the properties of acid soils.

Numerous studies have been devoted to the reversion of hydrogen-clay systems to aluminum-clay systems. Data taken from the work of Mathers[2], shown in Table 5, are generally typical of the results published. Apparently hydrogen adsorbed by permanent charge sites on mineral clays results in an unstable system, and by a mechanism not as yet well-defined, cations from within the clay structure, notably aluminum but conceivably also magnesium, are released and become exchangeable. The hydrogen ion apparently becomes permanently bonded within the crystal structure. Thus, as long as hydrogen ions are supplied from solution and exchange with

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[2] Mathers, A. C. The role of aluminum in ion exchange reactions of acid soils and clays. Unpub. Ph.D. thesis, North Carolina State College, Raleigh, N. C. 1956.

other cations held on permanent charge exchange sites, and as long as aluminum is suitably located within the clay mineral structure, there is an apparent mechanism whereby aluminum ions can become exchangeable. Under very acid conditions, these aluminum ions remain exchangeable; at about pH 5 and above, however, they are partially neutralized (5). Two or more of the resulting aluminohydroxy units may join together or polymerize and the product formed, a large complex cation, is very tightly bound to the clay mineral surface and is not exchangeable by normal neutral salt leaching.

Table 5. The reversion of < 2μ montmorillonite (U.B.) at room temperature as indicated by the percentage of H and Al in a 1N KCl leachate[a/]

Time in days	% H	% Al
2	80	20
5	79	21
7	75	25
9	69	31
12	59	41
16	55	45

a/ (Mathers, A. C. Unpub. Ph.D. thesis, North Carolina State College. Raleigh, N. C. 1956)

Occurrence of these polymers in the inter-layer space of vermiculite soil minerals results in the so-called vermiculite-chlorite intergrade clay minerals common to soils of the southeast (6, 11). These polymers may conceivably provide reactive sites for liming materials.

As the data indicate, acid soils and clays are in reality systems containing mainly aluminum ions and basic metal cations countering permanent charge exchange capacity. The acid reaction, i.e. low pH, is probably attributable to partial hydrolysis of the adsorbed aluminum ions. While the actual process is undoubtedly complex, the equation shown below may serve to illustrate what happens. Water molecules associated with the various ions are not shown.

$$Al^{+3}\ (Clay) + H_2O \rightleftharpoons [Al(OH)]^{+2}\ (Clay) + H(Clay)$$

It should be kept in mind that the hydrogen ions giving rise to an acid pH, say pH 4.0, represent only a very small fraction of the capacity of the average soil to adsorb cations. It would take only three or four pounds of ground limestone to neutralize the active acidity, i.e., the hydrogen ions actually measured using a pH meter in an acre six-inches of soil at pH 4.0. The amount of limestone needed to neutralize the source of those hydrogen ions, referred to as the total acidity, would, of course, be much greater.

An additional point brought out by the data in Table 4 is that the relation between pH and percent base saturation depends on the value assumed to represent the exchange capacity. If the exchange capacity determined at pH 8.2 is used as the base, this will include a part of the pH dependent component which is not operative in acid soils. Though the exchange capacity determined at pH 8.2 has commonly been used for determining percent base saturation, some workers (3) have suggested that the permanent charge represents a more realistic value.

Soil Reaction and Solubility of Plant Nutrients

The solubility or availability of plant nutrient elements in soils is closely allied to soil pH. This is illustrated diagrammatically for a number of elements in Figure 1. The figure suggests that, from the point of view of nutrient availability, slightly acid conditions should be optimum for most plants. One element not included in Figure 1, presumably because it is not normally considered to be a nutrient element, is aluminum. As has already been pointed out, aluminum ion concentration on the exchange complex increases with increasing acidity. The availability of aluminum might be expected to parallel or precede that shown for iron and manganese. Increasing soil pH by the addition of a liming agent thus might be expected to decrease aluminum, iron, copper, manganese, zinc and possibly boron availability. Calcium and magnesium availability would increase by virtue of being added in the liming material. It has also been noted that calcium and magnesium are not readily replaceable from permanent charge sites (4), but hydrolyze readily from pH-dependent sites. Phosphorus availability should increase as iron and aluminum are removed by precipitation as the hydrous oxides.

Acid Soils and Plant Growth

Several explanations for the poor growth of plants on acid soils and for the response to lime have been proposed over the years. Most of these proposals appear reasonable from a consideration of Figure 1. Poor plant growth in acid soils has been attributed to: (a) the presence of toxic substances, including excess iron, manganese, and aluminum; (b) insufficient calcium and magnesium; (c) low availability of phosphorus and potassium; (d) unavailable or excess trace elements; (e) undesirable microbiological environment. Probably all of these are operative to some extent. Liming will alter each of the above factors, so that it has been difficult to determine which factor is most limiting under acid conditions.

While several factors may limit plant performance on acid mineral soils, aluminum ion toxicity is undoubtedly of paramount importance. Schmehl, et al. (8) found that as soluble aluminum in the soil increased, yield of alfalfa decreased (Figure 2). Increasing the calcium content of the soil by adding calcium sulphate did not materially increase yields, suggesting that calcium supply was not limiting growth. This treatment would not, of course, increase soil pH. An acid conditions, per se, is apparently not always limiting to growth. Data in Table 6, taken from Schmehl, et al. (8), indicate that alfalfa grew very well on peat at pH 4.8. There would be little, if any, soluble aluminum in this system.

Table 6. Yield of alfalfa as affected by different treatments[a]

Treatment	Yield (gm/pot)	
	1st cutting	2nd cutting
Soil pH 4.75, control	0.64	1.45
Soil pH 4.75, + gypsum	1.13	2.06
Soil pH 5.5	5.68	7.16
Soil pH 6.5	6.94	8.46
Peat pH 4.8, + sand	7.04	9.34
Peat pH 6.5, + sand	5.57	7.80

a/ (Schmehl, et al., 1950 Soil Sci. 70:393-410)

Schmehl, et al. (8) further demonstrated that when acid soil was limed only in the surface, with alfalfa roots growing in limed and acid soil, the plants obtained as much as 80% of their calcium from the limed soil. The disproportionate uptake from the limed soil was attributable not only to the greater calcium concentration, but also to the deleterious effect of the acid soil on root development. The plants never developed a normal tap root in the acid soil layer. Mathers[3] used a split-root technique to study the effect of aluminum ions on corn plant growth. He found that as little as one ppm aluminum in nutrient solution stunted the corn roots. When half of the roots were kept in a complete nutrient solution the tops appeared to be unaffected by aluminum concentration in the solution containing the remaining roots.

Ragland[4] conducted a series of experiments with plants in two-layer soil systems, i.e., a surface soil with optimum properties for root growth and an initially acid lower layer or subsoil, treated with combinations of lime and fertilizer salts. He found, in general, that barley or sorghum roots did not grow well into acid subsoils. Addition of nitrogen, potassium, and phosphorus without lime did not improve growth nor did stabilization of soil aggregate structure. Lime was found to be the only beneficial ameliorating agent. This effect was interpreted as a reduction in soluble or exchangeable aluminum, though he did not rule out the possibility of other limiting factors. The data in Tables 7 and 8, taken from the work of Ragland[4], demonstrate the effects discussed

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3/ Mathers, A. C. The role of aluminum in ion exchange reactions of acid soils and clays. Unpub. Ph.D. thesis, North Carolina State College, Raleigh, N. C. 1956.

4/ Ragland, J. L. Some reactions of aluminum in acid soils and their implications concerning root growth. Unpub. Ph.D. thesis, North Carolina State College, Raleigh, N. C. 1959.

above. Acid soils inhibit root development and there is an apparent direct correlation between percent aluminum saturation of the exchange complex and inhibition of root growth. Neutralization of the acid conditions by a suitable liming agent is the only effective practical ameliorating practice known.

Table 7. Effect of subsoil lime, fertilizer, high phosphate rate and gypsum on growth of barley roots into layers of Orange subsoil under Norfolk topsoil[a]

Treatment	Root growth (g/pot)		
	Subsoil	Topsoil	Σ
Check	0.30	2.05	2.35
Fertilizer alone	0.80	1.20	2.00
High phosphate	0.50	1.90	2.40
Gypsum	0.30	2.15	2.45
2.5 Tons lime	1.90	0.90	2.80
2.5 T. lime + fertilizer	2.05	1.90	2.70
5.0 Tons lime	1.80	0.85	2.65
5.0 T. lime + fertilizer	2.15	0.60	2.75

[a] (Ragland, J. L. Unpub. Ph.D. thesis, North Carolina State College, Raleigh, N. C. 1959.)

Table 8. Effect of percentage neutralization of subsoil acidity on growth of barley roots into layers of rains subsoil under Norfolk topsoil[a]

Percentage neutralization of acidity, pH 7	Soil pH		Root growth, g/pot	
	H_2O 1:1	0.5N KCl 1:2	Subsoil	Topsoil
0	4.3	4.1	0	0.64
20	4.7	4.3	0	0.26
40	5.0	4.6	0.06	0.20
60	5.3	4.9	0.24	0.34
80	5.8	5.4	0.32	0.38
100	6.5	6.3	0.26	0.48

[a] (Ragland, J. L. Unpub. Ph.D. thesis, North Carolina State College, Raleigh, N. C. 1959.)

In summary, acid soils are characterized by base unsaturation of the permanent charge component of exchange capacity, the complementary ion being aluminum. Of the several possible factors contributing to poor plant growth on acid soils, aluminum toxicity is undoubtedly a primary limiting factor. Neutralization of acid conditions is the most beneficial first ameliorating practice.

Literature Cited

1. Broadbent, F. E. and Bradford, G. R. Cation-exchange groupings in the soil organic fraction. Soil Sci. 74:447-457. 1952.
2. Coleman, N. T., Kamprath, E. J. and Weed, S. B. Liming. Adv. in Agron. 10:475-522. 1958.
3. Coleman, N. T., Weed, S. B. and McCracken, R. J. Cation-exchange capacity and exchangeable cations in Piedmont soils of North Carolina. Soil Sci. Soc. Am. Proc. 23:146-149. 1959.
4. Harward, M. E. and Coleman, N. T. Ion exchange equilibria in the presence of small amount of electrolyte. Soil Sci. Soc. Am. Proc. 17:339-342. 1953.
5. Jackson, M. L. Aluminum bonding in soils: A unifying principle in soil science. Soil Sci. Soc. Am. Proc. 27:1-10. 1963.
6. Rich, C. I. and Obenshain, S. S. Chemical and clay mineral properties of a Red-Yellow Podzolic soil derived from muscovite schist. Soil Sci. Soc. Am. Proc. 19:334-339. 1955.
7. Robertson, R. H. S., Brindley, G. W. and MacKenzie, R. C. Mineralogy of kaolin clays from Pugu, Tanganyika. Am. Mineral. 39:118-138. 1954.
8. Schmehl, W. R., Peech, M. and Bradfield, R. Causes of poor growth of plants on acid soils and beneficial effects of liming. I. Soil Sci. 70:393-410. 1950.
9. Schofield, R. K. and Samson, H. R. The deflocculation of kaolinite suspensions and the change-over from positive to negative chloride adsorption. Clay Minerals Bull. 2:45-50. 1953.
10. Schofield, R. K. and Samson, H. R. Flocculation of kaolinite due to the attraction of oppositely charged crystal faces. Discussions Faraday Soc. 18:135-145. 1954.
11. Weed, S. B. and Nelson, L. A. Occurrence of chlorite-like intergrade clay minerals in Coastal Plain, Piedmont, and Mountain soils of North Carolina. Soil Sci. Soc. Am. Proc. 26:393-398. 1962.

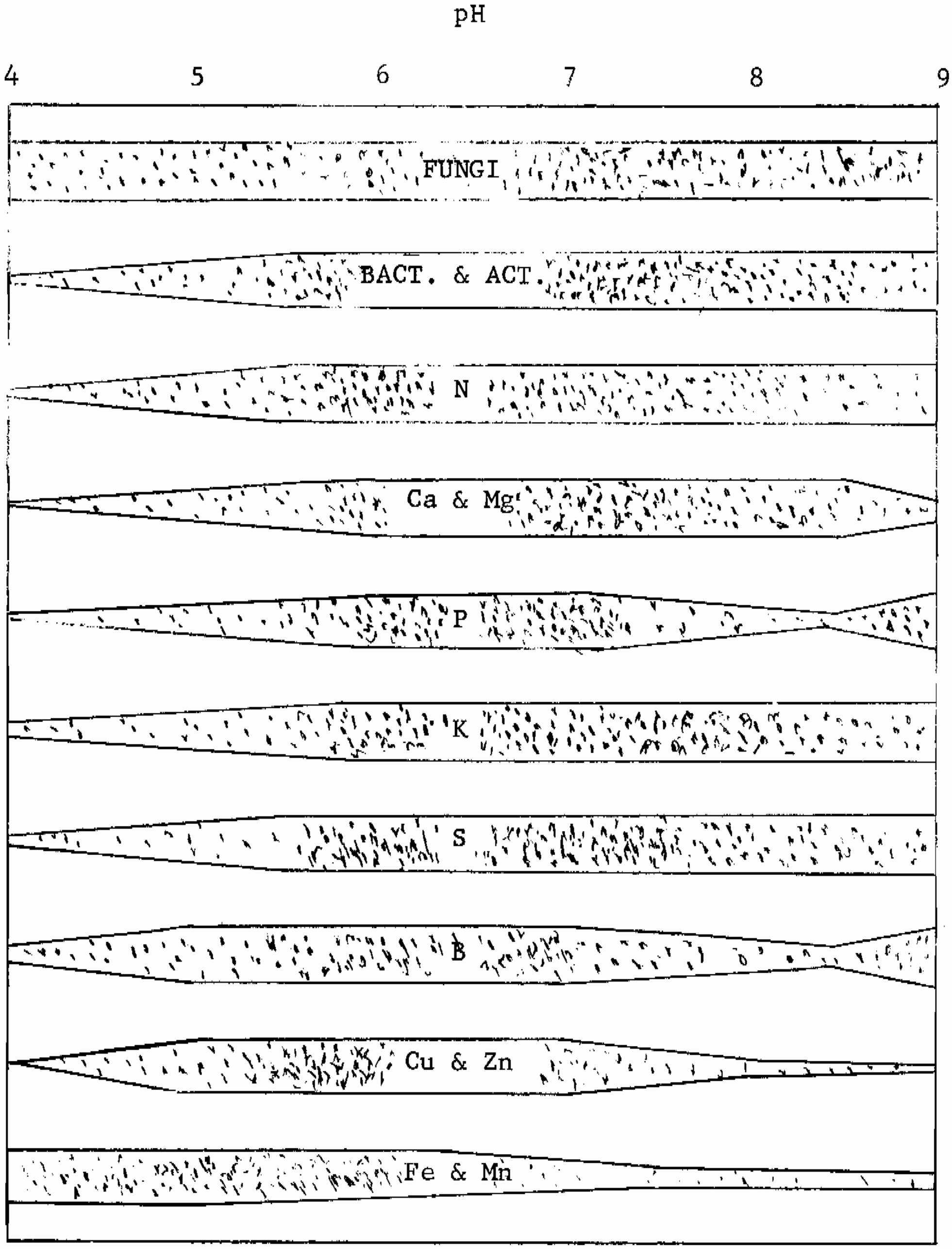

Figure 1. Relative availabilities of nutrient elements and activities of microorganisms as related to soil pH. (Lyon, Buckman, and Brady, The Nature & Properties of Soils, 5th edition, 1952, p. 405.)

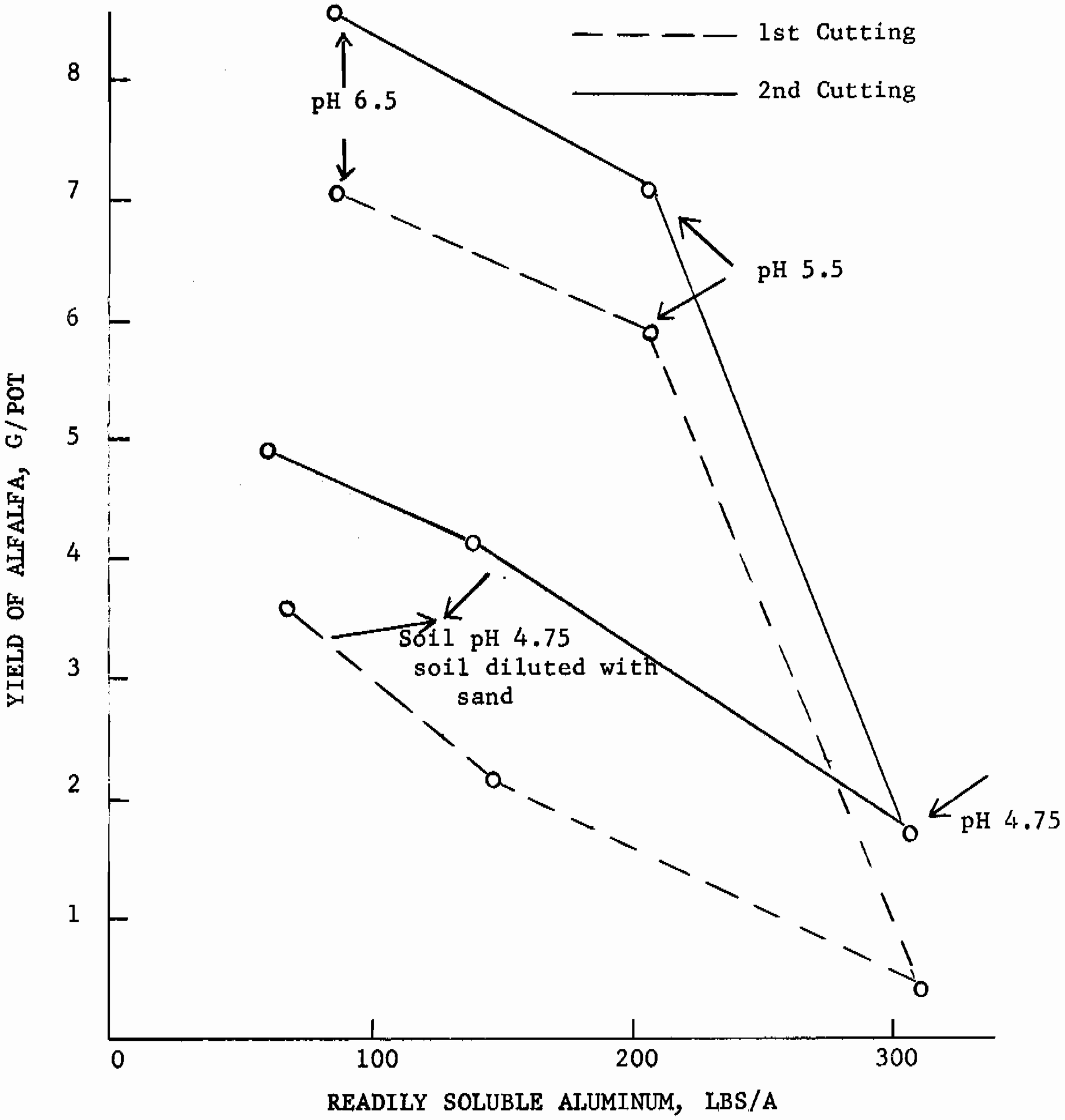

Figure 2. Effect of readily soluble soil aluminum on the yield of alfalfa. (Schmehl, et al., Soil Sci. 70:393-410, 1950).

ACIDITY CONTRIBUTED BY FERTILIZERS

W. C. White[1]

An acid is a substance that serves as a proton (H^+) donor. Conversely, a base is a proton acceptor. Hydrochloric acid is an example of the former,

$$HCl \longrightarrow H^+ + Cl^-$$

while calcium carbonate is a base:

$$CaCO_3 \longrightarrow Ca^{++} + CO_3^{--}$$

$$\overline{\hspace{6em}}$$

$$+\ 2N^+ \longrightarrow H_2CO_3$$

By the same definition, soils act as weak acids in that they serve as donars of protons or hydrogen ions (H^+). These are adsorbed on the negatively charged clay and organic matter.

How Fertilizers Acidify Soils

If fertilizers are to contribute to soil acidity, they must increase the concentration of hydrogen ions in the soil. Several ideas on how this occurs from fertilizers are:

1. Preferential uptake by plants of the cation (positively charged ion) of the fertilizer salt leaving the anion (negatively charged ion) to react with a hydrogen ion in the soil. Uptake of NH_4^+ ions, leaving NO_3^- ions to form HNO_3, could be cited as an example with ammonium nitrated.

2. Adsorption of NH_4^+ ions by the soil with the NO_3^- ions, or sulfate, subsequently existing as HNO_3 or H_2SO_4 in the soil solution.

3. Leaching of bases such as calcium and magnesium from the soil following nitrification of ammonium nitrogen. Pierre (3, 4) outlined this in 1928 as follows:

$$(1)\ (NH_4)_2SO_4 + Ca\ Soil \xrightarrow[\text{(nitrification)}]{} CaSO_4 + (NH_4)_2\ Soil$$

$$(2)\ (NH_4)_2\ Soil + O_2 \dashrightarrow 2HNO_3 + H_2\ Soil + 2H_2O$$

$$(3)\ 2HNO_3 + Ca\ Soil \longrightarrow Ca\ (NO_3)_2 + H_2\ Soil$$

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[1] Department of Soil Science, N. C. State College

Available evidence shows that the last - leaching of bases which leaves the exchange sites in soils countered with hydrogen ions - is the principal cause of the acidifying effects of fertilizers. This effect of applied nitrogen, however, is difficult to distinguish from indirect effects such as increased absorption of bases by plants resulting from increased growth, or from carbon dioxide formed in soil because of greater root growth.

The stipulation, "leaching of bases from the soil," is only one of many conditions that complicates an evaluation of acidifying effects of fertilizers. Several others are:

1. Proportion of NH_4^+ ions taken up directly by plants to those nitrified and which ultimately contribute hydrogen ions to the soil system.

2. Possible losses of ammonium nitrogen through volatilization or leaching.

3. Natural tendency of soils to become acid as a result of:

   a. Erosion
   b. Leaching of bases
   c. Plant removal of bases
   d. Oxidation of organic matter

Determining Acidity Effects of Fertilizers

The procedure reported by Pierre (5) in 1933 is the one adopted by the American Association of Official Agricultural Chemists for determining "equivalent acidity" of fertilizers. This is measured in terms of equivalent calcium carbonate required for neutralization. "Equivalent basicity" is likewise determined by the procedure and is in terms of calcium carbonate equivalent.

The computation factors are derived from the three equations above. Briefly what is involved is:

-- one molecule of ammonium sulfate forms four hydrogen ions that can contribute to soil acidity -- two in equation (2) and two in equation (3).

-- these four hydrogen ions can be neutralized by two molecules of $CaCO_3$ (1 Ca^{++} vs. $2H^+$).

-- thus, two molecules of $CaCO_3$ are needed to neutralize the acidity from one molecule of $(NH_4)_2SO_4$.

-- but the molecular weight of $CaCO_3$ is 100, and $(NH_4)_2SO_4$ is 132; two moles of $CaCO_3$ are 200 and 1 mole of $(NH_4)_2SO_4$ is 132--the ratio is 1.5.

-- therefore, 1.5 lbs. $CaCO_3$ is needed for 1 lb. $(NH_4)_2SO_4$, theoretically.

-- in practice the ratio has turned out to be 1.13 or approximately 1.2, only 3/4ths of the theoretical. Pierre explained this on the assumption that plant uptake of about half of the nitrate formed in equation (2) results in only one H^+ rather than two in equation (3). Hence, only 3/4ths as much H^+ is produced.

-- $(NH_4)_2SO_4$ is about 21%N, therefore, for 1 lb. N, 5.38 lbs. $CaCO_3$ would be required for neutralization (.21:1.13 as 1:5.38).

-- at this ratio (the ratios or factors may vary slightly depending on the % N used), it will take 538 lbs. $CaCO_3$ to neutralize the acidity from 100 lbs. N from $(NH_4)_2SO_4$.

The case for NH_4NO_3 is similar:

$$(4)\ 2NH_4NO_3 + \text{Ca Soil} \xrightarrow{\hspace{3cm}} Ca(NO_3)_2 + (NH_4)_2\ \text{Soil}$$

The quantity of "NH_4 Soil" is the same as in equation (1). However, twice as much N is applied in equation 4, ($2NH_4NO_3$), as compared to equation 1, ($(NH_4)_2SO_4$). It follows, therefore, that only half as much audity will develop from a molecule of NH_4NO_3 even though it has as much N as a molecule of $(NH_4)_2SO_4$.

Using the approximate value of 1.2 lbs. of $CaCO_3$ to neutralize the acidity from 1 lb. of $(NH_4)_2SO_4$, it follows that 0.6 lb. $CaCO_3$ would be needed for one pound of NH_4NO_3. Thus, for 1 lb. of N from NH_4NO_3 (33.5%), it will take 1.8 lbs. of $CaCO_3$ to neutralize the acidity. Or, for 100 lbs. N from NH_4NO_3, the acidity will be equivalent to 180 lbs. $CaCO_3$.

The "official" procedure for determining equivalent acidity and basicity values for various fertilizer materials is based on Pierre's procedure. Briefly it involves:

1. Dissolving a sample of fertilizer in Na_2CO_3 solution and heating to volalilize the nitrates.

2. Dissolving the remaining residue in excess HCl which is later titrated with NaOH. Differences in titrations indicate the amount of acidity of basicity in the fertilizer sample.

EQUIVALENT ACIDITY AND BASICITY VALUES

Using the procedure and calculations like those above, values have been determined for various materials. Some are shown in Table 1.

Dr. E. W. Constable, N. C. Department of Agriculture, took at random 25 registrations for each of the top four mixed fertilizer grades sold in 1962 and has reported equivalent acidity and basicity readings on them. Data obtained from this information are in Table 2.

The tonnage of the four grades, 5-10-10, 3-9-9, 2-12-12, and 4-8-12, represent 75.2% of the total tonnage, 1,327,319, of all mixed fertilizers sold in the state last year. A total net basicity of 4,450 tons of $CaCO_3$ for these four grades would give an average basicity of 8.9 lbs. per ton for these four grades.

Table 1. Equivalent acidity values for various fertilizer materials

Material	% Composition N $(P_2O_5)P$ $(K_2O)K$	Equivalent acidity or basicity in lb. $CaCO_3$ for 100 lbs. N Acidity	 Basicity
Ammonium sulfate	21	538	
Ammonium nitrate	33.5	180	
Aqua ammonia	25	180	
Anhydrous ammonia	82	180	
Diammonium phosphate	16 - (48)27 - 0	180	
Nitrogen solutions	19˙37	180	
Urea, & compounds	45	180	
Calcium cyanamid	22		285
Potassium nitrate	14 - 0 - (44)37		200
Sodium nitrate	16		180
Sodium nitrate-potash	15 - 0 - (14)12		180
ANL, Cal-Nitro	20.5	neutral	
Calcium nitrate	17		135

For other materials see the "N. C. Fertilizer Report, 1961-62," page 24. Bul. 170, N. C. Department of Agriculture, 1962.

Table 2. Equivalent acidity and basicity of the four top fertilizer grades sold in N. C. 1961-62, FY

	Grade				
	5-10-10	3-9-9	2-12-12	4-8-12	Total
Tonnage	405,707	385,423	111,472	95,931	998,533
Of 25 registrations:					
No. with residual acidity	14	1	3	4	22
No. with residual basicity	1	16	10	14	41
No. neutral	10	8	12	7	37
Av. Eq. Acidity, lb/T	128 A	4	12	24	
Av. Eq. Basicidity, lb/T	4 B	120	56	124	
Net effect, lb/T	124 A	116 B	44 B	100 B	
Total net effect, tons of lime for mixture tonnage	25,154 A	22,355 B	2,452 B	4,797 B	4,450 B

Tonnage of other N-P-K fertilizer grades was 233,949. At the same average basicity per ton these grades would be equivalent to 1,041 tons $CaCO_3$. Hence, an equivalent basicity of 5,491 tons $CaCO_3$ can be calculated for N-P-K grades sold last year. This figure does not include 0-P-K or N-0-K grades.

One could argue about applying the average figure for the four top grades to the others, many of which contain more nitrogen. This condition could very well weight the figures in the "acidity" direction. Nevertheless, a safe estimate for the N-P-K mixed fertilizers would be a theoretical basicity value equivalent to 4,000 to 5,000 tons of $CaCO_3$.

The beneficial effect of this net equivalent basicity on crop yields is difficult to establish. On rather acid soils, low in calcium and magnesium, there undoubtedly have been cases where benefits were realized. Yet, where a sound soil management and liming program is followed it is doubtful whether any material benefits may be claimed for a fertilizer formulation providing for basic effects over a formulation with acidic effects.

A report by Collins and Skinner (2) cites several conditions where fertilizers neutralized with dolomitic limestone gave higher yields of cotton, sweet potatoes, and Irish potatoes than acid-forming formulations. For the sake of brevity, only the results with cotton will be discussed.

The four-year cotton experiment was in Wayne County on a Norfolk sandy loam. Fertilizer, 6-8-6, (6-3.5-5.0) was applied in the row at the rate of 600 lbs/A. The equivalent acidity of the acid-forming formulation was 500 lbs. per ton. At the beginning of the experiment the pH was 5.6 to 5.7 Some of the results are shown in Table 3.

Table 3. Influence of an acid-forming and a neutral fertilizer on several soil properties and seed cotton yields

Fertilizer	Soil at end of experiment pH	 K	 Ca lbs/A	 Mg	Av. cotton yield, lbs/A for 4 years
Acid-forming	**4.9**	**94**	**178**	**32**	**899**
Neutral	5.6	92	224	79	1,192

Data from Collins and Skinner (2)

In regard to the nitrogen materials it would be presumptous to calculate theoretical acidity effects in view of so many qualifying conditions. As discussed previously, for a nitrogen material to have an acidifying effect, leaching of soil bases displaced by the hydrogen ions produced during nitrification must take place. One hundred pounds of N applied per acre on

Table 4. Effects of various nitrogen rates applied to Coastal Bermuda, 1955-59, on soil fertility conditions in a Eustis sand

Lb. N/A/yr.	pH	P	K	Ca	Mg	OM
		ppm	me/100 gm			%
0	5.8	41	.14	.93	.31	1.5
100	5.4	34	.11	.65	.10	1.9
200	5.3	31	.09	.58	.08	1.7
400	5.0	26	.07	.53	.03	1.8
600	4.9	18	.07	.55	.06	1.9

Data from W. W. Woodhouse, Jr.

Table 5. A comparison of several conditions in the Lee County Costal Bermuda experiment as a result of 1000 lbs. lime applied Feb., 1960

Lb. N/A/yr.	Lb. N applied 1955-1960	Lime needed to neutralize theoretical equivalent acidity *	Soil tests, 0-6" Dec., '60		
			pH	Ca	Mg
				me/100 gms	
0	0	0			
100	600	1080	5.8	.97	.67
200	1200	2160	5.6	.53	.47
400	2400	4320	5.3	.65	.47
600	3600	6480	5.2	.47	.32

* See Table 1, ammonium nitrate

Data from W. W. Woodhouse, Jr.

Data from another Costal Bermuda - nitrogen experiment of Dr. Woodhouse are illustrated in Figure 1. This experiment, on a thick surface phase Norfolk sandy loam, was started in 1957 at Clayton. Nitrogen treatments were applied for the first time in 1958. No lime was necessary in 1957.

As was the case with the Eustis sand, nitrogen rates had a marked effect on pH. In both experiments, however, the effect of nitrogen rates on pH tended to "level off" around pH 4.7-5.0.

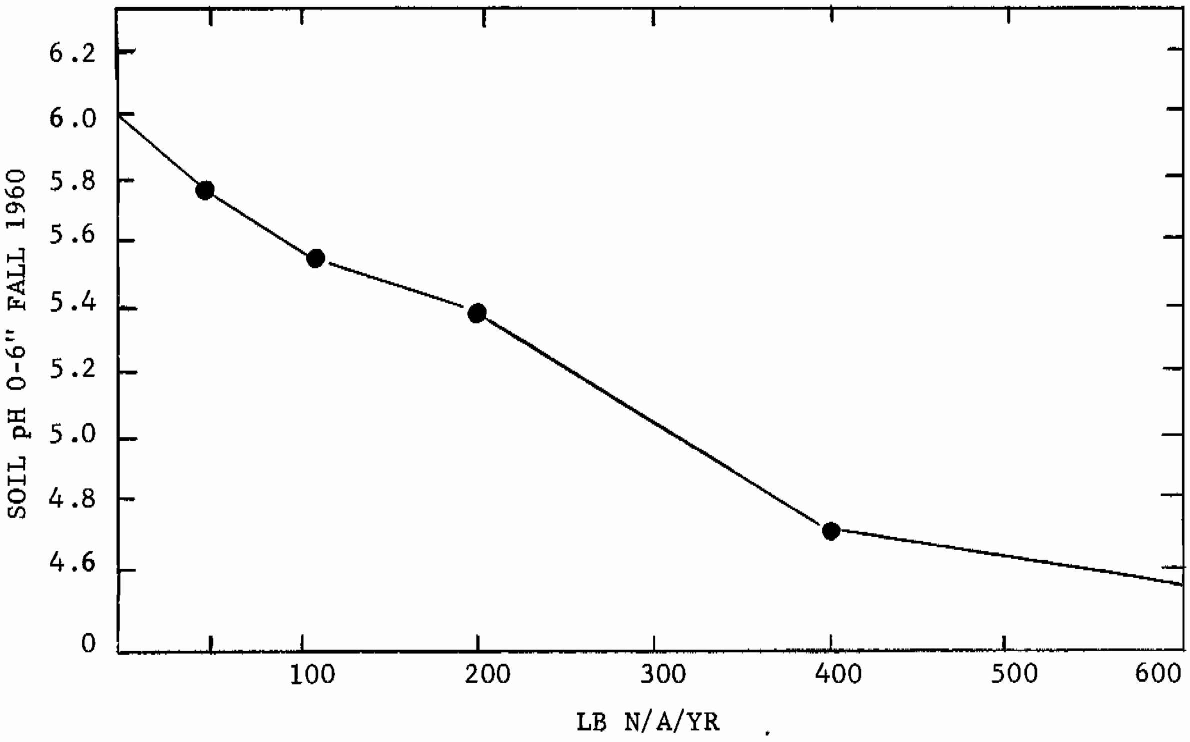

Figure 1. Effect of nitrogen rates (ammonuim nitrate) to costal Bermuda 1958-60 at Clayton on soil pH

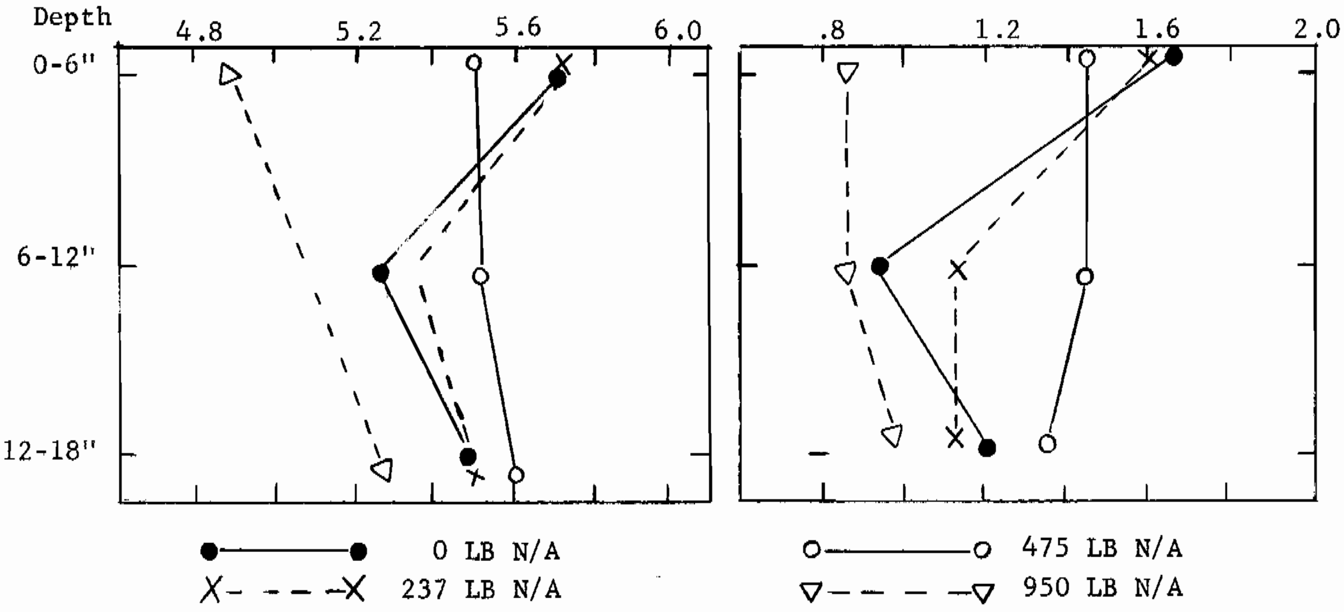

Figure 2. Effect of nitrogen rates applied to coastal Bermuda on soil fertility conditions. Cecil sandy loam. (Abruna et al (1))

a soil with no leaching probably will have no acidifying effect, whereas on another soil where leaching occurs the effect may be significant. Thus, the type of soil, existing leaching conditions, the crop involved, and other factors confound any figures one could calculate on the acidifying effects of nitrogen materials applied in North Carolina.

Instead, more fruitful efforts may be to evaluate the conditions where acidity resulting from nitrogen fertilizers may create significant problems.

MEASURED EFFECTS OF NITROGEN FERTILIZERS

Several experiments by Dr. W. W. Woodhouse, Jr. illustrate the variety of effects resulting from nitrogen applications. Three of his experiments are discussed briefly.

One was in Lee County on a Eustis sand with Coastal Bermuda. Lime (1T/A) was applied before sprigging the Bermuda in the spring of 1954. No other lime was added until February, 1960. Ammonium nitrate was the nitrogen material used. Annual P_2O_5 and K_2O was 0-100-200 (0-44-166 for P and K) for all nitrogen rates. The nitrogen treatments began in 1955.

Table 4 shows the soil fertility conditions in the 0-6" depth after five seasons of nitrogen application. Average dry matter yields for the five seasons (1955-59) were 1,276; 7,961; 9,749; and 8,783 lbs/A for the 0, 200, 400 and 600 lbs. nitrogen rates, respectively.

There were large differences in 1959 between nitrogen rates for each of the soil properties except for OM. It would be impossible, however, to distinguish with the information available the effects due to the acidity developed per se by the applied nitrogen from other effects such as increased base removal by the grass. Plant composition data from the same experiment show a marked increase in plant uptake of K, Ca, and Mg with added nitrogen.

The marked effects of the various rates of nitrogen are reasonable in view of the soil involved. The clay content is nil for 10-15 feet, and the exchange capacity, largely dependent on the organic matter content, is very low. Thus, the soil by virtue of its physical properties is very subject to leaching.

Dr. Woodhouse has information showing that leaching during the growing season was negligible. Roots extended to 6-8 feet and during the growing season there was no evidence of water moving from the root zone. Nevertheless, leaching during the winter could be severe.

In February, 1960, 1/2 T lime was applied to the soil surface. The following December soil samples were taken from 0-6" and the results are in Table 5.

It is interesting to note that 1000 lbs. lime applied to plots receiving 100 lbs. N/A/yr raised the pH to 5.8 - the same value the plot with the 0-N rate had before liming in 1960. In this case the theoretical amount of lime needed appeared to be a very satisfactory estimate of the actual needed.

Table 6. Effects of various nitrogen rates applied to bluegrass 1957-60 on soil fertility conditions in a Watauga silt loam. Ammonium nitrate was the source of nitrogen

LB N/A/YR	Soil fertility conditions, fall 1960					
	pH	P	K	Ca	Mg	OM
		ppm	me/100 gm			%
0	6.1	21	.78	4.85	1.41	4.3
50	6.1	20	.55	5.73	1.28	4.5
100	6.0	16	.67	5.52	1.22	4.4
150	5.9	38	.51	6.12	1.31	4.3

Data from W. W. Woodhouse, Jr.

As stated earlier, leaching of bases is one of the conditions necessary for the "equivalent acidity" of nitrogen fertilizers to be manifested. This condition prevailed in both experiments cited above.

In another experiment, Dr. Woodhouse obtained different results. This experiment was started in 1957 at Laurel Springs in Alleghany County on a Watauga silt loam. This soil has considerable clay and a high exchange capacity. Leaching of bases in this soil would be negligible during a period of several years. Data in Table 6 indicate this was the case. No lime was applied during the period reported.

There is one other aspect to soil acidity resulting from nitrogen fertilizers - the acidity developed below the plow depth. The three preceding experiments provide data primarily for the 0-6" depth.

A report from Georgia involving a Cecil sandy loam is given by Abruna et al (1). Their data show that effects below the plow depth may be significant. And, to fully evaluate the "acidity effects" this point would be considered particularly in view of the relatively acid and low base status of the lower soil horizons. There is also the very perplexing problem of correcting increased acidity at the lower depths. The Georgia data [illegible]
2 1/2 years.

GENERAL CONSIDERATIONS AND SUMMARY

Soil acidity will develop in unlimed soils in North Carolina as a result of many conditions. The application of fertilizers to soils is just one. Briefly, the points reviewed in this paper are:

1. Reactions of certain fertilizers in soils can result in increased soil acidity. Generation of hydrogen ions from nitrification and the replacement of bases from the soil exchange sites, with their removal from the soil by leaching is accepted as the causal factor.

2. Accepted procedures for determining equivalent acidity or basicity values of fertilizers can be useful for predicting relative effects. Many exceptions have to be acknowledged in view of diverse soil and climatic conditions.

3. Mixed fertilizers sold in the state last year had a net theoretical effect equivalent to 4,000-5,000 tons of lime. Some grades have average acidic effects, others basic, and others neutral.

4. Whether a fertilizer is acid-forming or non-acid forming can have various effects on crop yields depending on the soil conditions and crop involved.

5. Nitrogen materials can have very marked effects on pH and the base status of some soils, and very little if any on other soils. Effects on lower soil horizons may be very difficult to correct compared to effects on the plow layer.

6. The economy of various nitrogen materials has to be balanced with possible acidity effects. However, basicity from sodium should not be equated with basicity from calcium and magnesium compounds.

7. Equivalent acidity of basicity values for fertilizers with coarse limestone may be misleading. Any limestone included in fertilizer regardless of particle size is included in the analytical procedure. Information such as that of Taylor and Pierre (6) indicates that for any benefit to be realized during the year of application of limestone that it should be fine enough to pass a 20-mesh sieve. Coarser particles will have much less effect in the soil even though full value is considered in the equivalent basicity determination in the lab.

8. The effects of nitrogen are not the same on all soil bases. Data of Woodhouse for example show that effects on magnesium removal are much more pronounced than for calcium and potassium.

9. Acidity developed as a result of fertilizers can be evaluated best through soil testing. Theoretical effects may not necessarily agree with the actual effects. The actual effects will have to be taken into account along with the other conditions contributing to soil acidity. A judicious liming program consistent with all other sound soil fertility practices will assure that acidity resulting from fertilizers will not be a deterrent to most profitable crop production possible in North Carolina.

Literature Cited

1. Abruna, Fernando, Pearson, Robert W., and Elkins, Charles B. 1958. Quantitative evaluation of soil reaction and base status changes resulting from field application of residually acid-forming nitrogen fertilizers. Soil Sci. Soc. Amer. Pro. 22:539-542.

2. Collins, E. R. and Skinner, J. J. 1942. Effect of dolomitic limestone on soils and crops when used as a neutralizing agent in complete fertilizers. Agron. Jour. 34:894-901.

3. Pierre, W. H. 1928. Nitrogenous fertilizers and soil acidity: I. Effect of various nitrogenous fertilizers on soil reaction. Agron. Jour. 20:254-269.

4. Pierre, W. H. 1928. Nitrogenous fertilizers and soil acidity: II. The use of fertilizer combinations, lime, and basic slag in correcting the acidity formed by various nitrogenous fertilizers. Agron. Jour. 20:270-279.

5. Pierre, W. H. 1933. Determination of equivalent acidity and basicity of fertilizers. Jour. Indust. Eng. Chem. (Anal. Ed.) 5:229-334.

6. Taylor, J. R., Jr. and Pierre, W. H. 1935. Non-acid-forming mixed fertilizers: II. The value of dolomitic limestone supplement of different degrees of fineses or measured by the increase in water-soluble magnesium in the soil. Agron. Jour. 27:764-773.

SUPPLYING CALCIUM FOR SANDY COASTAL PLAIN SOILS

G. D. McCart[1]

The maintenance of an adequate supply of calcium is a problem in acid sandy soils. Lime is commonly applied to soils as a source of calcium for reducing soil acidity. The use of calcium salts, such as calcium sulfate or landplaster, is another way of adding calcium. However, such salts do not reduce soil acidity. This paper reports on experimental work in which calcium was supplied for plant growth from lime and from calcium sulfate.

Light colored sandy Coastal Plain soils were used in this experiment. These soils have a low clay content, are highly weathered, and contain minerals of low calcium content. They characteristically have a coarse texture in the root zone and include the sandy loams, loamy sands, and sands. Thus they are highly subject to leaching. Another common feature is that the organic matter level is low, usually less than two percent, often less than one percent. This fact, plus the low clay content of these soils, causes them to have a low cation exchange capacity (CEC) and consequently a low potential for holding calcium, magnesium, potassium, and other positively charged ions. This contributes to the problem of maintaining an adequate level of calcium in these soils.

The principal soil types in North Carolina that have these characteristics and the approximate acreage of each are shown in Table 1 (1, 2). The Norfolk and Ruston soils are distributed rather generally in the Coastal Plain region except for the tidewater area where only small areas are found. Lakeland and Eustis soils are most common in the Middle and Upper Coastal Plain regions with the greater acreage in the southern portion of this area. The St. Lucie soils are usually found in the lower Coastal Plain.

Table 1. "Light" sandy Coastal Plain soils and acreage (CEC usually less than 5.0 me/100 gs soil)

Soil series	Acreage
Lakeland	860,000
Eustis	300,000
St. Lucie	80,000
Norfolk	1,100,000
Ruston	300,000
Total acreage	2,640,000

In light sandy soils an important part of the exchange capacity comes from the organic matter (3). Some work done by Kamprath and Welch illustrates this point. They found for 18 soils studied that an average

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[1] Soil Testing Division, N. C. Department of Agriculture

of 55 percent of the CEC (at pH 7.0) came from the organic matter. This indicates that even though the organic matter content of a soil may be low, it is important as a source of CEC in sandy soils of low clay content. The capacity of organic matter to hold calcium and other positively charged ions increases as the pH is raised from 5 to 6. Therefore, liming acid sandy soils would increase the capacity of the soil to hold positively charged ions. Also, as the pH increases, more calcium and magnesium and less acid forming toxic aluminum occupy the exchange sites. This is shown in Table 2. At pH 5.0, the milliequivalents of aluminum are more than twice that of calcium. This situation is changed when the soil is limed to pH 6.0 and 6.5. At pH 6.0, for example, the milliequivalents of calcium and magnesium are 14 times that of aluminum. Also, there is more than four times as much calcium and magnesium present at pH 6.0 than at pH 5.0. Peech (4) obtained similar results with light sandy soils in Florida. Though, generally the aluminum level is low in acid sandy soils, it may have an important effect on the retention of nutrient cations in that the aluminum is strongly held and, therefore, may restrict their absorption. Non-adsorbed ions are more readily leached from the root zone.

Table 2. Calcium plus magnesium and aluminum levels in a Norfolk soil at different pH levels

pH level	Ca + Mg me/100 gs	Aluminum me/100 gs
pH 5.0	0.41	0.95
pH 5.5	0.77	0.32
pH 6.0	1.82	0.13
pH 6.5	2.33	----

The effect of liming a Norfolk soil to different pH levels on dry matter yield of cotton grown in a greenhouse experiment to the first square stage is illustrated in Figure 1. The data show a consistent increase in dry matter yield with increase in lime level as reflected by the increase in pH.

The question arises as to whether the increase in yield is the result of reduced acidity or of increased amounts of calcium and magnesium present in the soil from lime. To study this question further, an experiment was set up in which the pH, magnesium, nitrogen, phosphorus, and potassium levels were established and the amount of calcium varied. Table 3 shows the treatments and some of the results of this experiment for a Norfolk soil. The treatments include different pH levels. Sufficient calcitic lime was used to adjust the pH levels to 5.5 and 6.5. Additional calcium from $CaSO_4$ was supplied at the different pH levels. These data show a tendency for the yield to increase with additional calcium from calcium sulfate at a given pH level. However, the greatest increase in yield was with an increase in pH.

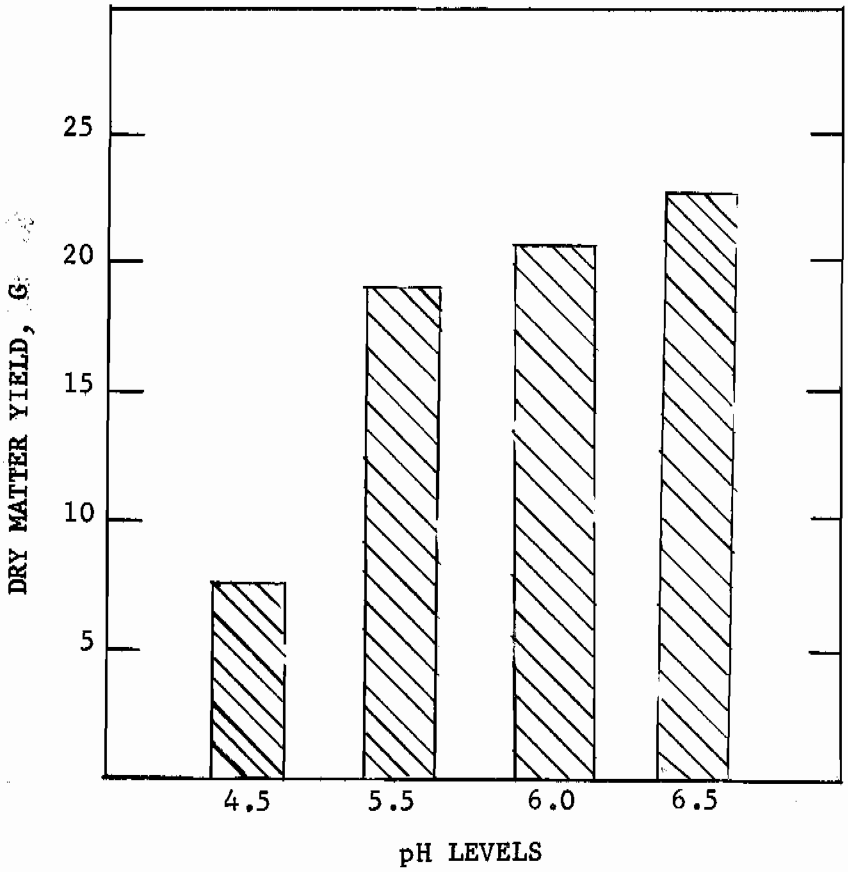

Figure 1. Yield results of cotton grown in greenhouse at different pH levels

Table 3. Yield of cotton grown in greenhouse with $CaSO_4$, $CaCO_3$ and $CaCO_3$ + $CaSO_4$

Treatment	Dry matter (gs)
pH 4.6 (+ $CaSO_4$)	3.7
pH 5.5 (with $CaCO_3$)	8.6
pH 5.5 (with $CaCO_3$ + $CaSO_4$)	9.1
pH 6.5 (with $CaCO_3$)	10.2
pH 6.5 (with $CaCO_3$ + $CaSO_4$)	10.7

Another way of supplying additional calcium to sandy soils, other than from soluble salts such as $CaSO_4$, involves adding additional amounts of coarse lime materials to the required amounts of fine lime needed for increasing the pH to the desired range. This was tried in further greenhouse work. Three cotton crops were grown to the first square stage of growth. The data shown in Figure 2 are those for the third crop. One hundred mesh dolomitic lime was used to adjust the pH to approximately 6.2 for the first three treatments. The same amount of 20-30 mesh lime was added to the 100 mesh in the second treatment, similarly for 40-60 mesh in the third treatment, and regular lime alone was used for the last treatment. Regular lime is coarser than 100 mesh lime and this probably resulted in its not reaching a pH of 6.2 during the equilibration period, but a pH of 5.6. This may account for the lower yield obtained with this treatment. Somewhat more dry matter was obtained where additional coarse lime was added to the fine lime.

The effect of these treatments on the pH level of the soil is illustrated in Figure 3. The pH levels of the various treatments at planting of the first crop did not differ greatly except where regular lime was used. This was also the case after harvest of the first crop. After the third crop, the results show that there is less tendency for the pH to drop where additional coarse lime was added than where only 100 mesh or fine lime was used.

A sand culture experiment was used to obtain information as to whether or not calcium and magnesium are released rapidly enough from coarse lime materials for normal plant growth. The treatments and results obtained are shown in Table 4. A complete nutrient solution, including calcium and magnesium, was used as the check treatment. For the other three treatments, a second nutrient solution was used which was complete except that it did not contain calcium and magnesium. The calcium and magnesium for treatments other than the check were supplied from various sizes of dolomitic lime mixed with the sand. Both nutrient solutions were adjusted to pH 6.0-6.2. The dry matter yield was highest for the complete solution and decreased with increases in the coarseness of the lime. The plants in pots where lime was used were more difficult to establish than the plants where the complete solution was used. This difficulty increased

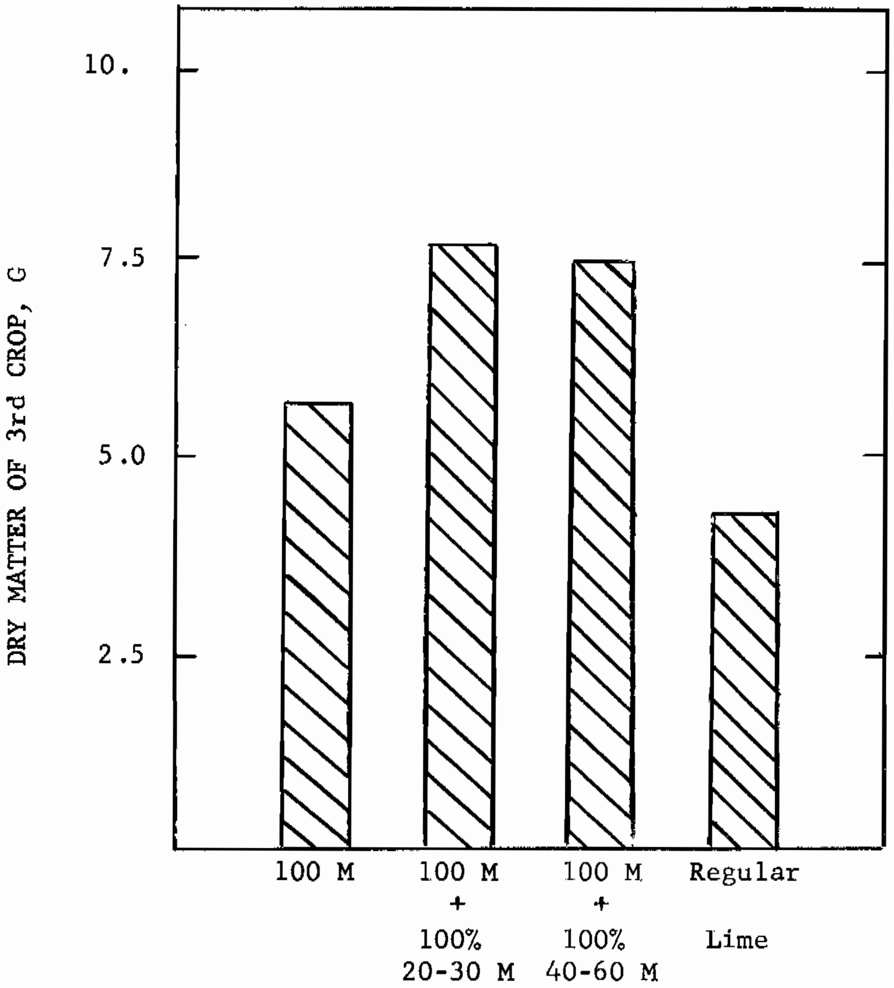

Figure 2. Yield of cotton grown in greenhouse with addition of coarse lime to 100 mesh lime (Norfolk Soil)

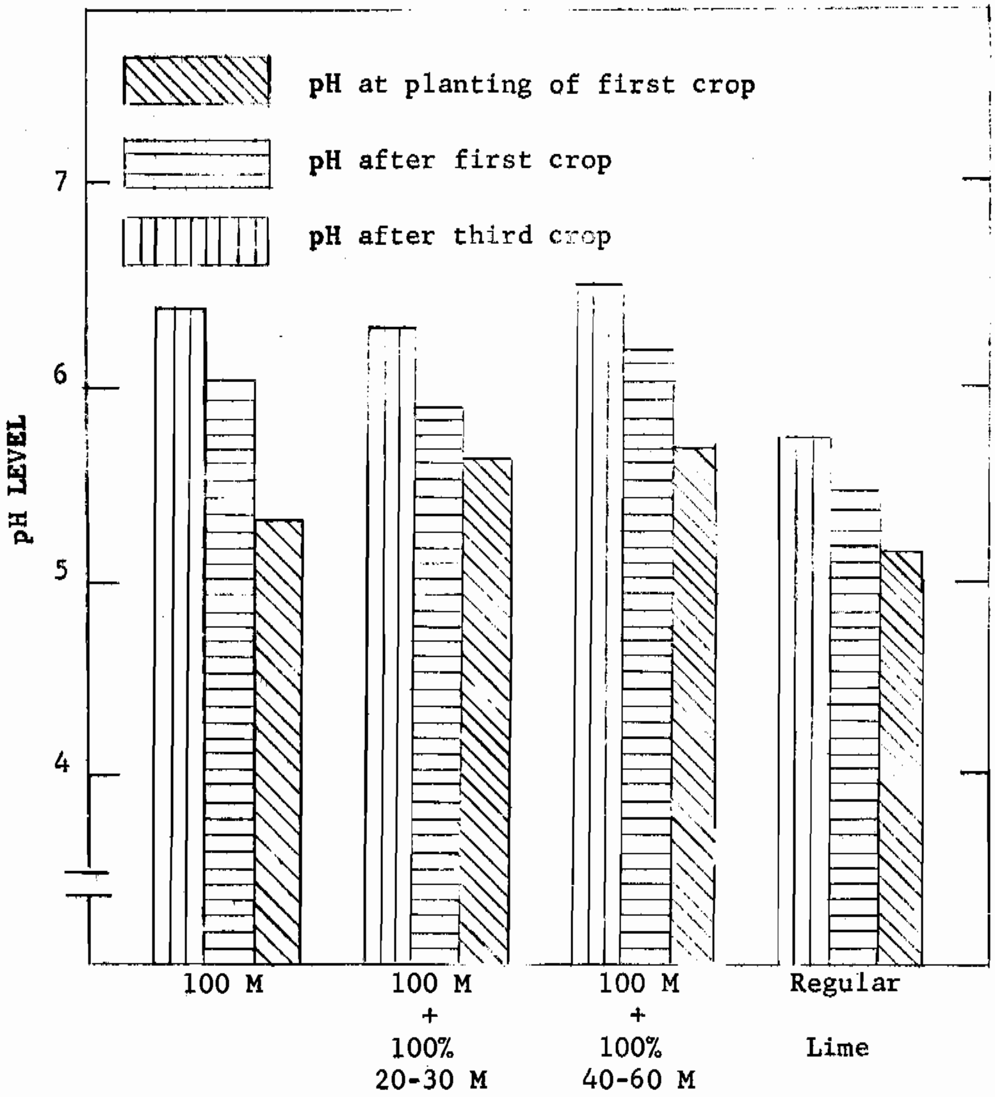

Figure 3. The affect on pH of including coarse lime with 100 mesh lime (Norfolk Soil)

as the lime increased in coarseness. Once established, the plants grew more normally, which may indicate that as the root system developed, calcium and magnesium from lime sources could be taken up more effectively. This did not occur, however, where these nutrients came from 20-30 mesh lime. These plants grew very little beyond the seedling stage.

Table 4. Yield of cotton in sand culture experiment

Treatment	Dry weight (gs)	
	Tops	Roots
1. Complete nutrient solution	3.6	1.41
2. Nutrient solution minus Ca and Mg plus 100 mesh dolomitic lime	1.6	0.75
3. Nutrient solution minus Ca and Mg plus 40-60 mesh dolomitic lime	1.06	0.47
4. Nutrient solution minus Ca and Mg plus 20-30 mesh dolomitic lime	0.37	0.11

Root growth for the treatments containing 20-30 mesh and 40-60 mesh lime was quite restricted. A deterioration of the root system was readily observed where 20-30 mesh lime was used. Spots of such root breakdown could also be seen in the root mass where 40-60 mesh lime was used.

SUMMARY

Light sandy soils present more of a problem in supplying adequate amounts of calcium because of their low cation exchange capacity or potential for holding calcium and other positively charged ions. An important source of the capacity of light colored sandy soils for retaining positively charged nutrient ions comes from the organic matter that they contain.

Although it is difficult to separate the effects of calcium level and pH level on growth, it appears that growth of cotton was favored more with an increase in pH and calcium level from the use of lime than with an increase in calcium level alone from the use of a salt such as calcium sulfate.

There is a relationship between the pH level of these soils and the amounts of exchangeable calcium, magnesium, and aluminum present. At pH 5.0 there was considerably more aluminum present than calcium and magnesium. The total amount of aluminum present at pH 5.0 in sandy soils may be small; however, if aluminum occupies a large proportion of the exchange sites, this could result in a reduction of plant growth. These soils should be limed to pH 6.0-6.5 to provide sufficient calcium and reduce aluminum to a low level.

The addition of 40-60 mesh and 20-30 mesh to fine lime such as 100 mesh did not increase the pH significantly above that of the 100 mesh alone and tended to hold the pH level up with time.

LITERATURE CITED

1. Lee, W. D. The soils of North Carolina, their formation and use. North Carolina Experiment Station Technical Bulletin No. 115, December, 1955.

2. Guides to Land Management in North Carolina. Soil information series No. 1, Department of Soil Science, North Carolina State College, in cooperation with North Carolina Department of Agriculture Soil Conservation Service.

3. Kamprath, E. J. and Welch, C. D. Retention and cation exchange properties of organic matter in Coastal Plain soils. Soil Science Society of America Proceedings 26:263-265. 1962.

4. Peech, Michael. Availability of ions in light sandy soils as affected by soil reaction. Soil Science 51:473-486. 1941.

SUGGESTED LIMING BASED ON SOIL TESTS

C. D. Welch[1]

My subject is not a new one. Most of us in agricultural work hear the word lime almost every day. But have you stopped to think what lime means to you, and what it means to North Carolina farmers? Do the farmers say "lime is most essential" or do they say "lime is not essential." A large number must be in the latter category since there isn't much lime being used in some areas of the state and a high proportion of the soils show moderate to strong acidity.

Acidity and Need for Lime

The extent of soil acidity is illustrated by soil test summary data in Table 1. 40 percent, 34 percent and 25 percent of the samples from the Coastal Plain, Piedmont and Mountain regions, respectively, had a pH below 5.5. Interpreted in terms of the need for lime, this means that in general, around 65 percent of the Coastal Plain soils, 60 percent in the Piedmont and 50 percent of those in the Mountains needed some lime.

Table 1. Percentage distribution of soil samples in three pH ranges and percentages of soils needing lime in the Coastal Plain, Piedmont and Mountains

Region	Percentage of samples testing			% of soils needing lime
	Below pH 5.5	5.6-6.0	Above 6.0	
Coastal Plain	40	47	13	65
Piedmont	34	41	25	60
Mountains	25	40	35	50

Statistics are not available to show what proportion of the total crop acreage is limed annually but estimates have been made to compare the amounts of lime needed with that used.

In Figure 1, a comparison is made between the estimated annual amounts of lime used and amounts that could be used if production practices were up-graded to give average crop yields within the ranges indicated on the back of the soil test report. This usage information was obtained from ACP and N. C. Department of Agriculture tonnage reports. In the Coastal Plain region around 150 thousand tons were applied in 1950 and about the same amount in 1960. In the Piedmont and Mountains about twice as much was used in 1960 as in 1950. This difference is partly related to changes in requirements for ACP payments.

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[1] Soil Testing Division, N. C. Department of Agriculture

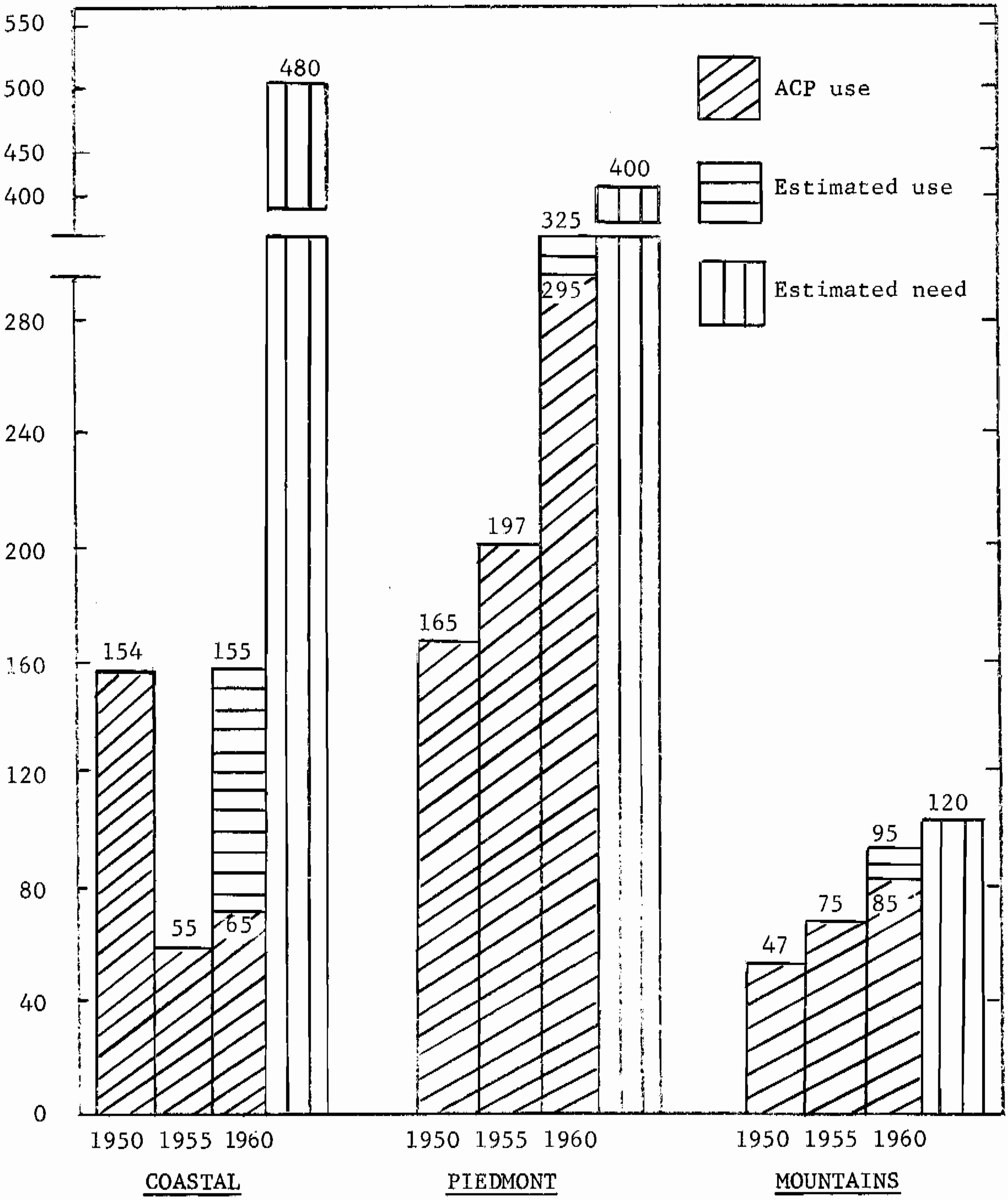

Figure 1. Estimated amounts of lime used and potential usage for North Carolina

The tallest bar represents estimated annual potential usage obtained from soil test summaries and acreage statistics. The largest difference between actual and potential usage shows up in the Coastal Plains where a high proportion of the land is planted in annual crops. In view of this difference, an examination of some of the reasons given for not using lime, especially in the Coastal Plain region, is in order. Some of the most common are:

1. Costs too much
2. Don't get ACP payment
3. Majority non-legume crops
4. Don't think it is needed
5. Haven't observed any benefits

All of these reasons are valid for an individual farmer, possibly due to his level of production or yield. For example, a farmer whose production practices are geared to 1/2 to 3/4 bales of cotton or 50 bushels of corn per acre may not see much need for lime, but suppose this man decides to set two bales of cotton and 100 bushels of corn as a yield goal, then lime becomes much more important. Top yields of most crops cannot be attained on soils which show strong acidity.

Effects of Liming Acid Soils

Some of the more important effects of liming soils are:

1. Increases crop yields
2. Supplies calcium and magnesium where dolomitic is used
3. Raises the pH which,
    a. Favors N fixation and nitrification
    b. Reduces soluble aluminum
    c. Reduces potassium leaching
    d. Increases phosphorus availability
    e. Affects trace element availability

The need for lime in growing legumes is commonly accepted. An example of the effects of lime on alfalfa is shown in an experiment conducted by W. W. Woodhouse, Jr. on a Norfolk soil at the Research Station near Clayton. As shown by data in Figure 2, the highest yield, after four years, was obtained where eight tons of lime had been applied prior to seeding. Yield differences were not this large during the first year of the experiment but the effects of the higher rates of lime became more pronounced with time. Mixing lime with the soil prior to seeding appears to be important since the yield with four tons initially was better than two tons plus 1/2 ton annually.

Non legumes also respond to lime but generally do not require a pH as high as legumes. For example, data in Figure 3, from an experiment on a Norfolk soil with a pH of 5.0, cotton produced 440 pounds of lint per acre with no lime, and 595 with one ton. There was no additional

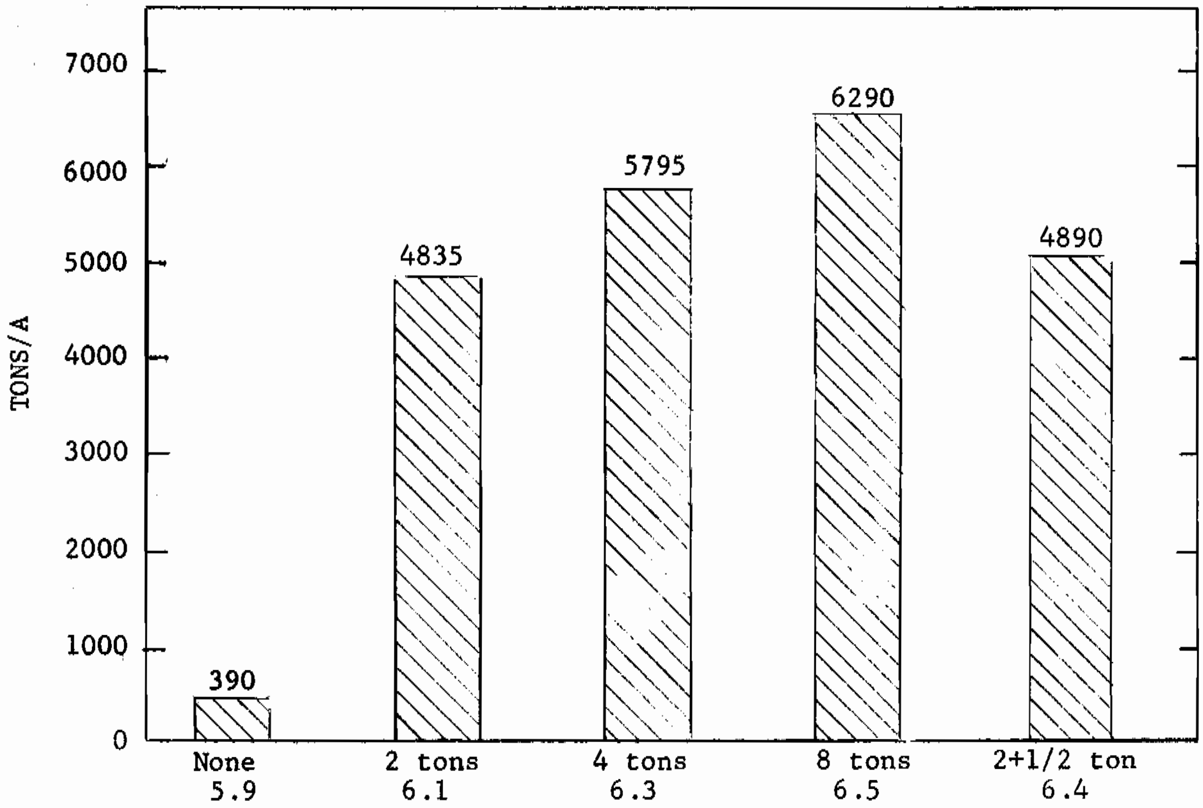

Figure 2. Yield response for alfalfa during the fourth year after application (Norfolk soil). (Data by W. W. Woodhouse, Jr.

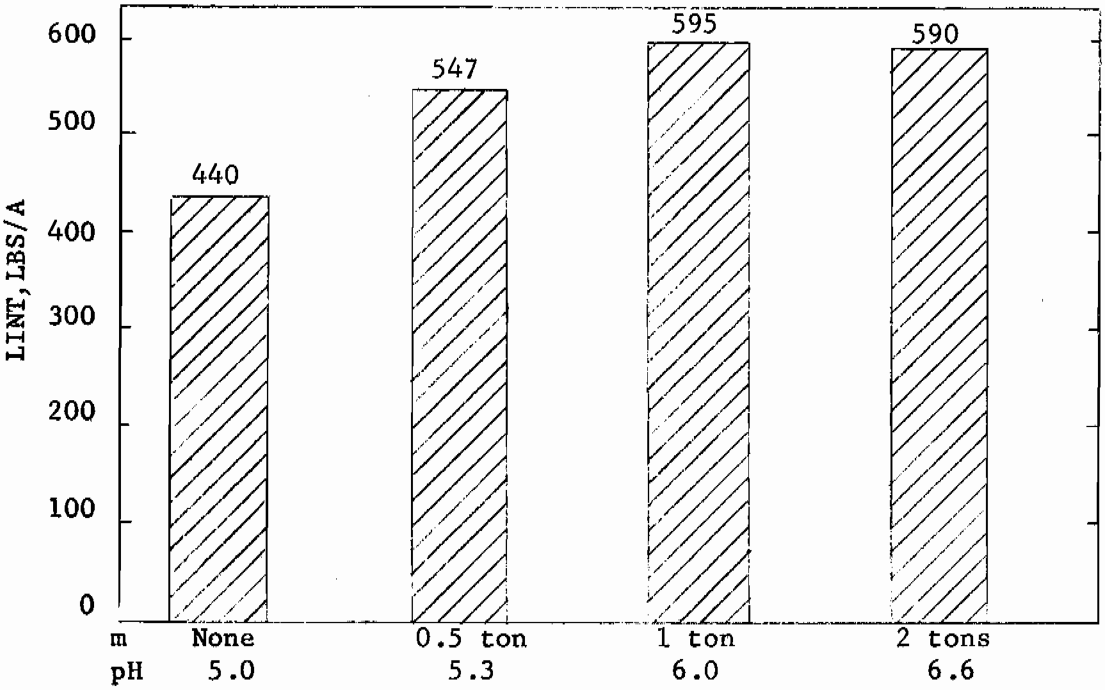

Figure 3. Yield response for cotton on a Norfolk soil after application of dolomitic limestone. (Data by W. L. Nelson and C. D. Welch.)

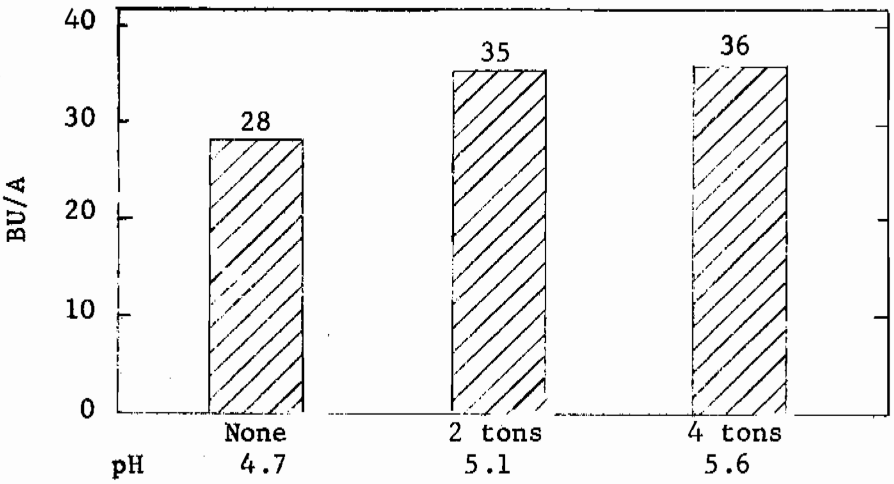

Figure 4. Yield response for soybeans on a Hyde soil during the first year after application. (Data by S. E. Younts and Robert Patterson.)

response from the two-ton rate. Even though responses have been obtained from liming soils, which have a low pH, liming practices should be aimed at keeping the pH from becoming too low; therefore, an immediate large yield response cannot always be expected.

Data by S. E. Younts and Robert Patterson in Figure 4 show that lime increased soybean yields on a high organic matter Hyde soil in the Tidewater area. The initial pH was 4.7 and the yields were 28 bushels with no lime, 35 bushels with two tons per acre. No additional increase was obtained from the four-ton rate. The pH appears to be somewhat less important in organic than in mineral soils, therefore, a pH between 5.0 and 5.5 is satisfactory in organic soils.

Liming acid soils has been shown to favor bacterial action including nitrogen fixation and nitrification. Data in Table 2 were obtained from a study using an organic soil with a pH of 3.5. Portions of the soil were limed and incubated three weeks. Even though liming did not produce a high pH, a marked increase in nitrate formation resulted. This is an extreme example since this soil was strongly acid and higher in total nitrogen than most of those found in North Carolina.

Table 2. The effects of adding lime on the amount of nitrate nitrogen produced during incubation (Data by C. D. Welch)

Rate of lime tons/acre	(Organic Soil) pH	Nitrate production during three weeks incubation[a]
None	3.5	4
4	4.5	40
8	5.3	84

[a] Pounds per two million pounds of soil

As has been pointed out previously, one of the major benefits of lime is to reduce the effects of soluble aluminum. This is illustrated by data in Table 3. In most soils the amount of active aluminum generally is low if the pH is above 5.5. Active aluminum contributes to phosphorus fixation, hence reduces availability, and introduces other undesirable effects.

The data in Table 4, obtained by J. R. Woodruff in a greenhouse study, show that lime increased the availability of phosphorus applied on two acid soils -- a Cecil and a Hyde. The initial level of acid soluble phosphorus in the Cecil was about four pounds per acre. With no applied phosphorus and no lime, the yield was 116 pounds of dry millet. Where lime was applied the yield was 220 pounds per acre. The acid soluble phosphorus was increased from five to 12 pounds due to lime. On the Cecil soil 220 pounds of applied phosphorus produced about the same yield with no lime as 110 pounds where lime was applied. On the Hyde soil containing about 10 pounds of acid phosphorus, there was a response from phosphorus with and without lime. Where no lime was used 448 pounds of applied phosphorus were required to give results similar to lime and 112 pounds of phosphorus. The maximum yield as well as the acid soluble phosphorus were considerably higher with lime indicating a greater availability of phosphorus.

Table 3. The effect of liming three acid soils on the soluble aluminum in three soils (Data by John Ragland)

Soil series	No lime	Lime
Appling	1 ppm	0 ppm
Creedmore	78 ppm	5 ppm
Portsmouth	42 ppm	2 ppm

Table 4. Effects of lime and rates of phosphorus on millet grown on two initially acid soils (Data by J. R. Woodruff)

Soil series	Rate of P	Dry matter from millet (lbs)[a/]	
	(lbs)[a/]	No lime (pH 4.6-5.0)	Lime (pH 6.1-6.9)
Cecil (4 lbs/acre)	0	116 (5)	220 (11)
	58	3056 (17)	2864 (12)
	110	3720 (28)	4760 (20)
	220	4520 (56)	4840 (48)
		No lime (pH 4.0-4.1)	Lime (pH 4.9-5.2)
Hyde (10 lbs/acre)	0	256 (10)	4436 (12)
	112	1064 (20)	3660 (31)
	224	2208 (35)	6040 (60)
	448	3840 (63)	5988 (132)

[a/] Pounds per 2,000,000 pounds of soil

Liming acid soils has been shown to increase the capacity of a soil to retain potassium. Three soil series were used in a study reported in Table 5. All soils were treated the same except for additions of lime. For the Norfolk soil 22 percent of the added potassium was recovered with no lime as compared to 49 percent with lime. Results were about the same for the Appling. For the Cecil 64 percent was recovered with no lime and 93 percent with lime.

Table 5. Effects of liming on the recovery of potassium added to three initially acid soils (Data by Grant Thomas)

Soil series	% of added K recovered	
	No lime	Lime
Norfolk	22	49
Appling	25	50
Cecil	64	93

In addition to other effects, the pH will affect the availability of most plant nutrients including trace elements. A slightly acid soil, pH around 6.0, is considered desirable from the standpoint of nutrient availability in mineral soils. Above pH 6.5, in some high organic matter soils, a number of the trace elements revert to a form which is difficult for the plant to get and growth can be reduced. This is one of the reasons why it is important to know the soil pH before liming.

Soil Tests and Liming

The pH range suitable for the cropping system is one of the factors considered in determining the lime requirement of a soil. According to information in Table 6, Irish potatoes, blueberries, camellias and a few other plants appear to grow best on strongly acid soils. A pH around 6.0 in a mineral soil is considered desirable for most crops grown in North Carolina. Some legumes grow best on nearly neutral soils. Crops will make satisfactory growth on organic soils at a lower pH.

The amounts of lime needed to bring the soil into a desired range will depend on the pH, the cation exchange capacity and other properties. Table 7 is a partial chart showing rates of lime suggested for mineral soils where the desired pH is around 6.0. The chart is divided according to the estimated cation exchange capacity. For example, if the cation exchange is estimated to be below five milliequivalents and the soil test shows a pH between 5.2 and 5.4, one ton per acre is suggested. If the cation exchange is estimated to be between 5 and 10 me/100 grams, 1 1/2 tons are suggested. The cation exchange is estimated from organic matter and texture. If the cropping system indicates that a pH of 6.5 is more desirable, a higher rate would be suggested. Therefore, the cropping system determines the desirable pH range to maintain but the rate must be adjusted according to soil properties.

For organic soils, containing more than five percent organic matter, the pH range appears less important than for mineral soils. Therefore, on these soils no lime is suggested if the pH is above 5.5 or if the pH is above 5.1 and the calcium test is high as indicated in Table 8.

Table 6. The pH ranges considered suitable for major crops grown in North Carolina

pH Ranges for Crops (Except soils above 5% organic matter)		
Strongly acid pH 4.8-5.2	Moderately acid pH 5.8-6.2	Nearly neutral pH 6.5-6.8
Irish potatoes	Cotton	Alfalfa
Blueberries	Corn	Cabbage
Camellias	Soybeans	Tomatoes
Azaleas	Peanuts	Clovers
	Small grains	
	Tobacco	

Table 7. Rates of lime generally suggested to bring the pH of mineral soils into the range 5.8 to 6.2

	Rates of Lime for Mineral Soils For pH 6.0 (tons/acre)	
Soil pH	Estimated CEC below 5 me/100 g	Estimated CEC 5-10 me/100 g
Above 5.8	None	None
5.5-5.7	1/2	1
5.2-5.4	1	1 1/2
4.9-5.1	1 1/2	2
4.6-4.8	2	2 1/2
Below 4.6	2 1/2	3

Table 8. Rates of lime generally suggested for organic soils

Rates of Lime for Soils Above 5% Organic Matter	
Range in pH	Tons/acre
5.5 or above	None
5.1 to 5.4	1[a]
4.7 to 5.0	2
4.4 to 4.6	3
Below 4.4	4

[a] None where Ca is above 4 me/100 g soil

Summary

Whether or not the amounts of lime suggested will result in the desired pH will depend on a number of factors including how well the lime is mixed into the soil. To accomplish a fair degree of mixing lime must be spread evenly before disking or harrowing. Where as much as four tons per acre are needed, better mixing may be attained by spreading half before and half after plowing.

When applied on acid soils "lime introduces many effects." Lime serves an important function in maintaining soil productivity. But I wonder how well farmers understand the effects of liming acid soils?

In view of the emphasis placed on efficient production through higher per acre yields, does liming warrant more emphasis in the production of many crops?

PREDICTING SOIL LOSSES BY EROSION

Forrest Steele and W. W. Stevens[1]

Sloping land erodes when cultivated. Many different cropping systems have been devised and many conservation practices have been used to minimize erosion from rainfall. These have had varying degrees of effectiveness. The serious need has been recognized for a way to predict the soil loss from a cropping system on a field of known physical conditions, with specified conservation practices.

History of Soil-Loss Estimation

Various means of calculating field soil losses have been developed during the past 25 years. Two principal systems evolved; one in the cornbelt states, and one in the northeastern states. The latter, developed by G. W. Musgrave, is used for computation of gross erosion from watersheds.

Zingg (1), in 1940, published an equation relating length and percent of slope to relative soil loss. Smith (2) added crop and conservation practice factors, and published a soil loss estimating equation for certain midwestern soils in 1941. Browning (3) developed the system for use throughout Iowa, adding soil erodibility and management factors.

A nation-wide conference was held in Cincinnati in 1946. This group reviewed all available soil loss data, re-evaluated factors previously used, and added a rainfall factor. Musgrave (4) published the results of this conference in 1947. Other workers studied the problem; and in 1957 Yearbook of Agriculture, Blakely, Coyle and Steele (5) included tables showing average annual soil losses under certain specified conditions.

These formulae and tables, developed prior to 1956, were satisfactory for use only in local areas, or at best in regions of fairly uniform climate and soils. In the fall of 1956, ARS scientists began concentrated efforts to develop a soil loss predicting equation that could be applied universally wherever rain causes significant erosion losses. The equation (6) that came out of this research embodies earlier concepts and procedures but also includes a new way of evaluating the erosive effects of rain.

Rainfall Erosion Index

It is readily apparent that the effects of rainfall differ from place to place and that relatively few storms cause most of a year's loss from cultivated fields. For erosion control, we are less concerned with differences in average annual rainfall amounts than with differences in the erosion potential of the rainfall.

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[1] Soil Conservation Service, U. S. Department of Agriculture, Raleigh, N. C.

Two types of distribution of rainfall erosion potential must be recognized. One is geographic; the other is in time. Geographically, there is much less rainfall erosion potential in Ashe County than in Wake; seasonally, in North Carolina, there is much less in February than in July.

Wischmeier (7), in a study of rainfall data at 144 stations with 22 years of record, and soil-loss measurements in 23 states, found that soil loss from cultivated fallow was directly proportional to the product of kinetic energy times the maximum 30-minute intensity of the rainstorm. The sum of these products, called EI values for any period, provides a numerical rainfall-erosion index that evaluates the erosion potential of the rainfall within the period. It is the most effective parameter yet discovered, surpassing the combined effect of several factors previously used. Values may be expressed on an average annual basis or on any desired probability level.

Annual erosion indexes and monthly distribution curves have been computed for 181 locations in the United States where rainfall-erosion is significant, and maps showing iso-erodent lines have been prepared.

Development of the rainfall erosion factor made the new, universal, soil loss prediction equation possible.

Soil-Loss Tolerance (T)

In the practical application of a method of predicting erosion losses, the estimates are compared to a previously established standard or permissible amount of loss. Soil-loss tolerance factors (T values) have been set up for the commonly cultivated soils in the state which are subject to erosion by rainfall. The tolerance factor is the estimated maximum average annual soil loss, in tons per year, that can be permitted in a soil management system that gives the degree of conservation needed for sustained economic production in the foreseeable future; in view of present technology, acceptability of conservation practices, and needs of expected population.

Soil loss tolerance values have been established for North Carolina soils on the basis of the thickness of the cultivatable soil layers. Values are now set in classes of 1, 2, 3, and 4 tons per acre per year.

Factors in the Universal Soil-Loss Equation

The new equation is as follows:

$A = R\ K\ L\ S\ C\ P$, where $\underline{A}$ is the average annual soil loss in tons per acre predicted by the equation.

$\underline{R}$ is the rainfall erosion factor for the specific locality, as defined above.

K is the soil factor. Research and observation show that various soils erode at different rates under the same environmental conditions. This variation must be accounted for in the prediction of soil loss. The factor K is a numerical expression of the relative erodibility. It may be defined as the soil loss in tons per acre per unit of rainfall-erosion index (EI) on a 9 percent slope 72.6 feet long, under tilled continuous fallow.

The most desirable soils from the standpoint of resistance to the erosion hazard are those with a low K, or soil erodibility factor, and a high T, or soil loss tolerance. These can be combined in a T/K value. The higher the T/K value, the more favorable is the soil in this respect.

L is the length of slope factor. This is the ratio of soil loss from any given slope length compared with the soil loss from the specific length (plot length) on which the soil factor K was determined. Slope length on a field is measured from the point of origin of overland flow, either to the point where runoff is slowed to the extent that deposition begins, or to the point where the water enters a well defined channel, such as a terrace.

S is the percent of slope factor. It expresses the ratio of soil loss from any given slope percent to the soil loss from that percent where the K value was determined (plot slope). Values for slope length, L, and slope percent, S, can be combined into one value. They are most easily expressed in graphic form - (see chart).

Cropping-Management Factors

The cropping-management factor "C" combines the effect of crops, crop sequence, crop cover, time of preparing land, time of planting, time of harvesting and the many other management practices. It is the ratio of soil loss from land cropped under specified conditions to soil loss from continuous cultivated fallow on identical soil, slope, and rainfall conditions.

Erosion from a field is, of course, greatly influenced by the quantity and quality of crop cover and root growth, water use by growing plants, quantity of prior-crop residues in the plow layer, etc. These conditions differ significantly within the period from crop planting to harvest. The distribution of erosive rains within the year differs by location. Therefore, the erosion-control effectiveness of each crop and practice was approximated on the basis of five-crop-stage periods so that the effectiveness in each stage of crop development may be related to the severity of the rainfall expected in that period at a specific location.

Practice Factors

The erosion control practice factor "P" is the ratio of soil loss with a specified practice to that of up-and-downhill cultivation when other conditions are the same. Practice factor values are listed below.

Values for contouring and contour stripcropping were established by ARS; values for field stripcropping were established by SCS by interpolation. Value of "P" factor for straight row or up-and-downhill cultivation is 1.00. The effective slope length is used in determining the value of slope length factor in the erosion equation for contouring, contour stripcropping and field stripcropping.

"P" Factors

Percent slope	Contouring	Field Stripcropping	Contour Stripcropping
1.1-2.0	.60	.30	.30
2.1-7.0	.50	.35	.25
7.1-12.0	.60	.40	.30
12.1-18.0	.80	.50	.40
18.1-24.0	.90	.60	.45

No "P" value is used for terracing, because the effective slope length on a terraced field is the horizontal spacing between terraces; similarly, on a field with diversion(s), the effective slope length will be altered according to spacing of diversions.

All soil loss predictions using this equation are based on the assumption that natural waterways are stabilized, either with or without vegetation.

Use of Soil Loss Prediction Equation in Conservation Planning

Sound planning is essential to getting conservation on the land. It has always been and still is a basic policy of the Soil Conservation Service that we assist farmers and ranchers to get a conservation program on the land in accordance with a conservation plan.

It is not practical to develop individual plans for each field or pasture of a farm while ignoring the developments on the other fields or pastures of that farm, because the farmer must manage the entire farm as a unit for successful, economic operation.

Conservation planning is systematic decision making, based upon a logical evaluation of the alternatives for land use and treatment.

It is not practical to consider each and every alternative for each plot of land on a large farm. But it is possible, and usually practical, to consider several alternatives for the farm as a whole.

Throughout its 26-year history, the Soil Conservation Service has obtained from any and all sources the best information available on suitable alternatives for land use and treatment. It has used this information with landowners and operators in helping them arrive at sound decisions about how to use and treat their soil, water, plant, and wildlife resources. Much of this information was the result of research; much of it, however, had to be based on observation and experience of the farmer-technician teams at work on farms. We, therefore, have used estimates liberally -- most of which were judgment estimates based on observation and influenced by scattered and often unrelated research findings.

This has been especially true with respect to soil losses by water erosion under varying conditions of use and treatment. At the present time SCS technicians lack definite, concrete estimates of expected soil loss under given conditions and of tolerable limits of soil loss. These same technicians have made and are using with farmers quite effectively estimates of the intensity of conservation treatments needed, field by field; and this is true in spite of the fact they have not had the benefit of all the applicable research findings.

They can be much more effective than ever before once they have esimates on soil losses based on an analysis of combined research and observation. They need a yardstick to measure the expected soil loss against a tolerable limit on every site and under every set of use and treatment conditions they will encounter. And they need to be able to talk in tons of soil, inches of soil and in such concrete terms they and the farmers can visualize and understand. This is comparable to being able to talk with farmers about the economics of conservation in dollars and cents -- terms he understands.

We need these quantitative estimates not only so we can more effectively discuss reasonable alternatives with farmers but also so that we may establish for our own guidance standards and specifications for land use and treatment.

Let's keep in mind, however, that a sound conservation program of a farmer for his operating unit involves far more than attaining a reasonable level of erosion control. We believe you understand this without any further elaboration. And let's also keep in mind at all times that soil loss predictions are only guides and not iron-clad limits that must be adhered to to the letter. The fact is, if you develop and bring into use soil loss predictions, they could result in a lower level of conservation than you now are getting accepted by farmers if these predictions are used unwisely. How can the SCS technician use predicted soil losses to increase his effectiveness with the farmer during the decision-making process of farm planning? We said that the technician needs to be able to use concrete, quantitative terms both he and the farmer understand. Lacking these, he often has to use such expressions as "You're losing a lot of soil here," or "This field's washing pretty bad," or "You'll probably have to terrace and contour this field to check erosion," of "If you expect to keep this field in crops, you should plan on contour stripcropping it, using a rotation that would keep it in meadow at least half of the time."

To use the Soil Loss Prediction equation takes knowledge, judgment, and experience. It is a tool which should serve as a guide and not an absolute answer. It is applicable on sloping land only, and does not apply to flat lands. It is to be used as a basis by soil conservationists for presenting acceptable, desirable alternative solutions to soil erosion problems on sloping land. To use the equation, one must consider dominant conditions, controlling influences of the land, and an averaging or compensating weighting of soil and its environmental influences.

It illustrates the significance of a single factor or practice and the relationship of a combination of practices. Usually, it is the combination of practices and the interrelationship of each of these practices to the others that determine the total amount of erosion which will take place in any given field. For example, terraces alone might be used, which would give one value. Terraces in combination with contour cultivation would give another value, or terraces and contour cultivation with a specified cropping-management factor would give another value. Any or all of these individual practices may be altered if other practices such as diversions, stripcropping and different cropping-management values are used to accomplish the job of erosion control.

Unfortunately, the soils in any given field usually are not uniform but vary. Also, the degree and amount of erosion is variable, and slope length and slope percent are usually variable within a field. Therefore, to use the Soil Loss Prediction equation, one must see and study the conditions of the land in the field and be able to relate logical solutions to the problems encountered. The Soil Loss Prediction equation gives the field technician another tool with which to work in presenting sensible alternatives to practical soil erosion problems in a sensible manner.

The Soil Loss Prediction equation is not a tool for any great amount of use by the farmer, but it is a tool which the technician can use to illustrate alternatives and possible solutions to problems which the farms and landowners present.

Example of use of equation: $A = K \times R \times LS \times C \times P$

References

1. Zingg, A. W. Degree and length of land slope as it affects soil loss in runoff. Agr. Engr. 21:59-64. 1940.

2. Smith, D. D. Interpretation of soil conservation data for field use. Agr. Engr. 22:173-175. 1941.

3. Browning, G. M., Parish, C. L., and Glass, J. A. A method for determining the use and limitation of rotation and conservation practices in control of soil erosion in Iowa. J. Amer. Soc. Agron. 39:65-73. 1947.

4. Musgrave, G. W. The quantitative evaluation of factors in water erosion, a first approximation. J. Soil & Water Conserv. 2:133-138. 1947.

5. Blakely, B. D., Coyle, J. J. and Steele, J. G. Erosion on cultivated land. Yearbook of Agriculture, 1957, pp. 290-306.

6. ARS Special Report. A Universal Equation for Predicting Rainfall-Erosion Losses. ARS 22-66. March 1961.

7. Wischmeier, W. H. A rainfall erosion index for a Universal Erosion Equation. Soil Sci. Soc. Amer. Proc. 23(3):246-249. 1959.

8. USDA Agricultural Research Service, Soil and Water Conservation Research Division cooperating with the Purdue Agricultural Experiment Station, 1960, Annual Report.

NEW CONCEPTS IN SOIL TILLAGE

J. M. Spain[1]

The average annual rainfall in North Carolina ranges from about 44 inches to as high as 80 inches. The latter figure represents a region in the southwestern part of the state, along the Georgia state line. Most of the state receives between 45 and 55 inches. The average distribution of precipitation is very nearly ideal. As we move into the growing season in May, the rainfall increases and reaches a peak in July. It holds up well through August, then begins to drop markedly in September, reaching a low in October, giving us a favorable harvest season.

Average potential evapotranspiration rates follow the same general seasonal pattern as the rainfall, especially during the growing season. Only for a short period from late spring to late summer does the potential evapotranspiration rate exceed the precipitation rate. It should be emphasized that we are speaking of averages. If we had no deviations from these average conditions, we would be living in a veritable paradise for crop production! The extreme, and even the not so extreme cases are the ones that cause us trouble. Climatic conditions range from drought to drowning, sometimes all within the same year. I would like to focus your attention on drought and some tillage ideas that may improve our crop production during periods of dry weather.

van Bavel has defined agricultural drought as being that condition in which there is insufficient soil moisture available to a crop. As is well known, that phenomenon is far too common in North Carolina. Let us examine some of the reasons. Drought is not simply a function of weather. We must also consider the soil, and perhaps most important to us because it is the factor we can best hope to control, management.

First, let us consider weather. Precipitation patterns vary greatly from year to year. Records are available from enough stations over a sufficient period of time to make it possible to predict with fair accuracy the chances for a given precipitation pattern to occur during the growing season in a given region. Evapotranspiration rates do not vary greatly from year to year but do vary from region to region and can be calculated and/or measured. As pointed out above, average evapotranspiration rates exceed average precipitation rates in much of North Carolina during the summer growing season. Weather is an important contributing factor in our drought problem, but it is relatively favorable.

Let us look now at the soil. Many of our North Carolina soils have rather low water holding capacities, and there is not much we can do about this property. However, other soil properties influence the development of plant roots in the soil and, therefore, greatly influence the amount of plant-available moisture. Many of these latter properties can be altered to favor greater root penetration and proliferation. Infiltration of rainfall is primarily influenced by soil physical conditions, many of which are subject to modification.

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[1] Department of Soil Science, N. C. State of the University of North Carolina at Raleigh, Raleigh, N. C.

Management should be considered as the most important aspect of our drought problem. Good management greatly minimizes the danger of crop failure or reduced crop yields in periods of dry weather. The scope of management is broad, including such things as: choice of crop and cropping sequences, irrigation, drainage, conservation practices, and tillage. We are primarily concerned in the present discussion with management practices which alter soil profile characteristics such that crop roots will develop to greater depths and utilize soil moisture more efficiently.

Our first step is to decide what features of a given soil profile need to be modified. These may be physical, chemical or both. We must then decide how best to accomplish the needed modifications. Several possible approaches are open to us. Most of these involve some form of deep tillage. The term "deep tillage" is very general and seldom clearly understood. For that reason, I have attempted to classify deep tillage systems into five major categories. I am defining deep tillage as being any tillage operation extending below the normal plow layer.

Now, let us consider these five categories I have spoken of.

1. Subsoiling is probably the best known and most commonly used form of deep tillage. It may be useful in shattering plow pans or hard pans, although seldom has field research indicated any significant response to the practice. It affords very little opportunity for appreciably modifying the chemical properties of subsurface soil layers. Fertilizers and amendments can be introduced behind the subsoiler but a very small percentage of the total subsoil volume is treated. The physical effects are almost always of very short duration.

2. Vertical mulching is a modification of subsoiling which involves blowing crop residues into the channel behind the subsoiler as it is pulled through the soil. Its chief advantage over subsoiling is that the results are much longer lasting than subsoiling; the residues serving to hold the channel open and stabilize it.

3. Deep plowing is accomplished with more-or-less conventional implements, differing principally in size and power requirements. Theoretically, it should afford us the best means of creating a very deep, homogeneous plow layer.

4. Layer transportation is an ingeneous tillage method reported in the Russian literature by Botov. He calls the operation a "three layer" tillage method. A specially designed, three unit plow lifts the plow layer, and simultaneously transposes the A2 or a portion of it down the profile, replacing it with a portion of the B horizon. This might be compared to the process of taking the cream filling out of a Bost Cream pie and putting it on the bottom! The Russians have experimented with this system in the reclamation of solenetzic and podzolic soils with considerable success being reported. The power requirements are very high and the machinery is rather complex.

5. Subsurface zone tillage is an experimental method under study at N. C. State. It involves the mechanical manipulation of a specific subsurface layer, without appreciably displacing any of the soil profile. The layer in question can be rather thoroughly modified chemically and

under some conditions is also subject to considerable physical modification. The methods being used in our research have relatively modest power requirements. For many of our soils in North Carolina, it appears to be the most promising of the five categories discussed. We are, however, interested in all of the above discussed approaches; and we are presently conducting field research involving subsoiling and subsoil fertilization, and deep plowing as well as subsurface tillage.

In summary we would emphasize the following points.

> Drought is frequently serious in North Carolina during the summer growing season.
>
> Drought is largely a function of climate, soil, and management.
>
> Through proper management, we can alter some of the soil characteristics which limit root growth and make crops highly susceptible to drought.
>
> Many soil profiles in North Carolina will require both physical and chemical modification for maximum root development.
>
> Subsurface zone tillage is being studied at N. C. State along with other deep tillage methods as means of accomplishing the needed chemical and physical modifications.

USE OF SOIL SURVEY IN URBAN DEVELOPMENT

S. S. Obenshain [1]

It is a pleasure as well as a privilege to discuss the use of soil survey in urban development before this group. This is a subject, as many of you know, which is close to my heart. So that there can be no misunderstanding, I pause here to express the thought that soil survey is not a field into itself but is a part of soil science - a very important part. When it is separated from the main body of soil science, it loses its value.

Coming to North Carolina, the cradle of soil survey, to speak on so hallowed a subject is something like carrying coals to Newcastle. Some people credit Milton Whitney with being the father of soil classification; others give C. F. Marbut credit for being the guiding hand. As for me, I would gladly join those who insist that the guiding spirit back of soil survey in America was a geology professor at the University of North Carolina, Chapel Hill, one Collier Cobb. Among his students were Hugh Bennett, Ed Hearn, Tom Rice, Robert Winston, Dolf Mangum, "Riz" T. Allen, L. L. Brinkley, William Cobb, Robert Jurney, "Bob" Devereux, and James E. "Red" Caudle.

What I plan to say during the next few minutes is old stuff to many of you; but assuming this is an audience of varied soil background, it might be appropriate to briefly outline the program of work and a little of the philosophy of the soil scientist, known both as a soil surveyor and "dirt dauber." Soil survey has as its purpose the identification, description, and mapping of our soil resources. In making a soil map the surveyor examines the soil and underlying formations systematically and carefully and in many places. While he carries with him a 42-inch auger as a part of his equipment, it should not be assumed that he examines the soil only to that depth. In addition many test pits are dug and studies are made along highway banks, railroad cuts, and other deep exposures.

In arriving at a decision as to the proper identification of a soil, the surveyor studies each horizon (layer) of a soil with particular attention to its color, depth, structure, porosity, consistence, texture, density, organic matter content, amounts and kinds of roots and stones, and many other features. The map, which results from the decision based on these studies, gives the location and extent of each kind of soil found in a particular area, the slope on which it occurs, and erosion conditions.

There are a few assumptions made by the soil scientist which must be understood by those attempting to make use of his product. One is that the soil exists only in the field. The soil as we classify it is a three-dimensional individual piece of the landscape. What we may bring into the laboratory for study is simply a sample representing a horizon or part of a horizon of a particular kind of soil. The second assumption is that a trained soil scientist after careful field study can predict a lot concerning behavior of the soils that no known

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[1] Department of Agronomy, Virginia Polytechnic Institute, Blacksburg, Virginia.

laboratory procedure has yet been able to do. This does not lessen the importance of laboratory studies but does put them in their proper perspective for best use.

But let's get back to the subject--Use of soil survey in urban development. What can we contribute as soil technologists? Our part should be to furnish detailed soil information about the area involved and to render what assistance we can in the interpretation of this information.

For a proposed subdivision, information about the soil should come early and, furthermore, should relate to the problems involved. If water and sewage are available, the problem may be one thing; if these facilities are not available, the problems are increased.

First, the developer should look at the soil resources to find out if the proposed area is suited for subdivisions and if so, just what the handicaps are. There have been many instances in Virginia, and there will continue to be many more, where areas bought for subdivisions have been entirely unsuited for that purpose because of poor soil conditions. In those places where the developer has purchased undesirable areas but is prevented from building there, he alone suffers. However where he is allowed to construct houses on poor soil areas, he who buys the home is the victim.

What are some of the problems, and what can the soil scientist do to avoid them before building or to correct them after the house has been built? In those areas where public water and sewage systems are not available, the problems of development are serious, many, and complex. First and foremost is the problem of health. It is in this field that we have been most active in Virginia. The health authorities are concerned with providing satisfactory individual absorption systems for sewage disposal and with the problem of getting pure water. These two problems are very intricately connected, and here is where the health officer and the soil scientist need to work closely together.

The soil scientist and the sanitarian have a very strong tie and, therefore, should be able to work together for mutual benefit. They are both concerned with soil-water relations. The sanitarian is interested in the ability of the soil to filter and purify effluent from absorption systems in a manner which will allow uncontaminated water to return to the ground water supply. The soil scientist is interested in these same water relations from the point of view of practical interpretations such as plant growth, drainage, irrigation, etc. Thus we see that both are concerned with those soil properties which indicate good soil-water relations.

The soil scientist does have one extra tool which might enable him to combine the experience of both fields so that the results will be usable to all. In his program of soil mapping or soil survey the soil scientist gives geographic expression to experiences in soil behavior which not only allows a more rapid accumulation of information but also gives him a tool for extension of such information. Its main contribution is to increase prediction value of what will happen with the soil occupying any particular area under different types of use and manipulation.

Apparently it is agreed that individual absorption systems for sewage disposal do work well in certain soils and will not work in others, and that because of certain soil conditions an absorption field might work better than a seepage pit, or conversely. The extent to which the soil scientist can help the sanitarian recognize and locate these favorable and unfavorable soils is the extent to which he can be of help to him. Experience in various localities; Fairfax County, Virginia, for instance, has proven that the soil scientst can be of assistance in this respect.

The soil surveyor's first service, then, might be the pinpointing of soil conditions which the sanitarian knows to be good or bad for certain uses. Such a map would be of inestimable value in helping to determine whether a subdivision should be encouraged or discouraged, approved or disapproved - depending, of course, upon the authority of the health department. In many instances this decision may be denied the sanitarian for in areas where the developer has become familiar with soils information, he will likely study the soil map before purchasing an area for development. If the soil conditions are unsuitable for individual absorption systems for sewage disposal, he will not likely buy the property. In some areas the soil map is given serious consideration in approving new subdivisions.

The soil map can be a tremendous help in pointing out soil conditions where percolation tests are likely to be unreliable. There are many such soil conditions but the two most conspicuous examples are those soils with a high water table and those having clays with high shrink-swell ratio. A number of proposals have been made to solve the problem of misleading percolation tests on soils which at some periods during the year have high water tables. One suggestion is that tests be made only from November to June.[2/] Another is that a soil moisture testing service be set up which would inform sanitarians relative to the proper moisture condition for percolation tests. Soil scientists insist that soil color as an indication of the height of water table during the wetter period of the year is more reliable in general than either of the above suggestions.

High swelling clays are impermeable when wet. When dry, the cracks are wide and water runs through the soil profile rapidly. It often takes a considerable period of time for the soil to take up enough water to swell the cracks shut. Therefore until the soil is thoroughly wet, the water may run through it rapidly and give misleading percolation results.

Another important assist the soil scientist can give is in pointing out the place or places in a lot or area proposed for development where percolation tests will most likely pass. More important than that, however, he can show the spot where absorption systems will work best. He can also be of considerable assistance to the sanitarian in suggesting which kind of system would probably give best results - an absorption field or seepage-pit. Often under an impervious layer there may be a fairly thick layer of soil which will serve as absorbent and filtering material for septic tank effluent.

[2/] Washington Post. Sunday, August 12, 1962.

A very important area in which the soil scientist, the sanitarian, and the geologist have an excellent opportunity to work together is in relating individual absorption systems for sewage disposal to water contamination. It would seem that if filtering and purification of effluent is the object of the individual absorption field, seepage pit, or stabilization pond, then water contamination is a serious problem. If, however, the objective of absorption systems is just to keep effluent below the surface, then the problem is to take care of water contamination when it occurs. Assuming that contamination is as serious a problem as effluent showing on the surface, then much research is needed to test filtering and other desirable properties of many of our soils.

One overall problem of great importance is the question of the stability of the soil for individual housing units. Possibly you saw the pictures in the Saturday Evening Post of June 14, 1958, showing the houses sliding down the hill. Well, this was in California and couldn't happen here, but it did. If you don't believe it, ask the people from Fairfax County about Blue Bell Lane. Similar conditions are reported in Maryland, and evidently there are many areas with similar problems in your state as well. The soil map will indicate areas with such problems.

Clays that swell when wet and shrink when drying constitute an unstable soil condition which exists in all our states. Such areas must be guarded against for individual housing developments. Some of these clays expand to twice their dry volume with a force of up to 10,000 pounds per square foot and when proper precaution is not taken to minimize the bad effect, which of course involves added expense, this swelling and contracting can cause serious flaws to develop in the foundation of the structure and, of course, in the structure itself.

Common in many areas proposed or selected for subdivision development is the lack of adequate drainage. This is, indeed, a very serious problem. Where there is available sewage and water, you might ask what difference does it make? If your basement is built for a swimming hole, then we would say the problem is nil, but usually a flooded basement is not only quite annoying, it is also quite expensive and little to be desired. Even if not flooded, a basement which is constantly wet can be, and often is, an unhealthy and expensive nuisance. A preliminary study of soil conditions such as soil color, depth to and kinds of mottles, closeness to natural drainage ways, and structure and consistence of soil will enable one to predict the problem of wet basements.

The horrible mistake of locating a subdivision on flood plain soils has been made too many times. The major problem here is the determining of those areas where flooding can be expected. The soil map has proven to be remarkably accurate in outlining flood plains, and a few counties have ordinances against building on flood plains designating the soil map as an authority. In many places, however, the hazards of flood water seem to be strangely overlooked by both builder and buyer.

In the planning of a subdivision development, certainly a great deal of money, time, and effort can be saved if care is exercised in the location of public buildings, roads, utility lines, and other features.

Roads or streets located properly with respect to soil type will not only be more economical in installation cost but also in upkeep. Too often roads are built in those areas not well suited for other purposes. Features of great importance in the location of roads are depth to rock, type of rock to be encountered, swelling clays, and drainage conditions. To know depth to rock is important. It is also important to know type of rock to be encountered. Some rock can be removed by heavy equipment, while other rock (diabase, limestone) can normally be removed only after blasting with dynamite. Poorly drained and very poorly drained soils not only restrict the season of construction but also greatly increase problems of footing for roads. Improper footing can be of extreme importance in the cost of construction and road upkeep.

R. A. Helmer, Research Engineer, Oklahoma Department of Highways, gives an example of cost saving in highway construction by considering soils.[3/] He states that one such example is U. S. Highway 70 across Choctow County, Oklahoma. Of the 45 miles, 13 miles are on sandy loam soils of the Bowie and similar series, with 32 miles on soils such as the Denton and San Saba clay. The latter soils require approximately 26" pavement versus 15" for the sandy loam soils. This, on the basis of 1950 cost, would represent approximately $600,000 in tax money. The soil map, which was not available at the time of the location of the highway, indicates that the undesirable soil condition could have been avoided by moving the highway not more than one mile.

Land slides are another costly hazard in road building. These slides are usually associated with varying types of soil and soil material in relation to rock strata.

The construction of public buildings may pose many problems from footing to landscaping. Securing proper footings can be a two-edged sword. If the footings are not adequate to hold the type of structure involved, trouble is in store. Adequate footing on unstable soil can be costly compared to a more stable condition if such can be found. An illustration often quoted is the school building in Fairfax County which cost $233,000 for extra footing which could have been prevented by moving a short distance. On the other hand, the added cost of excavating dense rock can be very expensive, as can the cost of landscaping.

It is apparent that the developer and planner of subdivisions and the soil scientist have mutual interests in working together, hence the question is immediately posed: How can this be done most efficiently? The soil scientist has or can obtain information that is significant to the planner and developer in many of their decisions. By working closely together, planner and developer will not only learn the value and limitations of soil information but will with a little training learn to apply this information with a minimum of assistance from the soil scientist. In a few situations the planner or developer may even become a soil scientist, and in some instances a soil scientist may become a planner or developer, but it is not likely that many will bridge this gap.

[3/] Helmer, R. A. The use of soil classification in making engineering predictions. Paper given before Southeastern Regional Soil Work Planning Conference, Fayetteville, Arkansas. October 7-11, 1957.

There are a number of ways in which this pleasant working relationship between planner and the soil scientist may be disrupted. For instance, one of the pitfalls is for either one of the parties to think he can operate individually and without a mutual understanding of the other man's field. However, where each has acquired at least an elementary knowledge of the other's field, they will be able to receive mutual help. The soil scientist working with the planner and developer will become familiar with the principals involved in their decisions and the planner and developer will be able to use information about the soil in making safe decisions.

Let us review some of the things which are being done and which we think should be done if soil technology is to be properly applied to planning subdivisional developments and related fields. We believe that a big step in Virginia has been the establishment of a course in soils which enables the student to study the soils in the field where they exist. For the past seven years two such courses have been taught each summer in different areas of Virginia. During the period of each two-week course the instructor and the students spend their time together out in the field looking at soils, discussing their characteristics, and what they mean in use and management. This course has done more than anything else to make the use of soils information in the field practical.

Another step which we feel is a milestone in our working together is the placing of a soil scientist in the State Health Department to study ways and means of making soil information more meaningful to sanitarians and others in planning subdivisional developments.

What will it take to make this job a success? We believe, as a minimum, a pattern must be followed, such as we have started in Fairfax and Prince William Counties and are now beginning in Henrico, Loudon, and Chesterfield Counties. First, we must have a good soil map and second, we must have a trained soil scientist to help interpret the soils information. Many feel that either one or the other of these two requirements is sufficient. We contend that both are necessary. No map can be sufficiently accurate to eliminate the necessity for on-the-spot inspections for many important decisions. The soil scientist must have training plus a wide background of experience in the identification and evaluation of soils. Nothing less will do, and less may be worse than nothing.

NITROGEN STUDIES ON CORN AND SMALL GRAIN

R. E. McCollum[1] and W. H. Rankin[2]

The rapid pace of fertilizer technology in recent years is common knowledge. Nitrogen, for example, is available for farm consumption in either solid, liquid or gaseous form. Simultaneously, machinery companies have designed equipment suitable for applying any of these materials at the rate desired. One result of this expansion in technology has been that of offering the farmer an almost infinite number of alternatives in selecting the material and the method of application which best fits his objectives or desires.

The purpose of this report is to summarize some preliminary results concerning the nitrogen nutrition of corn and wheat. Two kinds of experiments of two or more year's duration are involved. The first year's results are reported. These experiments originated from what appeared to be a poor response to nitrogen when an approved material was applied by accepted techniques. Because of their origin, a brief summary of the observations leading to the designing of each experiment is in order.

Prior to 1961, farmers in the Nash-Edgecombe area noticed that small grain top-dressed with nitrogen solutions containing urea did not respond like adjacent fields that had been treated with equivalent quantities of nitrate-nitrogen. Research and extension personnel agreed that the symptoms were similar to nitrogen deficiency.

In the fall of 1961, the Soil Science Department established wheat experiments at two locations in Edgecombe County with the purpose of evaluating the response to several nitrogen materials applied as top-dressing the following spring. The materials used and the quantities of nitrogen applied are shown in Table 1. Both experimental sites were in farmer's fields; and all operations, other than nitrogen treatments and harvesting, were performed as routine operations by the cooperator.

The corn experiment is in Wayne County. This site was selected for the following reasons. In 1960, the area was planted to corn, and the farmer had sufficient nitrogen applied as anhydrous ammonia by a custom operator. During the period of heavy nitrogen demand, the crop deteriorated measureably and had the appearance of severe nitrogen deficiency. Corn in an adjacent field that had received a different nitrogen material did not exhibit similar symptoms. Nematode assays of soil from the problem area showed a high population of several nematode species. Similar complaints from a number of farmers in the Wayne-Duplin area were registered with the extension service throughout 1960 and 1961.

Inquiries and preliminary tests by extension personnel revealed two items common to most of the complaints. Most of the farmers had used anhydrous or solution nitrogen placed between the rows, and most of the soils assayed high in nematode infestation. Since similar

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[1] Department of Soil Science, N. C. State of the University of North Carolina at Raleigh, Raleigh, N. C.

[2] Department of Soil Science, N. C. State of the University of North Carolina at Raleigh, Raleigh, N. C., Emeritus

Table 1. The effect of different nitrogen top-dressing materials on yields of wheat grain and straw at two locations in 1962

Nitrogen source[a]	Yield (lb. straw or bu. grain/acre)			
	Davenport farm		Baker farm	
	Straw	Grain	Straw	Grain
Sodium nitrate	5430	36	3042	30
Ammonium nitrate	5442	36	2957	26
Uran	4927	33	2481	23
Urea	4725	30	2625	25
LSD (.05)	Not analyzed	3.0	Not analyzed	N.S.

a/ Top-dress nitrogen was applied at the rate of 50 lbs. per acre. All treatments received 30 lbs. of nitrogen at seeding

Table 2. The effect of nitrogen source, nitrogen placement, and soil fumigation on nitrogen uptake and yield of corn in nematode-infested soil (Wayne County, 1962)

Treatment[a]		Nitrogen uptake (lbs./A)	Yield (bu./A)
Source and placement of sidedressed nitrogen	Fumigation		
Anhydrous Ammonia	None	94	65
(in middles)	Fumigated	86	65
Solution 37	None	86	62
(in middles)	Fumigated	88	66
Urea	None	88	58
(in middles)	Fumigated	90	62
Ammonium Nitrate	None	80	62
(in middles)	Fumigated	89	66
Ammonium Nitrate	None	98	66
(drilled on row)	Fumigated	105	64
LSD (.05)		10.6	N.S.

a/ Nitrogen treatments were applied at the rate of 120 lbs. N per acre, and zinophos fumigant (Cyanimid) was broadcast preplant at 16 lbs. (active) per acre practices with the same nitrogen materials have proven satisfactory, both experimentally and in practice, it was hypothesized that nematode damage to the corn root system was inducing a condition of positional unavailability of the nitrogen. In this event, a technique permitting the placement of nitrogen in closer proximity to the damaged roots may provide a partial solution to the problem.

To test this hypothesis, an experiment was designed to evaluate the response of corn to different sources and placements of nitrogen under two nematode populations. A split-plot experimental design, with four replications, was used. Nitrogen treatments were the main plots with one-half of each nitrogen plot being fumigated for nematode control. The treatments imposed are shown in Table 2.

Results

Wheat

Grain and straw yields for different nitrogen sources are shown in Table 1. At one location (Davenport farm), there was a significantly higher yield of grain from nitrogen sources that did not contain urea. Although straw yields have not been evaluated statistically, the data show trends similar to those for grain. At the other location (Baker farm), differences in grain yields were not of sufficient magnitude for statistical significance. In addition to the yield data, it should be pointed out that visual differences in growth and color in favor of the high yielding treatments were obvious throughout the spring growing season. This effect on vegetative growth was similar to the earlier observations in farmer's fields.

Corn

Nitrogen uptake at mid-season and final yields for the fumigation-nitrogen source experiment are summarized in Table 2. Although there were no significant differences in yield, the likelihood for any treatment response was reduced by unfavorable weather conditions during the early season. No rainfall records were kept, but the experimental area did not receive any rainfall in the six-week period between April 30 and June 10. The resultant drouth condition was believed to have reduced the yield potential considerably and may have leveled out any treatment effects possible under a more favorable moisture regime.

The nitrogen uptake data, as estimated from nitrogen analyses on whole-plant samples, indicate a response to nitrogen placement but no response to fumigation nor form of nitrogen. As the data in Table 2 show, corn plants recovered more nitrogen from ammonium nitrate drilled on the row than from the same or other materials drilled in the middles. It is not known, however, to what extent the early drouth influenced these results; and without further evidence, they should not be interpreted as favoring this method of placement under favorable conditions.

Summary

Two types of field investigation concerning the source and placement of nitrogen fertilizer for corn and small grain are in progress. First-year results on wheat suggest a differential response to nitrogen when equal quantities of nitrogen from different sources were used as top-dressing. For corn, no yield response was observed when different forms of nitrogen were applied to fumigated and unfumigated soil. Nitrogen uptake was greater, however, from ammonium nitrate drilled on the row than from an equal amount placed in the middles.

It must be emphasized that no definite conclusions should be drawn from only two field tests carried out over a period of one year. Climatic, soil and other factors are too varied to permit the complete solution of problems such as these in so short a time. The studies on which this report is based are being continued.

FUTURE SOIL RESEARCH NEEDS

E. Hervey Evans, Jr.[1]

I remember a statement made by Dr. Lovvorn at a meeting some years ago "To be really successful in research, you need to be able to anticipate the needs ten years hence." Unfortunately, too much of our so-called research effort in soils is undertaken within the framework of today's, or even yesterday's, cultural methods and ways of doing things. Agriculture is too dynamic for this type of approach.

There are many categories one could talk about on soil research needs. I have made a rather arbitrary selection of three categories and would like to limit my remarks under these headings. First, in my opinion, one of the facts that cannot be disputed is that we will move more and more toward intensive cultural methods. This fact raises many questions that need answering. Secondly, in my opinion, one of our major problems has to do with nematodes, and I would like to make a few remarks concerning this area of study. Finally, I would like to make a few remarks concerning deep fertilization.

Within the framework of more intensive cultural methods, we need to place a great deal more emphasis on crop responses over long periods of time on the same soil using intensive cropping methods. Examples that come to mind are silage corn and coastal bermuda grass, where much is removed from the ground and little is put back into it. Under these conditions:

a. Do fertilization requirements change over longer periods of time?

b. Do some minor elements, not initially limiting, become in short supply after awhile?

c. In particular, what changes take place in the subsoil and how can any deficiencies or difficulties be corrected? I think we need to look especially in the subsoil at calcium, magnesium, phosphorus and the minor elements.

Also, we need to determine the limits of crop response on specific soils. We need to know the potential performance of soils under optimum climatic conditions, especially where water is not the limiting factor. We should be able to plot curves showing the relationships of yield to various levels of fertilization.

In this connection, it seems to me that an effort should be made to collect enough climatological data so that predictive statistics then could be applied to a given geographical area to aid in planning a fertilization program. With good research information of the above type available, it should then be possible to supplement fertilization more intelligently as needed following unusually heavy rains. The work of Dr. McCants and Dr. Woltz on tobacco illustrates what I am talking about. I understand that some recent work at North Carolina State has been done

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[1] NcNair Farms, Laurinburg, North Carolina

using specific crops as indicators of soil potentials. For example, in some of our soils, one bushel of corn is the equivalent of .42 bushels of soybeans. This approach might simplify the correlation of soil potentials with specific crops.

We should remember that decisions made in producing a crop should not be one-time static things, but are dynamic changing things. As a result, the information from research should be designed with this in mind. When conditions change during the season, we need to know what new decisions to make in fertilization, weed control, etc., to get optimum results. All of this places a new and great burden on the Extension Service in my opinion, and indicates some changes that should take place in the organization of the Extension effort. I do not wish to elaborate on these here; nevertheless, the Extension Service should be better organized to help modify recommendations to farmers in localized areas during the crop season as conditions change.

Secondly, I consider the complex of problems related to nematodes to be some of our biggest. Apparently large soil particles, low fertility, droughty soils, and certain other conditions go along with the high populations of nematodes. At any rate, the plant reactions to nematodes under these conditions are more acute.

Is this due to nematodes themselves, or to the primary soil conditions? What are the interrelationships involved? Why does one spot in the field show severe nematode damage year after year when another three feet away never shows the same symptoms? In my opinion, we ought to seek some biological means of control in hopes that we might not have to place so much emphasis on the synthetic chemicals which are expensive and not very long lasting.

Thirdly, there are many questions raised in my mind that revolve around the subject deep fertilization. Can we find ways to inject liquid fertilizer materials into the A_2 and B horizons and get thereby good distributions of the desired elements?

We need to do basic research, I believe, with the A_2 and B horizons with all our major agricultural soils answering such questions as these:

a. What minerals are present?

b. How do they behave when exposed to the surface of the ground?

c. How do they behave when mixed with the A horizon in varying amounts?

d. What happens when they are treated with large amounts of lime, phosphate and other materials?

e. What effect on them does water have when applied in varying amounts?

f. What are the effects on them of other physical and chemical stimulii?

Finally, it seems to me that we have a wonderful opportunity to answer some of the above questions by proper use of the Phytotron. Undoubtedly, the emphasis with the Phytotron will be on measuring specific crop responses to controlled climate under various treatments. But what about the possibilities of measuring the soil responses to varying treatments under controlled and changing climates? This seems to me to offer an excellent way to learn much about many different soil types with a minimum of time and field plot work.

FUTURE SOIL RESEARCH NEEDS AS SEEN BY A RESEARCH WORKER

J. W. Fitts[1]

Acquiring information to increase the efficiency of production of North Carolina soils, so that farmers in this area will be more competitive with farmers of other areas, is the responsibility of our soil research program. Currently, there are thirty-four research projects in the Soil Science Department. All of these projects must be constantly reviewed and revised to keep them up to date with current problems. In the review process, some projects are closed out and new ones initiated, always taking into consideration the problems which are most pertinent.

Research needs may be divided in various ways. For the purpose of this discussion, research will be divided into immediate needs and future goals.

Immediate Needs

In the immediate future, one of the questions will be the optimum utilization of nitrogen. With several new plants under construction, nitrogen will be much more plentiful than at present. Considerably more nitrogen than now used can be consumed profitably in North Carolina, but it must be used where needed. Tobacco is a high return per acre crop but indiscriminate use of nitrogen will result in tobacco of an undesirable quality. More information is needed on balancing rates and time of nitrogen application with climatic conditions in order to obtain highest yields with desirable quality.

Grasses will be a good crop on which to apply nitrogen. However, it must be remembered that pounds of milk or pounds of beef per acre are the important economic considerations rather than pounds of grass per acre. Studies must continue on getting the most from forages in terms of livestock production as influenced by fertilizer practices.

Stabilizing the Outer Banks should be of immediate concern to all North Carolinians. Fertilizing the dunes to increase grass cover appears the most practical procedure for accomplishing this. More information is needed on fertilizing grasses which are adapted to the Outer Banks.

North Carolina soils generally are acid in reaction, but North Carolina farmers are reluctant to apply lime. No doubt much of this is due to the pH range which is optimum for various crops. For example, cotton requires a much higher pH than tobacco. Further information is needed on the optimum soil pH for our major crops.

Soil acidity influences the solubility of some of the micronutrients and there is a rather narrow range where they are greatly influenced by a slight change in pH. Also aluminum solubility is related to soil acidity. Furnishing adequate calcium and magnesium for the various crops and also controlling acidity at the level desired is a big problem. Research is underway on this but needs to be expanded.

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[1] Department of Soil Science, N. C. State of the University of North Carolina at Raleigh, Raleigh, N. C.

The deficiency of copper is more widespread than originally anticipated. The interaction of manganese with copper and other soil conditions also needs more study. A considerable acreage in the Coastal Plains appears to need copper or manganese or both.

Crops such as tobacco, cotton and corn do not root deeply on many North Carolina soils. Several factors are responsible for this restricted rooting. Determining the causes of the poor root growth and how to improve the conditions requires much more research.

Long Range Requirements

Yields of most crops in North Carolina have made large gains during the past 20 years. Much greater gains are needed, however, for the State to keep pace with other regions. More efficient use of moisture and nutrients will be required. To do this, studies must be initiated on building soils for maximum production. This will not be achieved in a single year or even in two or three years. Procedures will vary with soil and climatic conditions.

As higher yields are attained, what nutrients are likely to become limiting? At the present level of production most of our soils appear to have sufficient micronutrients. Maintaining the correct balance of nutrients for high production over a period of years will require much more information than is now available.

The average precipitation in North Carolina is about 50 inches per year. Of course, this varies from one locality to another. This appears to be sufficient water for high yields but drought is a greater hazard than might be expected. How to utilize more fully the precipitation received is a big challenge. Watershed management and storage of water, both in the soil and in reservoirs, should receive much greater attention.

Balancing crop requirements with soil conditions (both fertility and water) and climate will largely determine the progress in both quantity and quality of yields that will be obtained in the future.

AWARDS

In 1959 during the second annual meeting of the Soil Science Society of North Carolina, a committee chaired by Dr. H. C. Folks made the following proposal:

1. The North Carolina Soil Science Society shall support a program of awards for the recognition of outstanding workers in soil science and soil management.

2. Specifically, an award shall be made every year to:
   a. That person who, in the opinion of the Awards Committee, has made the most important contribution to the knowledge of soils and their management; and
   b. That person who, in the opinion of the Committee, has made the most outstanding contribution in furthering education pertaining to soils and their management.

3. To implement such a program, a standing committee shall be appointed by the President to screen and select the recipients of these awards.

The proposal was accepted and two awards have been presented each year since 1959.

In 1963 during the fifth annual meeting of the Society, it was proposed that the citations for the achievment awards be printed in the Proceedings along with photographs of the recipients and that small photographs of past recipients be included on a separate page. The proposal was accepted.

NORTH CAROLINA SOIL SCIENCE SOCIETY
ACHIEVEMENT AWARD for 1963
in
EDUCATION

EUGENE FRIZZELLE GOLDSTON

Eugene Frizzelle Goldston arrived in North Carolina on November 3, 1905, his first stop being on a farm in Chatham County. Since then, except for a ten-month period working in Virginia, his stopping points have been every county in North Carolina.

He was educated in the public schools of his native county, and at North Carolina State College, receiving the Bachelor of Science degree in 1929. The candidate had equal credits in Geology and Soils, and there was a question of which College unit would award the degree. Soils won, probably because Soil then was considered the finished product.

Upon graduation, Mr. Goldston accepted a position in Soil Survey with the Department of Agronomy, North Carolina State College. While his work has been primarily with soil classification - making field surveys, preparing maps, and writing reports - he has served also as a teacher and as an Extension Specialist for North Carolina soils. He has done considerable graduate work in soils and geology.

He has taught the course "Soils of North Carolina." Presently he is handling the laboratory instruction for this course. For the past four years he has coached the Soil Judging Team of the College. His teams have won two second places and one third place in the Southeastern regional contests, and placed third one year in the National contest.

In addition to his teaching and coaching responsibility, Mr. Goldston is serving as soil consultant and surveyor to the State Agricultural Experiment Station. He has made detailed surveys of the central station, and of all the branch stations and outlying farms, thus supplying basic data for the entire research program. His assistance to project leaders has been invaluable.

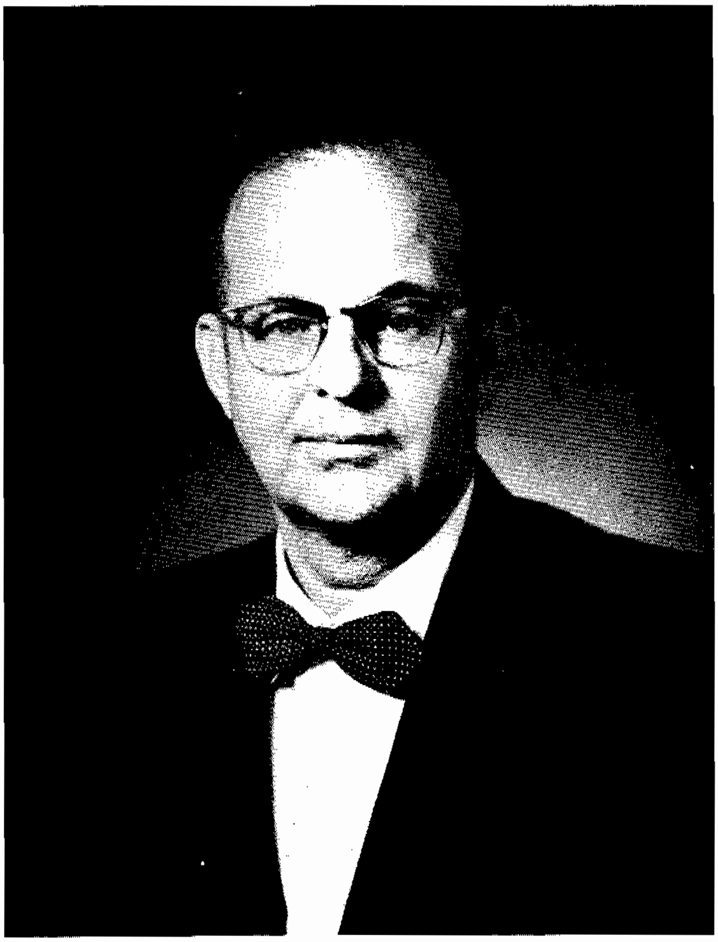
Because of his knowledge and wide experience with the soils and agriculture of the Mountain region of the State, he served as Extension Soil Specialist in that area during the period 1946 to 1949. He rendered valuable assistance to the Extension workers of the entire 15-county region. Upon completion of this assignment he returned to regular Soil Survey work.

Mr. Goldston was in charge of the Soil Surveys and prepared the reports for Alamance, Avery, Buncombe, Duplin, Graham, Haywood, Jackson, Macon, and Madison Counties. He was the associate surveyor in Brunswick, Carteret, Clay, Franklin, Henderson, Lee, Stokes, Surry, and Transylvania Counties, and junior author of the reports.

He is an accomplished draftsman, and an expert in map interpretation.

Gene always indicates keen interest in his work. He has the most willing attitude to go far beyond the call of duty in his various assignments. In recognition of his ability, and of his outstanding contribution to the accumulation and advancement of knowledge of soils and their management, the Soil Science Society of North Carolina is pleased to honor the MAN with the Soil Auger!

NORTH CAROLINA SOIL SCIENCE SOCIETY
ACHIEVEMENT AWARD for 1963
in
RESEARCH



WILLIAM WALTON WOODHOUSE, JR.

William Walton Woodhouse, Jr. is a native North Carolinian and holds the Bachelor of Science and the Master of Science degrees from North Carolina State. He received the Ph.D. degree from Cornell University.

His professional career has been devoted to agricultural research in North Carolina. In 1936 he joined the staff of North Carolina State College as Assistant Professor of Agronomy in forage fertility. He is now Professor of Soils in charge of soil fertility with forages. During these 27 years he has become a national and international authority on forage fertility and management. He was among the first to recognize that certain species then commonly grown were not responsive to fertilizer treatment. This led to work with other species of both grasses and legumes. Primarily because of the work done by him and his co-workers, Ladino-fescue, Ladino-orchardgrass, bluegrass and Coastal Bermuda pastures cover over a million acres in North Carolina.

Recently he has had much success with bluegrass in the mountains. His fertility and management work with alfalfa resulted in the expansion of this crop to nearly 100,000 acres in the state. Repeatedly he has shown an increased need for potash and nitrogen by many grasses and for mixed fertilizers by annual lespedeza and other forage crops. He found that animals chose sericea which was well supplied with lime and phosphate. He has been actively associated with watershed research in the mountains, and more recently with the control of erosion on the outer banks. The green pastures and hay fields of North Carolina, supporting an ever-increasing number of livestock, are a tribute to his good work.

In 1953 he was chosen as the only American member of a team to make a Survey of Forage Resources in Europe, and in 1960 he returned to review the results of the earlier recommendations. Twice he has been assigned to the North Carolina State College program in Peru as a forage expert. While on one of these assignments, he served as a consultant for the IBEC Research Institute in Brazil. Students who have studied under his supervision are now in responsible positions in many countries.

Perhaps the greatest personal tribute to him is the confidence which all who know him in this country and abroad have in his sound judgment and wise counsel; he commands the respect and high esteem of all who know him.

He is married to the former Margaret Christian; and they have two children, a daughter in high school and a son who is working for his doctor's degree at the University of Wisconsin.

PAST RECIPIENTS OF THE NORTH CAROLINA SOIL SCIENCE SOCIETY ACHIEVEMENT AWARDS

IN EDUCATION

IN RESEARCH

1960

E. R. Collins

W. D. Lee

1961

E. Y. Floyd

A. Mehlich

1962

J. F. Lutz

W. H. Rankin