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ELMER R. KIEHL, *Director*

THE SOIL

Its Broader Implications

Proceedings of the 1959 Soil Fertility and Plant Nutrition Short Course

presented in recognition of

DR. WILLIAM A. ALBRECHT

Presented in cooperation with Soil Fertility and Plant Nutrition Council of Missouri

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COLUMBIA, MISSOURI

Dr. William A. Albrecht

This publication is a modest tribute to the life and work of Dr. Wm. A. Albrecht, who retired as Chairman of the Department of Soils on August 31, 1959, after 43 years on the staff of the University of Missouri. The Soil Fertility and Plant Nutrition Council cooperated with the University of Missouri in conducting a short course December 2 and 3, 1959, which was dedicated to Dr. Albrecht in recognition of his services to science, to agriculture, and to the University of Missouri. Assistance of the Council has made possible the publication of these short course papers. These authorities in the field discuss topics in the broad realm of Dr. Albrecht's interest in soil—plant—animal relationships.

PREFACE

Dr. Albrecht was brought up on an Illinois farm and went from there to the University of Illinois. It is literally true to say that he came into science from agriculture, but his viewpoint, more and more forcefully expressed with advancing years, has always been to look at agriculture and its problems from the vantage of science. His special field was soil microbiology and soon after his arrival at Missouri he set up the legume inoculation service for farmers, which for many years improved our stands of red clover and soybeans. This is one example of a continuous thread through his career—the cheerful and immensely competent undertaking of a professional University or community chore. It can be traced back to his family ideal of service through education.

The study of the delicate relationship between host plant and nitrogen-fixing organism led, through acute observation and logical deduction, to the recognition that it was not sufficient to bring host and organism together; the most favorable chemical environment must also be provided. This turned out to depend very largely on calcium. Further steps led to the recognition of the very general importance of this element, especially in processes leading to the production of proteins by plants, and the maintenance of their health and vigor.

Many investigators would have been content to pursue these plant—soil relationships in greater and greater detail, but Dr. Albrecht saw, in addition, a broader vision encompassing the whole biological dependence of higher organisms upon plants. This was readily demonstrated with small animals and insects and could be seen in operation with larger farm animals and even with human beings under the right combinations of circumstances.

The understanding of these relationships came at a time in his career when he was called upon to explain the applications of soil science to groups interested in agriculture, first in Missouri, and then, with increasing public recognition, all over the country. In the past few years there has probably been no individual from the Land Grant Colleges so widely known as he.

This public acclaim is connected also with another thread running continuously through his career, namely his concept of the role of the teacher. Many generations of students have paid tribute to his patient and often humorous insistence on the three essentials for genuine scientific education—a clearly defined objective, complete integrity in carrying it out, and finally the conviction that science is an integrated whole. Applications of science are for him not recipes for success but rather distillations of basic principles. Many are the weekends when he has taken home piles of quizzes and themes and by his penciled comments made this clear to his students.

Dr. Albrecht helped to initiate the annual Soil Fertility and Plant Nutrition Short Course and has contributed to its continued growth.

George E. Smith
Chairman
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INTRODUCTION

It is a great pleasure to be back in Missouri where, 30 years ago, I was encouraged by Dean emeritus M. F. Miller and Professor William A. Albrecht to examine soil nitrogen problems in their relation to environment and the influence of man. This field of work has remained attractive to me and whenever an opportunity presented itself—I pursued it enthusiastically. Since leaving Missouri my interests have shifted to high mountain massives and to the tropics. Hand in hand went improvements in sampling techniques, and in the formulation of a broad, conceptual scheme, the pedogenic functions of soil organic matter.

THE ECOSYSTEM

To understand soil, particularly its organic matter problems, it is advantageous to consider the *ecosystem* which is the totality of soil plus its cover, the plant and animal life.

Static Aspects

Instead of analysing soil only, the entire ecosystem is evaluated, as is illustrated for total nitrogen and organic carbon in Table 1.

In a cold and humid alpine ecosystem (18) consisting of a slightly podsolized moraine covered with shrub *(Rhododendron, Vaccinium,* and *Juniperus),* a tessera was cut out, that is, a vertical square prism having a crossection of 20 cm. x 20 cm., and a height of 123 cm. The vegetation portion of the tessera rose to 23 cm., which was equal to the height of the shrub, and the soil portion descended to 100 cm., which corresponded to the depth of the soil profile.

TABLE 1-RATES AND EFFICIENCIES OF ANIMAL GAINS AND YIELDS AS HAY AND AS ANIMAL GAINS PER ACRE ON DIFFERENT SOIL TYPES WITHOUT AND WITH SOIL TREATMENTS.

Soil Type	Rabbit Gains, Grams		Hay Consumed per Gram of Gain*		Yields of Hay, Lbs. per Acre		Yields as Lbs. of Gain per Acre*	
	Untreated	Treated	Untreated	Treated	Untreated	Treated	Untreated	Treated
Putnam	315.7	419.9	13.23	9.41	2,180	3,800	116	254
Clarksville	419.0	616.6	7.85	5.49	520	2,020	39	233
Eldon	504.7	674.8	6.79	5.88	2,500	4,500	241	471
Lintonia	561.4	741.9	6.95	5.06	2,250	2,800	180	316
Grundy	637.1	593.9	7.43	6.47	2,400	3,760	180	303
Average	487.6	609.4	8.45	6.46	1,970	3,376	151	315
Range of difference, %	101.8	79.1	94.9	86.0	380.8	122.7	507.7	101.2

*Assuming all gains from the hay.

(From paper Biological Assays of Some Soil Types Under Treatments, Soil Science Soc. of Am., Vol. 8, 1944; McLean, Eugene O.; Smith, G.E.; and Albrecht, Wm.A.)

The nitrogen content of the entire ecosystem is 224.1 g/m^2, the organic carbon content 5144.1 g/m^2. Extrapolated to an acre-basis, using the factor 8.92, the nitrogen content is 2000 lbs./A. The bulk of it is in the soil proper; only a small portion, 15 percent, is located in the vegetation part, in the leaves, stems, and roots.

On the basis of historical records Mercanton (25) estimated the age of the moraine (Rhoneglacier) as 315 years. Therefore, the mean annual net gain of nitrogen in the ecosystem was 0.711 g./m.^{2} or 6.35 lbs./A. This gain was derived from the *outside* of the ecosystem, presumably as nitrogen compounds in precipitation, and as biological fixation of nitrogen molecules.

In England, Ovington (29, 30, 31) has published extensively on nitrogen and carbon contents of young ecosystems, viz. forest plantations up to 47 years old.

Dynamic Aspects

Translocations of organic matter *inside* ecosystems, especially forests, may be ascertained by placing trays on the ground and measuring the litter fall at frequent intervals throughout the year. Examples (20) of tropical rainforests in South America—at sea level (Calima) and at 4701 feet (Chinchina)—and of temperate and cold mountain forests, in California (Shaver Lake, Mt. Givens) are shown in Table II.

At the tropical sites nitrogen in the litter fall is nearly ten times that of the temperate sites, 86 and 140 lbs./A. against 11 and 14 lbs./A. These additions to the soil are not real gains, for the nitrogen in the plant parts is itself derived from the nitrogen reservoir in the soil, unless the plants are nitrogen-fixing legumes, or the leaves and needles fix nitrogen from the air.

Measuring at these sites the forest floor, that is, the fresh and the partially decomposed plant debris resting on the mineral soil, we note that the relationships are reversed. In the California mountains the quantity of forest floor is several-fold greater than in Colombia. Presumably, the reversal is related to the rate of decomposition of the litter material, which is influenced by climate.

The rate of decomposition of the forest floor, more precisely its rate of loss, may be evaluated by choosing a steady-state forest in which the forest floor, over a period of years, remains about the same in its general appearance.

At a chosen date one square meter of average forest floor is weighed, and its weight is found to be F_e grams. For an entire year falling leaves and debris are prevented from contaminating this average spot of forest floor, and at the end of the year the remainder is weighed again. Because of decomposition the weight is now less than F_e; the portion k_2F_e has been lost. To maintain the forest floor in steady-state condition the loss has to be made up by decay residues (α) from the annual litter fall (A). On the one hand,

$$\alpha = k_2F_e$$

and on the other

$$\alpha = A - k_1A$$

where k_1 and k_2 are the decomposition constants of the litter fall and the forest floor. Hence,

$$A - k_1A = k_2F_e, \text{ or } A = k_2F_e + k_1A$$

While we cannot readily determine k_1 and k_2, we may relate the combined loss $k_2F_e + k_1A$ to the sum of $F_e + A$ as

$$k = \frac{k_2F_e + k_1A}{F_e + A} = \frac{A}{F_e + A} \qquad (1)$$

Some investigators prefer to write as follows:

$$A - k_1A = k_2F_e, \text{ or } A(1 - k_1) = k_2F_e$$

$$A = \frac{k_2}{1 - k_1} F_e = k_3F_e, \text{ whence } k_3 = \frac{A}{F_e}. \qquad (2)$$

In this case, however, k_3 cannot be identified with rate of loss of forest floor materials because k_3 is a ratio of two separate rates, and in forests where $A > F_e$, as in hot climates, it exceeds 100 percent.

Decomposition rates computed with equation (1) are given in Table 2. They are vastly greater in the equatorial forests than in the temperate-cold forests. In the latter, oak leaf material decomposes more than twice as rapidly as pine needles.

TABLE 2-THE VALUE OF SOME PASTURE FORAGES FOR FATTENING STEERS

Forage and Number of Observations	Intake of Digestible Protein	Intake of Digestible Organic Matter
	lbs/day	lbs/day
Ky. 31 fescue	1.24	7.1
Bluegrass	1.50	9.0
Orchard grass	1.82	9.6
Alfalfa	2.84	11.9
Ladino clover	4.44	14.8
Lincoln bromegrass	2.86	18.8

Since fattening steers of this size requires approximately 1.4 pounds of digestible protein per day, all forages with the exception of Ky. 31 fescue were satisfactory in meeting the protein requirement. However, under the conditions imposed in these trials, only alfalfa, Ladino clover and Lincoln bromegrass met the daily requirements of approximately 12 to 14 pounds of digestible organic matter needed for satisfactory gain.

This climatic trend of decomposition rates has been verified by placing into the ground open cans containing alfalfa shreds. The annual losses were as follows (29):

Calima, Colombia, at sea level	99 percent
Shaver Lake, California, 5000 feet	70 percent
Mt. Givens, California, 9800 feet	43 percent

The 99 percent value at tropical Calima, though high, underestimates the real rate of decomposition, for the major loss, 80-90 percent, took place during the first three months.

The fate of nitrogen released from the decomposing forest floor was ascertained at Hoberg's pine forest in Lake County, California (23). Eighty tin cans, open at both ends, and containing soil of uniform and known composition, were placed into the soil in vertical position. Forest floor material was placed over the cans which, in the ensuing year, gained 11.1 lbs. of nitrogen per acre. At the identical site the annual litter fall contained 12.1 lbs. of nitrogen per acre. That is to say, the quantity of nitrogen which the decomposing forest floor delivered to the mineral soil was equal to the quantity it received in the litter fall.

The quantitative study of entire ecosytems is still in its infancy, but it holds a promising future. Dynamics and energy flow per unit area of land, including the gains and losses of carbon and nitrogen, will become as fundamental in conceptual importance to soil science as are free energy and entropy in chemistry.

STATE FACTOR ANALYSIS

The amout and nature of humus in the soil, characterized here by the total nitrogen content (N) and the organic carbon content (C) of the soil, is conditioned by the soil forming factors, or state factors, as follows (15)*:

$$N,C = f(cl, o, r, p, t, \ldots)$$

The symbols have the following meaning: cl = environmental climate, o = biotic factor, r = topography, p = parent material, t = time. With the exception of time, all factors are essentially groups of factors.

Over the earth as a whole the state factors occur in great variety of combinations, and, accordingly, the humus content of the soil also varies widely. Records of thousands of analyses show that for well-drained soils the total nitrogen content, to a depth of eight inches, ranges from less than 0.010 percent to over 2.000 percent, a more than two-hundred fold span.

In order to assess the climatic influences on the distribution of humus we must either control the remaining state factors by keeping them "constant", or make adjustments to their potency. The following information proves helpful in this respect.

Time Factor

The study of time sequences or chronosequences on the mudflows of Mt. Shasta, California, (6), and on the sand dunes of Lake Michigan (28), suggest that the accumulation of organic matter in young soils is rapid during the first decades, slows down subsequently, and approaches steady-state condition (Fig. 1) in about 1000 years. This is a short span considering that redwood trees *(Sequoia sempervirens)* reach ages of 2000-3000 years and over. Evidently, in forests of long

*Only recently has Dokuchaev's soil genesis equation become available in America (7):

$$\pi = (K, O, \gamma)B$$

where π = soil, K = climate ("The most important soil former"), O = organisms, γ = geologic substratum, and B = age of soil. Dokuchaev's defiinitions of the variables are too vague to permit a solution, and he never established a function. But he deserves lasting credit as the author of the first general equation.

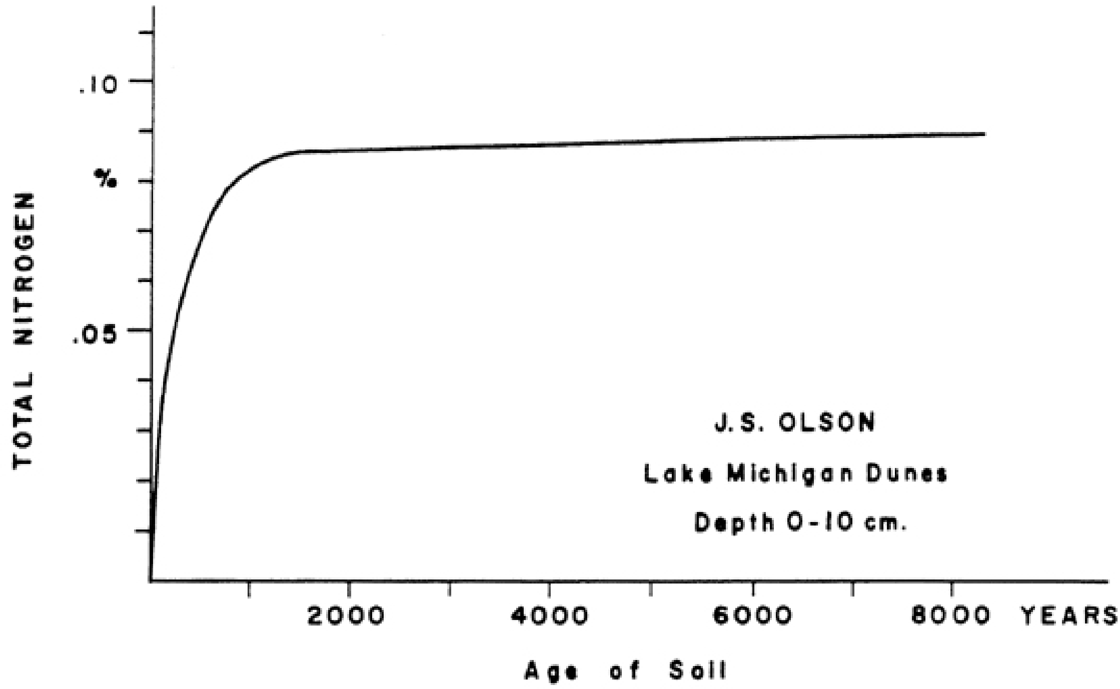


Fig. 1—Build-up of soil nitrogen in relation to age of soil. Nitrogen accumulation is rapid during the first 1000 years; later it approaches steady-state conditions. J. S. Olson (28).

standing organic matter is readily stabilized, dN/dt, which is the slope, approaches zero, and the time factor may be "neglected", as it has become ineffective. The curves suggest that we need not be overly concerned about the role of past climates upon the organic matter content of the soil, since it readily readjusts itself to new climates.

Soils taken into cultivation adjust themselves to new "environments" even more rapidly. From early Missouri work (14, 15) and from later contributions from the central portion of North America (8), steady states in cultivated soils are approached within a century or two.

Parent Material Factor

Barring extremes, such as quartz sand on one hand, and limestone rock and phosphate-rich (35) deposits on the other, the chemical and minerological composition of the parent material is mainly effective through its control of *soil texture.* In the Sierra Nevada of the Pacific Coast, soils derived from basic igneous rocks (e.g. basalts) are higher in nitrogen and organic carbon than adjacent soils derived from acid igneous rocks (e.g. granite), in the proportion of 1.83:1. Whereas the basalt soils are predominately clay loams, the granite soils are mainly sandy loams, and if we compensate for texture differences by comparing loams only, the two groups of soils have nearly identical nitrogen contents (10).

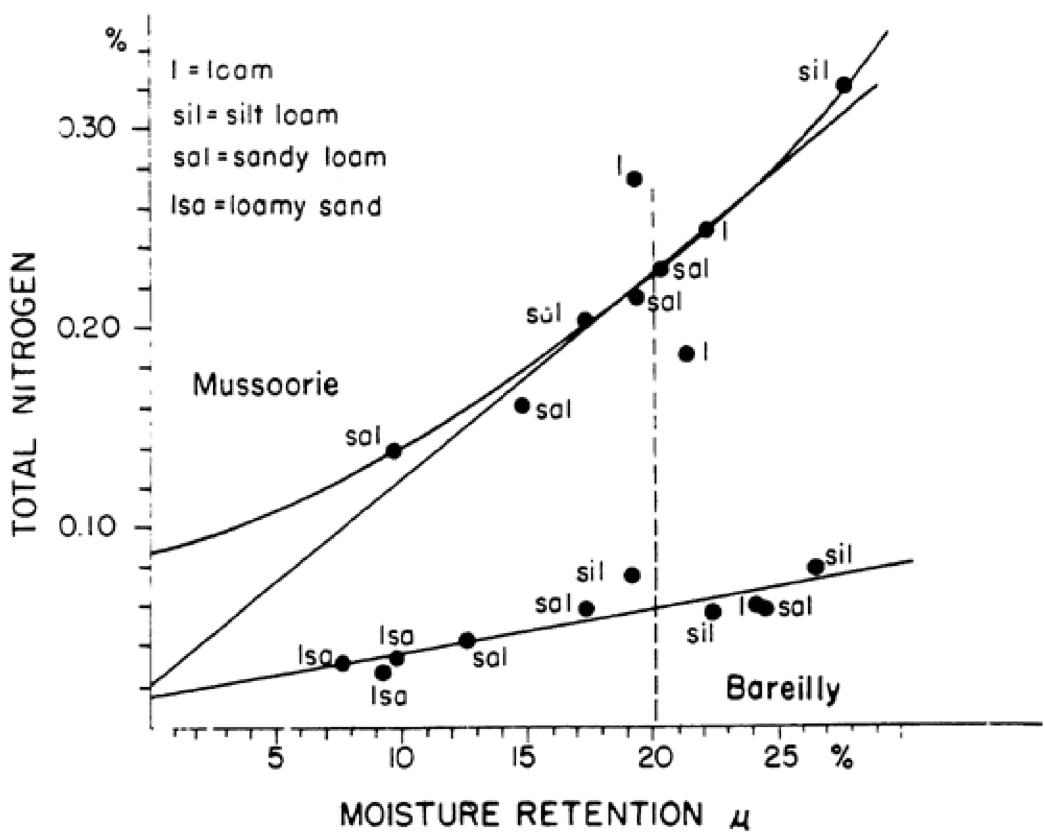
In the work done at Missouri with soils from the central and eastern United States, the texture effect was controlled by restricting soil sampling to loams and silt loams. But in other areas, as in California and in India, where loams and silt loams are few and far between, adjustments to loam were made with the aid of moisture retention M. R., either the moisture equivalent or its relative, the "one-third-atmosphere percentage". The procedure is briefly outlined in the ensuing paragraphs (21).

Moisture retention of any soil is an integral of the partial moisture retentions of the mineral soil (μ) and of the organic fraction (ω). The latter may be determined by correlation analysis. In California ω was found to be 232 percent for sandy loams, and 243 percent for loams. In Indian soils ω varied from 138-227 percent, the average being 175 percent, that is, 175 g. H_2O are associated with 100 g. of oven-dry organic matter, the latter defined as C x 1.724.

Texture adjustment to loam is accomplished in two steps. First, the organic matter percentage of a given soil is multiplied by ω, and the product is subtracted from the measured M. R. value, the resulting difference being μ. Second, the nitrogen contents of climatically related soils are plotted against their μ-values, as illustrated in Fig. 2 for soils from the hot Indo-Gangetic plains at Bareilly, and from humid, cool Mussoorie in the Western Himalaya ranges.

The curves demonstrate how nitrogen varies with the texture of the mineral soil in two different climates. Selecting arbitrarily the value μ = 20 percent as the moisture retention of an average loam free of organic matter, the nitrogen

Fig. 2—Method used to adjust the nitrogen content of soils of variable texture to that of a loam having a moisture retention of 20 percent. Indian soils from Mussoorie and from Bareilly.



and carbon contents of sands, sandy loams, clay loams, etc., may be readily adjusted to μ = 20 percent by displacing them (the "points" in Fig. 2) parallel the regression line until they come to rest on the vertical, dashed line.

In Fig. 2 the ten Bareilly soils, which range from loamy sands to loams and fine silt loams, have a mean nitrogen content—adjusted to μ = 20 percent, which is designated as N_{20}—of 0.057 ± 0.0028 percent. For nine Mussoorie soils, N_{20} = 0.233 ± 0.009 percent.

Topography Factor

On loess in Iowa, Aandahl (1) showed how total nitrogen varies with slope and surface configurations. Exposure also is important, as demonstrated by Harradine (9) who found north slopes richer in soil organic matter than south slopes. To "control" exposure and slope, the author and his collaborators confine all sampling to slopes facing southeast, and in mountain areas to gradients not exceeding 30 percent. Soils having water tables near the surface are placed into a separate group.

Biotic Factor

A detailed analysis of the concept of the biotic factor has been published recently (18), and it need not be repeated here. Suffice it to say that the biotic factor of a site or region is defined as the pool of species available to the site or region, and not as the vegetative growth observed. The latter is itself governed by the state factors.

Quite generally speaking, spacial variability of soil organic matter is much greater under native vegetation than in cultivated fields. In the Putnam prairie soil the variability of nitrogen and carbon, expressed as the standard error of the mean, is twice as high as in the adjacent corn fields (14, 15).

Since in young ecosystems the initial germule dominates the vegetation pattern, areal variability of organic matter contents of the soil may be extreme. When steady-state is reached, organic matter becomes more equalized, especially in the humid region, but in the drier, open forests distinct, horizontal nitrogen gradients remain discernible, as indicated in Fig. 3, taken from the work of Harradine (9). Our technique is standardized to the extent that in open forests samples are collected six feet from a tree trunk, in a southeast direction.

Climatic Factor

There are valid arguments as to where climate should be measured; inside the soil, on its surface, under the trees, or in the open? In our work we employ the regional climate, that is, the climate *outside* the ecosystem. The climate inside the ecosystem, or inside the soil, is treated as a dependent variable which is itself conditioned by the state factors.

Mean annual precipitation (P) and mean annual temperature (T) are used as an arbitrary reference grid. Seasonal effects on soil properties may be evaluated

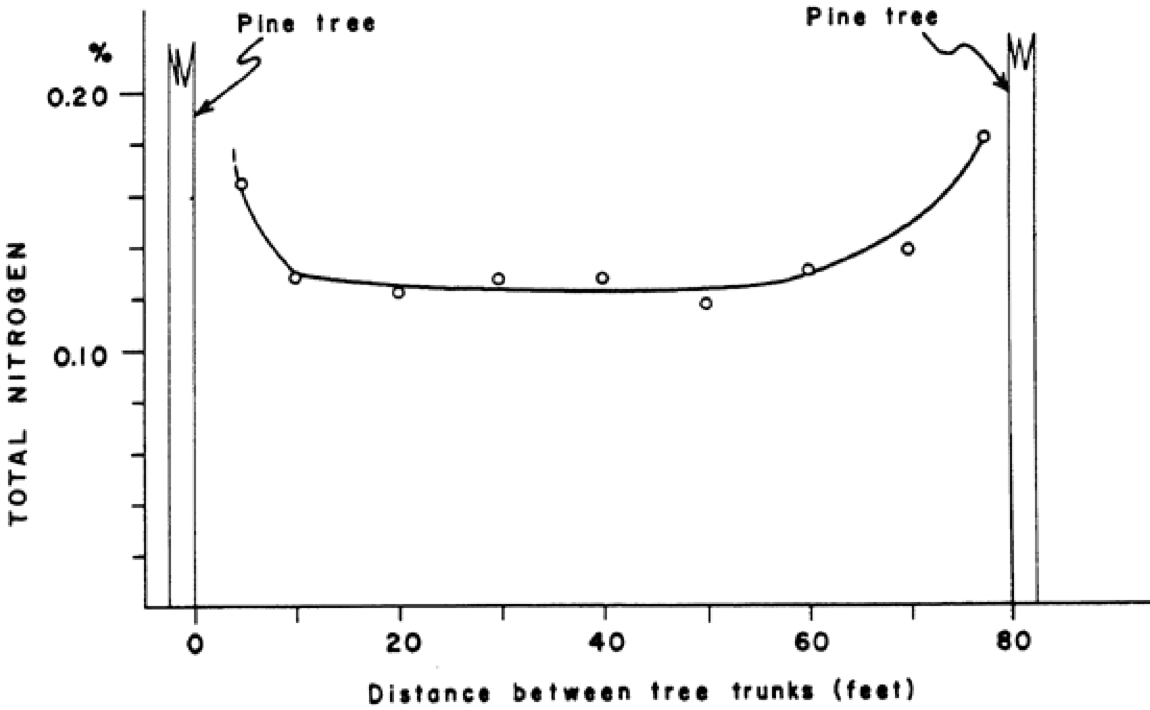


Fig. 3—Horizontal gradient of soil nitrogen (0-8 inches, mineral soil) in open pine forest *(Pinus ponderosa)* **in California, after Harradine (9).**

by comparing sites having equal P and T coordinates, and, of course, similarity in other state factors.

To illustrate, the Indian stations Lumding and Belgaum, though 1,300 miles apart, have equal mean annual P and T coordinates:

	T (°F)	P (inches)	Thornthwaite index
Belgaum	74.4	50.9	65.9
Lumding	74.7	51.3	16.3

In contrast, the seasonal distributions of T and P are markedly divergent, which is reflected in the enormous, four-fold spread of Thornthwaite's index (precipitation minus evapotranspiration).

In both locations, forest soils on basic igneous rocks are clay loams, and they have similar reactions, pH 5.6-6.8 at Belgaum, and pH 5.3-6.5 at Lumding. There is little difference in nitrogen content, $N_{20} = 0.208 \pm 0.0177$ at Belgaum for five samples, and $N_{20} = 0.171 \pm 0.0105$ at Lumding (7 samples). But, in the former place organic carbon is significantly higher ($C_{20} = 3.05 \pm 0.308$ percent) than in the latter ($C_{20} = 1.59 \pm 0.070$ percent). Evidently, not all soil properties respond in equal manner to variations in seasonal patterns.

ORGANIC MATTER—CLIMATE FUNCTIONS

Over twenty climatic nitrogen and carbon functions have been obtained in the Americas. Eight functions from the United States east of the Rocky Moun-

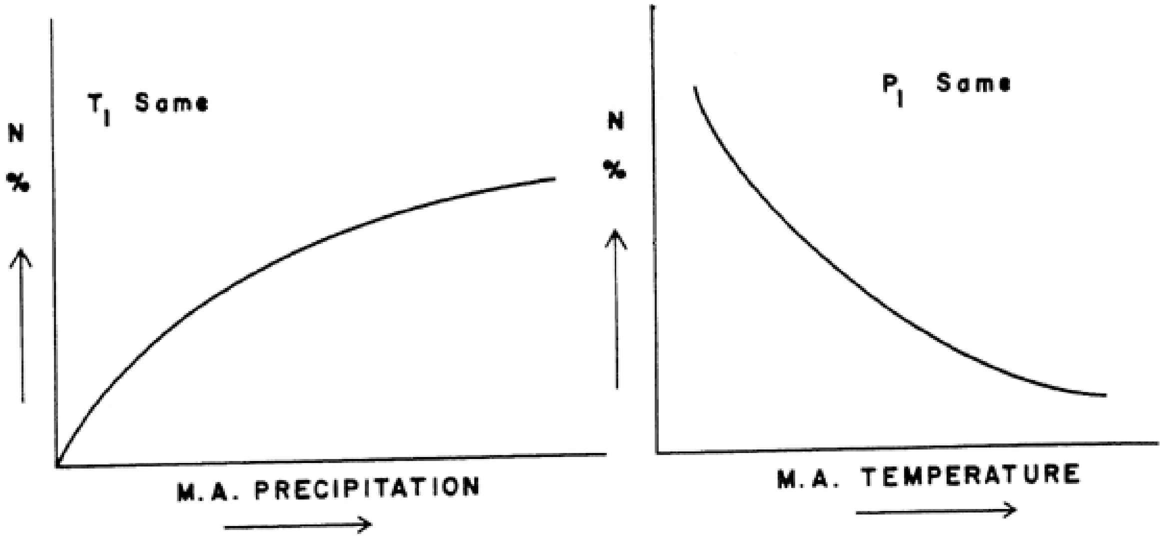


Fig. 4—Schematic graph (left) of *nitrogen-precipitation (P) function*, all sites having the same mean annual temperatures T; and, (right) *nitrogen-temperature (T) function* with all sites having the same mean annual precipitation P. North and South America.

tains were published in the thirties in Soil Science (12), and in Missouri Research Bul. 152, long out of print. Eight from California (9, 10, 22) have been published in part only. Four functions from Colombia, S. A., appeared in Soil Science in the early fifties (17).

In all instances, soil nitrogen and organic carbon increase as mean annual temperature decreases, mainly in exponential fashion (Fig. 4). Rising precipitation augmets the soil's content in organic matter, more markedly at low than at high precipitations, in the fashion of the law of diminishing returns. Above 40 inches of mean annual precipitation, the effectiveness of any additional inch is very small.

Functions recently obtained in India (21) will now be presented and compared with their American counterparts.

N,C-Moisture Functions in India

The 81° F (27° C)-Isotherm. Along the entire West Coast of India mean annual temperature is uniform, 80.3 to 81.3° F. Mean annual precipitation (P), on the other hand, varies widely, from 22 and 24 inches at Bhavnagar and Cape Comorin to 186 inches at Karkal. The trend of (Kjeldahl) nitrogen (0-8 inches depth) of cultivated soils, exclusive of paddy fields, is depicted in Fig. 5. The regression line

$$N_{20} = 0.041 + 0.00041P$$

has a correlation coefficient of 0.75. Most of these soils have been under cultivation for centuries, and it is surprising that they still exhibit a rainfall dependency.

The 75° F (24° C)-Isotherm. In the temperature interval 73-78° F (23-26° C) mean annual precipitation ranges from 10 inches (Sri Ganganagar near West Pakistan) to 361 inches at Agumbe on the Western Ghats. The areas

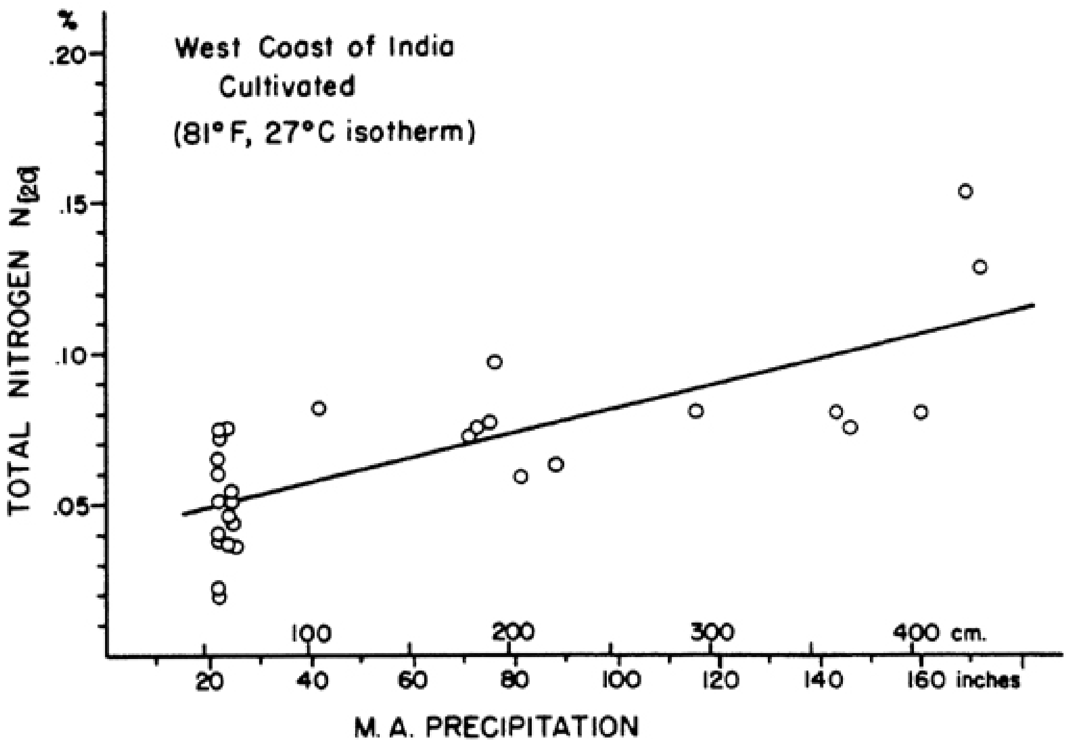


Fig. 5—Dependency of soil nitrogen percentage upon mean annual precipitation (West Coast of India, cultivated, nonpaddy, loam soils, 0-8 in. depth).

sampled include the Indo-Gangetic plains between Ambala and Bareilly, the Dehra Dun slopes, the rolling country of Jaipur, the Tista-Brahmaputra plains and adjacent Assam Hills (mainly Gauhati and Lumding), the Mysore Plateau (including Bangalore), and the Western Ghats.

In Fig. 6 the means of organic carbon contents (by dry combustion) are plotted against precipitation. The sizes of the dots reflect the number of samples, and the length of the vertical bar denotes the standard error of the mean (mean error). As no territory below 10 inches of rainfall was accessible, two means from the deserts of upper Egypt (unpublished data) and southern California (10) were included to mark the start of the function.

The upper curve illustrates the trend of soil organic matter under native vegetation which is represented by barrens in the desert, brush and shrubs below 30 inches of rainfall, and open and dense forests above it. The curve has a logarithmic shape, familiar from the earlier U.S.A. work.

The function for cultivated soils, exclusive of paddy, is discontinuous at 50 inches of precipitation, and it merits special consideration. The pronounced break is properly attributed to the influence of man, since the virgin curve does not display it. The left-hand, depressed, portion of the curve comprises areas of great antiquity, the Indo-Gangetic Divide, the Jaipur Hills, and the Mysore Uplands. Here soil management practices are exhaustive, and have been so for a long time, for the scarcity of wood as a result of deforestation compels people to use cowdung as fuel. Also, the pressure for food crops does not permit green

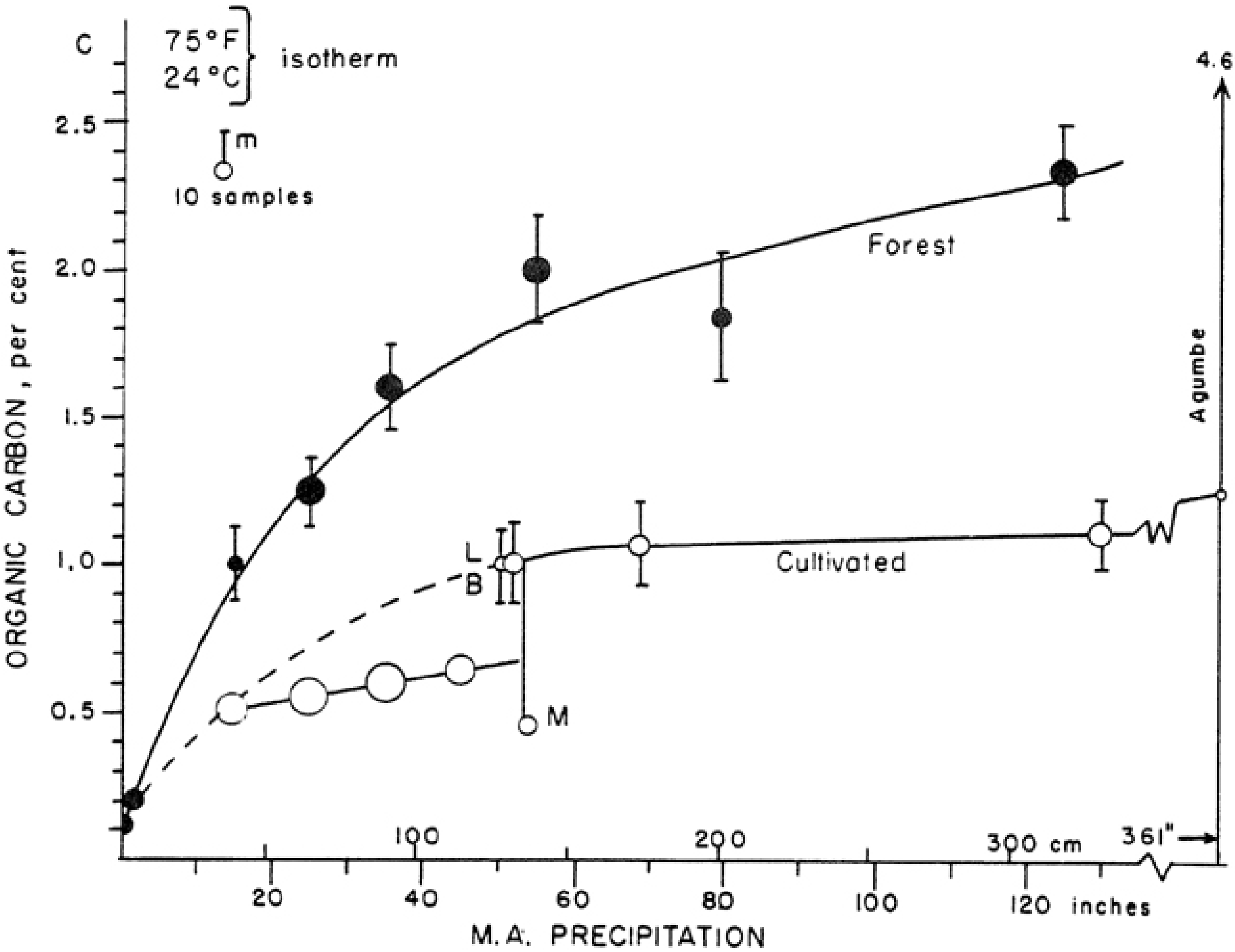


Fig. 6—Dependency of organic carbon in loam soils upon mean annual precipitation. Forests and cultivated fields. Size of circle is proportional to number of samples; length of vertical bar denotes standard error of mean.

manuring. The right-hand portion of the curve reflects conditions in eastern India, specifically Bengal and Assam, where forests and thickets are plentiful, where people can afford to put cow manure into the fields and where they green-manure with forest litter. This historic-economic explanation, a conjecture, could be scrutinized by extending the lower curve into the higher rainfall belt of the lower Gangetic Valley. The discontinuity should persist.

For nitrogen the rainfall functions are very similar, except that in the old, cultivated regions nitrogen-dependency on rainfall has been obliterated; on the left-side of the discontinuity the curve of cultivated soils is horizontal.

N,C-Temperature Functions in India

Humid Region. Impressive temperature effects can be recognized in the humid region (51-88 inches of mean annual precipitation), which comprises portions of the West Coast, Assam, and the Lesser Himalaya ranges, specifically Kalimpong, Dehra Dun, Mussoorie, and Simla.

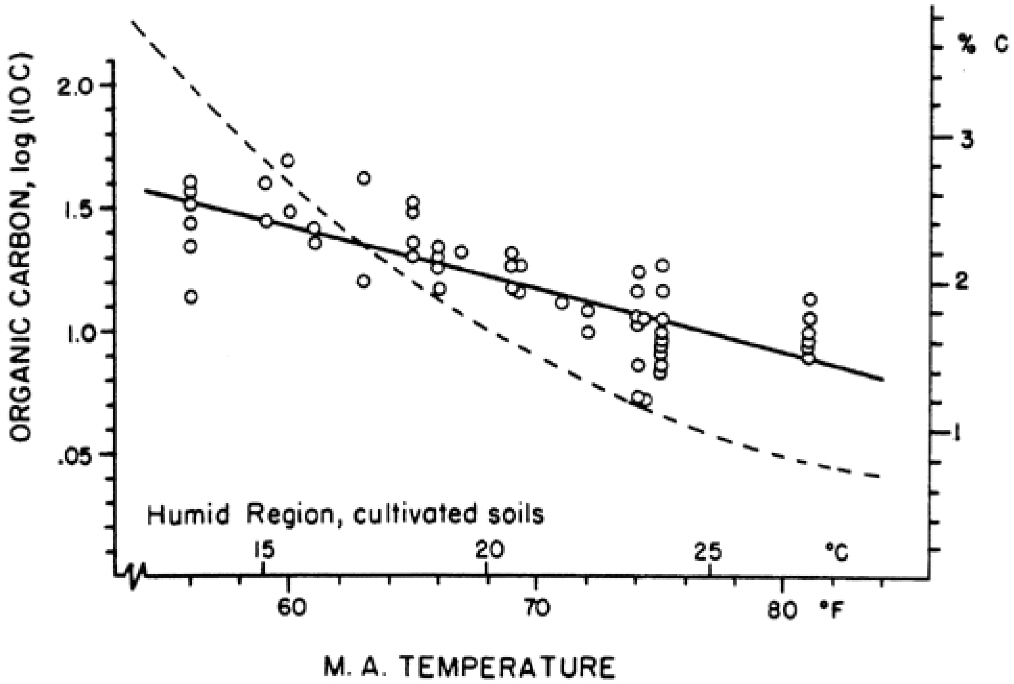


Fig. 7—Organic carbon contents of cultivated soils (0-8 in. depth) as influenced by mean annual temperatures. Solid line: log(10C), dashed line: percent C. Humid region. Each circle represents an individual soil sample.

In Fig. 7 are plotted the carbon contents—precisely, log (10C)—of 55 soil samples from cultivated fields. The linear regression equation has a correlation coefficient of -0.79, and it reads as

$$\log (10C) = 2.9093 - 0.0249\ T$$

where T denotes mean annual temperature in degrees Fahrenheit. The number 0.0249, which is the temperature coefficient, is designated as k_2. The absolute function, given by the dashed curve, is exponential, which agrees with organic matter-temperature curves in the United States.

The corresponding nitrogen curve for the cultivated soils has the form

$$\log (100N) = 2.7232 - 0.0236T \qquad (r = -0.77)$$

Substracting the nitrogen curve from the carbon curve furnishes the trend of the C/N ratio with temperature. For cultivated soils

$$\log \left(\frac{10C}{100N}\right) = 0.1861 - 0.0013T$$

At T = 54° F the average C/N ratio is 13.1, at T = 84° F it is 11.9. Thus, the C/N ratio becomes narrower as temperature increases, which is in accord with observations in the United States.

Perhumid Region. The very high precipitation range of 100-150 inches characterizes the Bengal Himalayas (Darjeeling and Tista Canyon), the Tista-Brahmaputra plains, and the Malabar Coast. The nitrogen curves for for-

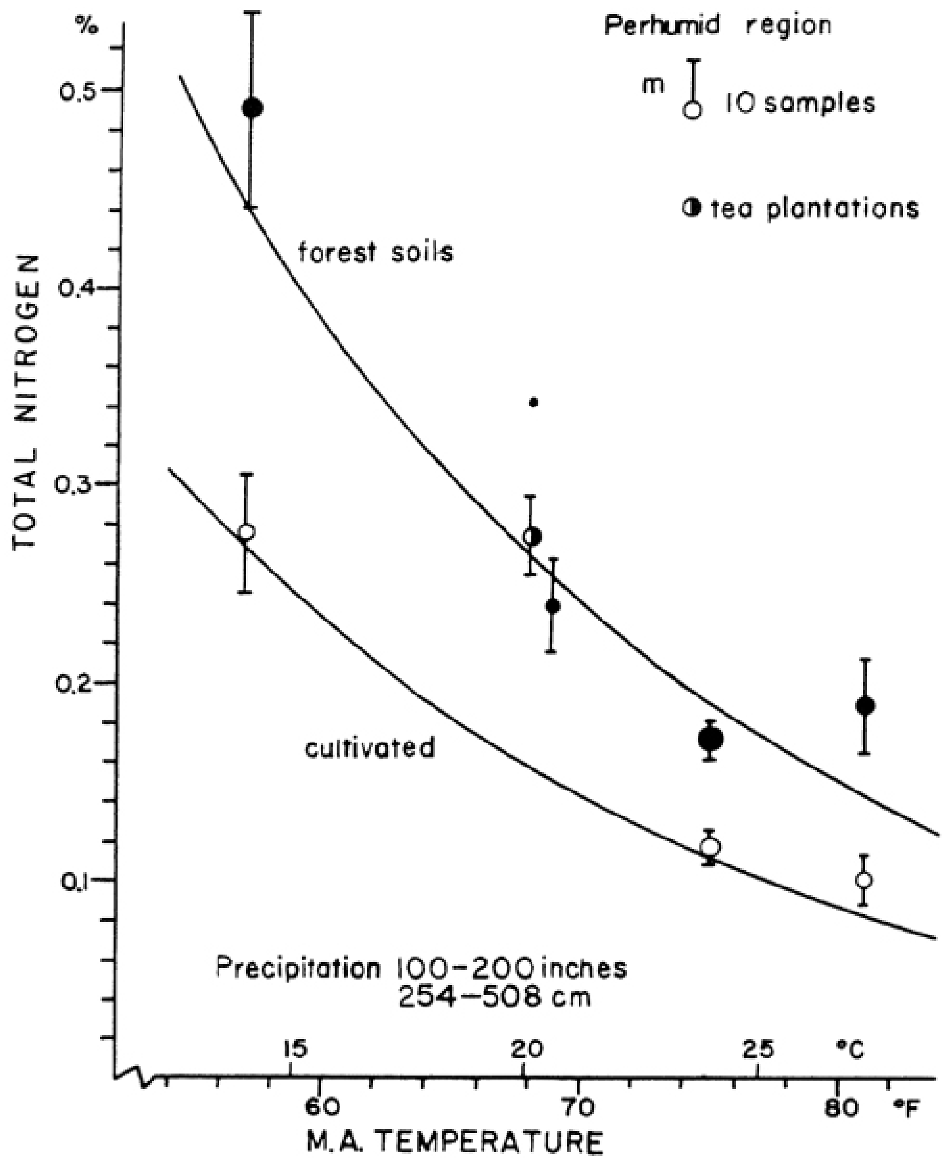


Fig. 8—Effect of mean annual temperature on nitrogen content of forested and cultivated soils, 0-8 in. depth. Perhumid region.

ests (48 samples) and cultivated lands (26 samples) are plotted in Fig. 8. Relating log(100N) to temperature, we get for

cultivated soils: $\log(100N) = 2.6165 - 0.0209T \qquad (r = -.87)$

and for

forest soils: $\log(100N) = 2.8144 - 0.0206T \qquad (r = -0.79)$

The carbon curves are very similar, in fact all four functions have nearly identical temperature coefficients, k_2, the mean being 0.0209.

Detailed, statistical computations prove that each one of the N- and C-temperature functions is well established. Thus, temperature exerts a powerful influence upon the humus content of Indian soils. Hot climates keep nitrogen and carbon contents at relatively low levels.

COMPARISON OF INDIAN SOILS WITH NORTH AND SOUTH AMERICAN SOILS

Indian soil scientists compare the low nitrogen contents of Indian plains and plateaus with the high values observed in Europe and in North America, and they justly lament the large and unfavorable discrepancy. In order to assess realistically the causes of the diversities we must compare sites that have similar state factors.

Focusing attention on the climatic variables, the *T-P fields* in Fig. 9 are instructive. In this system of temperature and precipitation coordinates, any meteorological station is represented by a point, the ordinate being its mean annual temperature, the abscissa its mean annual precipitation.

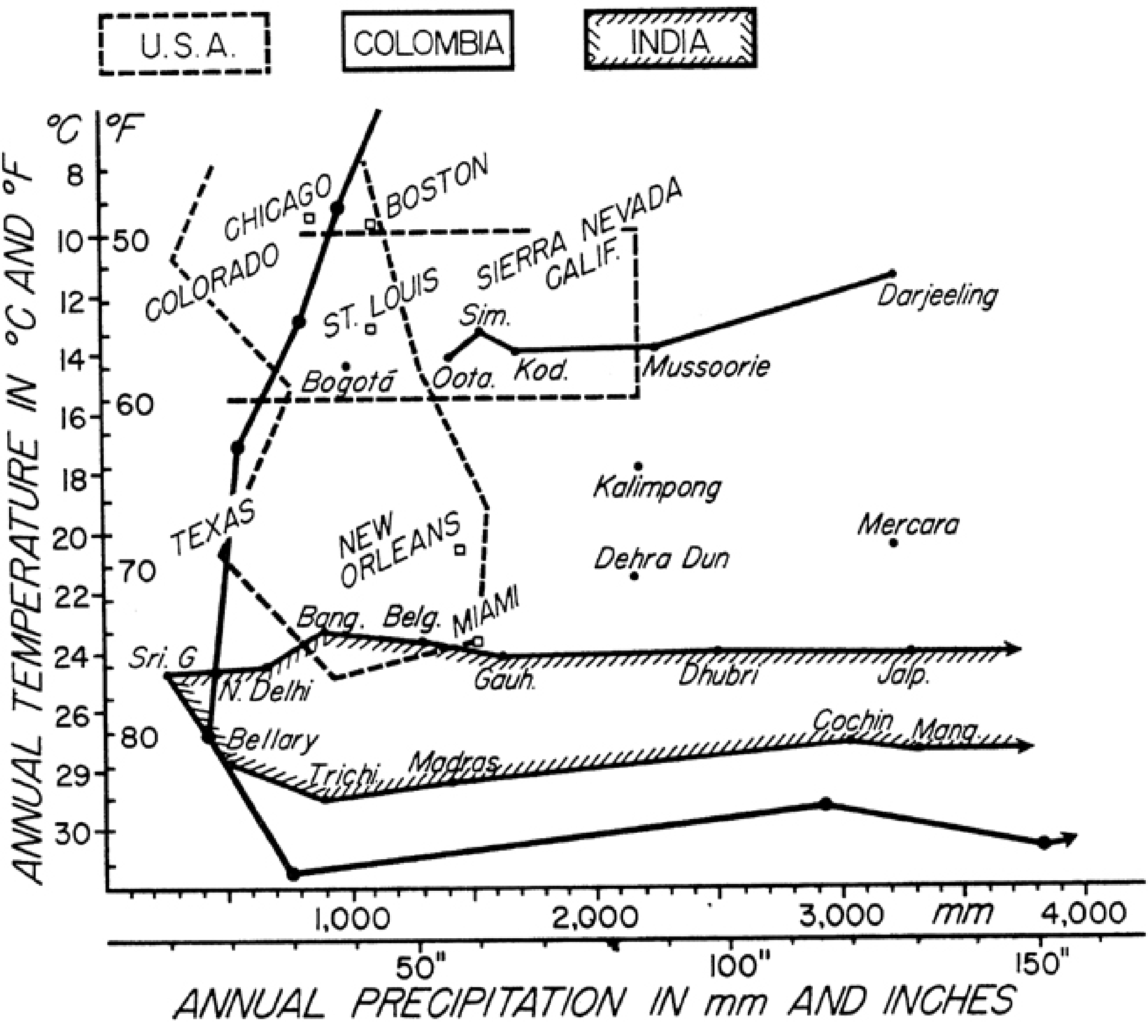


Fig. 9—Climatic fields of U. S. A., Colombia, and India, based on mean annual temperatures and precipitations (T-P-fields).

The crosshatched field embraces the lower elevations (<3000 ft.) of the *Indian* subcontinent, which is the area where most of the people live. Mountain stations in the Himalayas and in southern India also are shown. They lie in a more or less horizontal, narrow climatic strip.

The heavy lines denote the arid and tropic boundaries of the extensive *Colombia field* in equatorial America. It is so large that it includes all of the Indian sites from which soil samples were obtained.

The chosen *United States field* has dashed lines as contours. It extends from the Rocky Mountains eastwards to the Atlantic Coast, and southward from a line connecting Chicago and Boston. Its shape is narrow and its climatic area small compared with the Colombian and Indian fields. A section of the Sierra Nevada in California also is shown.

These T-P fields are convenient for locating sites and functions that permit valid comparisons.

Halving Temperatures

Quite generally, soil nitrogen and organic carbon decrease as temperature increases (Fig. 4), but the rates of decline exhibit striking, regional peculiarities.

A convenient measure of rates is provided by the temperature span τ which is the span in mean annual temperature which halves or doubles the organic matter content of the soil. Whenever the N– and C– temperature dependencies follow the negative exponential equation

$$N, \text{ or } C = k_1 e^{-k_2 T}$$

as they often do, then τ is given by

$$\frac{\ln 2}{k_2} = \frac{0.693}{k_2} \quad ; \quad \frac{\log 2}{k_2 \log e} = \frac{0.301}{k'_2}$$

Since the California curves are an exception, their τ values were obtained by graphic means.

From the list of τ-values of 23 temperature functions (Table 3) it is seen that the South American Andes have the lowest values, 5.04° C, whereas California's Sierra Nevada has the highest, 14.6° C. Expressed in other words, temperature changes are most effective in Colombia and least in California. India and the portion of U. S. A. east of the Rocky Mountains have nearly identical τ-means. They lie between the two extremes.

In mountains we may relate the τ-means to the change in annual temperature with elevation, which is 0.31° F/100 feet in the Himalayas and Andes, and 0.29° F/100 feet in the Sierra Nevada. To observe a doubling of soil organic matter contents, we would have to climb—along isohyets—the following elevation spans:

Colombia	:	2920 feet
India	:	4440 feet
California	:	9060 feet

TABLE 3-HALVING TEMPERATURES, $\mathfrak{T}$
(Span in mean annual temperature which halves or doubles the N and C content of the soil)

Region, and Nature of Function		Halving Temp. °C.	°F.
I. Colombia, S.A. (forests, pastures, and cultiv. soils)			
Rainfall Zone; 35-59 inches,	N	4.9	8.8
Rainfall Zone; 59-79 inches,	N	5.3	9.5
Humidity Zone; 120-200 N.S.Q.,	N	5.0	9.0
Humidity Zone; 201-400 N.S.Q.,	N	5.0	9.0
Humidity Zone; 401-600 N.S.Q.,	N	5.0	9.0
	Average	5.04	9.06
II. India			
Rainfall Zone; 51-88 inches, cultiv. soils,	N	7.1	12.8
Rainfall Zone; 51-88 inches, cultiv. soils,	C	6.7	12.1
Rainfall Zone; 100-150 inches, cultiv. soils,	N	8.0	14.4
Rainfall Zone; 100-150 inches, cultiv. soils,	C	7.7	13.9
Rainfall Zone; 100-150 inches, forested soils	N	8.1	14.6
Rainfall Zone; 100-150 inches, forested soils	C	8.1	14.6
	Average	7.62	13.73
III. United States of America			
Western Great Plains, grassland*, cultivated,	N	9.5	17.1
Eastern Great Plains, grassland*, cultivated,	N	7.3	13.1
Central, prairie* region, grassland*, cultivated,	N	6.9	12.4
Central, timbered*, terrace soils, cultivated	N	6.1	11.0
Central, timbered*, bottom soils, cultivated	N	5.7	10.2
Central, timbered*, uplands soils, cultivated	N	(7.8)	(14)
Atlantic Coast, timbered* upland soils cultivated	O.M.	6.7	12.1
	Average	7.15	12.8
California, Sierra Nevada, forested soils			
Rainfall Zone; 68-82 inches,	N	19.1	34.4
Rainfall Zone; 58-62 inches,	N	9.1	16.4
Rainfall Zone; 40-50 inches,	N	11.5	20.7
Rainfall Zone; 30-40 inches,	N	20.1	36.2
Rainfall Zone; 26-36 inches,	N	13.2	23.7
	Average	14.6	26.30

*The expressions "Grassland", "prairie", "timbered", indicate the kind of vegetation that existed prior to cultivation.

These figures vividly portray the regional individuality of nitrogen-temperature gradients.

Regional Comparison of N and C Levels in Forest Soils

Comparative data for virgin forest soils—virgin in the sense that they have never been deforested and cultivated—are given in Table 4. The sampling depth was, as usual, 0-8 inches (0-20 cm.) of mineral soil, the forest floor having been excluded. The mean annual temperatures are "temperate", 54-66° F. (12-19° C.), and the mean annual precipitations, 48-88 inches (120-224 cm.), are representative of humid climates.

Looking at the nitrogen means, we note that U.S.A. ranks lowest, Colombia highest, and that India stands between. Even as far north as Illinois (T = 49-57° F., P = 32-47 in.) the mean organic carbon content of 34 forested silt loam

TABLE 4-COMPARISON OF SOILS UNDER FOREST COVER
(Soils having similar parent materials, textures, slopes, and exposures. Sample depth 0-8 inches.
Mean Annual Values of Temperature (T) and Precipitation (P).

Region	Lat. North	Number of Samples	T °F.	P Inches	Total Nitrogen Per cent	C/N
U.S.A.						
Sierra Nevada, Calif. (10)	37-40	16	55-59	50-81	0.134±0.0046	16-20
Tennessee[1] (26)	36-37	17	58-62	48-51	0.132±0.013	-----
India						
Mussoorie[2], Simla[2]	26	15	56-63	85-88	0.271±0.022	14-18
Ootacamund, Kodaikanal	10	6	58-65	55-62	0.499±0.0513	15-18
Colombia[3] (19)	3-6	8	54-66	59-80	0.809±0.118	12.6

[1] On sedimentary rocks, other factors not specified.
[2] Abused forests on shallow, rocky ground.
[3] Includes a few pastures.

soils on loess and moraines is only 1.12 ± 0.071 percent (27), as compared with 4.12 ± 0.267 percent for Mussoorie-Simla, and 7.25 ± 0.822 percent for Ootacamund-Kodaikanal (Table 4).

The regional differences are enormous, and many of them are statistically highly significant. We must conclude that for similar constellations of soil forming factors, including T and P, the humus content of the soil displays wide regional differentiations which, in broad terms, appear to be associated with latitude. For the data at hand, the closer to the equator the sampling sites are located, the higher are the N and C contents, provided we compare locals having similar mean annual T and P coordinates. Geographically speaking, to secure these latitude comparisons we must collect samples at high elevations in equatorial regions and at low elevations in the northern regions.

Unpublished analyses of soils collected in 1955 in the Mau Mau mountains of equatorial East Africa appear to be in line with these findings, as are those of Birch and Friend (2).

Comparison of N and C Levels in Cultivated Soils

India and Latin America. Two broad climatic groups are available for comparison (Table 5.) The *humid region,* represented by two areas with spreads in precipitation from 40-64 inches (102-163 cm.) and 50-80 inches (127-203 cm.), and the *perhumid region,* with 100-150 inches (254-381 cm.) of mean annual rainfall. The latter is extensive enough to comprise two temperature belts. In all instances, without exception, the Latin American soils are much richer in soil organic matter than the Indian soils. This differential is most pronounced for the Costa Rican members. It is worthwhile to point out that the cultivated soils reflect the behavior of the forest soils.

India and U.S.A. The stations Dehra Dun-Rajpur and Kalimpong in the Himalaya foothills have the same mean annual temperatures (65-69° F., 18.3-20.5° C.) as parts of *Texas, Louisiana, and Mississippi;* but, precipitations are somewhat higher. Since, however, as shown in Fig. 10, in these southern states the nitrogen-rainfall function from 30-60 inches is a straight line parallel to the horizontal axis, it may be extended to the 86-94-inch zone which is characteristic of the Indian stations.

Along the Texas-Louisiana-Mississippi transect (3) the nitrogen content of 60 cultivated loam soils, formerly under deciduous forest cover, is 0.046 ± 0.0013 percent. The corresponding mean of loams and sandy loams of the 14 Indian soils, also originally forested, is 0.170 ± 0.0114 percent, a value which is three times higher. Length of cultivation may be considered equal in both regions, 150 years and less.

Another approach to comparative humus survey is provided by extending the organic matter (O.M. = %C x 1.724)—temperature function of *Atlantic Coast* soils to the temperatures prevailing in the plains of India. This function (12, 13) has the form

$$\text{O.M.} = 6.50e^{-0.0104T} \qquad (r = -0.87)$$

TABLE 5-COMPARISON OF CULTIVATED SOILS FROM INDIA AND LATIN AMERICA

(Similar mean annual temperatures (T) and precipitations (P); n represents number of samples.

Location	n	T °F	P Inches	Total nitrogen per cent	C/N
Humid Region					
Rainfall Group I					
Colombia, Cauca Valley	9	73-75	40-60	0.278±0.055	11.2
India, Indo-Gang. Plains	19	74-76	41-50	0.054±0.0027	10.8
India, Indo-Gang. Plains	6	73	51-60	0.047±0.0013	10.3
India, Belgaum	8	74	51	0.069±0.0106	15.5
India, Asam	9	75-76	51-64	0.111±0.0080	9.4
Rainfall Group II					
Costa Rica, Turrialba	12	73	74	0.36 ±0.04	11.9
Colombia*	9	71-75	50-80	0.307±0.0719	10.4
India, Dehra Dun-Rajpur	8	68-73	86	0.129±0.0074	11.5
Perhumid Region					
Temperature Group I					
Costa Rica, Cairo	3	75-76	148	0.26, 0.32, 0.35	10.3
India, Tista plains	14	75	100-150	0.119±0.0070	10.3
Temperature Group II					
Costa Rica, Juan Vinas	6	65	141	0.99 ±0.06	15.2
India, from Fig. 8	--	65	100-150	0.181±0.02	12.7
India, Tista Canyon, Tea plant.	8	67-70	118-124	0.268+0.021	11.9

*mostly pasture

Its lower segment, from Virginia to Georgia (68° F.), is shown in Fig. 11. Extrapolation to subtropical temperatures is indicated by the dashed line. Since the Atlantic Coast states under consideration have a range of mean annual precipitation from 40-60 inches, the Indian relatives are found in the Indo-Gangetic Divide and on the Coromandel Coast (Madras Hills and Cauvery Delta). For the former the means of organic matter are as follows:

Indo-Gang. Divide
- 73° F., 51-60 in., 6 samples, $[O.M.]_{20} = 0.79 \pm 0.34$ percent
- 75° F., 41-50 in., 19 samples, $[O.M.]_{20} = 1.12 \pm 0.076$ percent

Projecting 19 Atlantic Coast loams and sandy loams to 75° F., we obtain from Fig. 11: O.M. = 0.53 ± 0.076 percent. The difference between the Indian and American 75° F. groups is in favor of India, and is statistically significant at the one percent level.

For the Coromandel Coast the individual samples are shown as field crops (solid dots) and as paddy (crosses). Taking all 12 analyses together, their

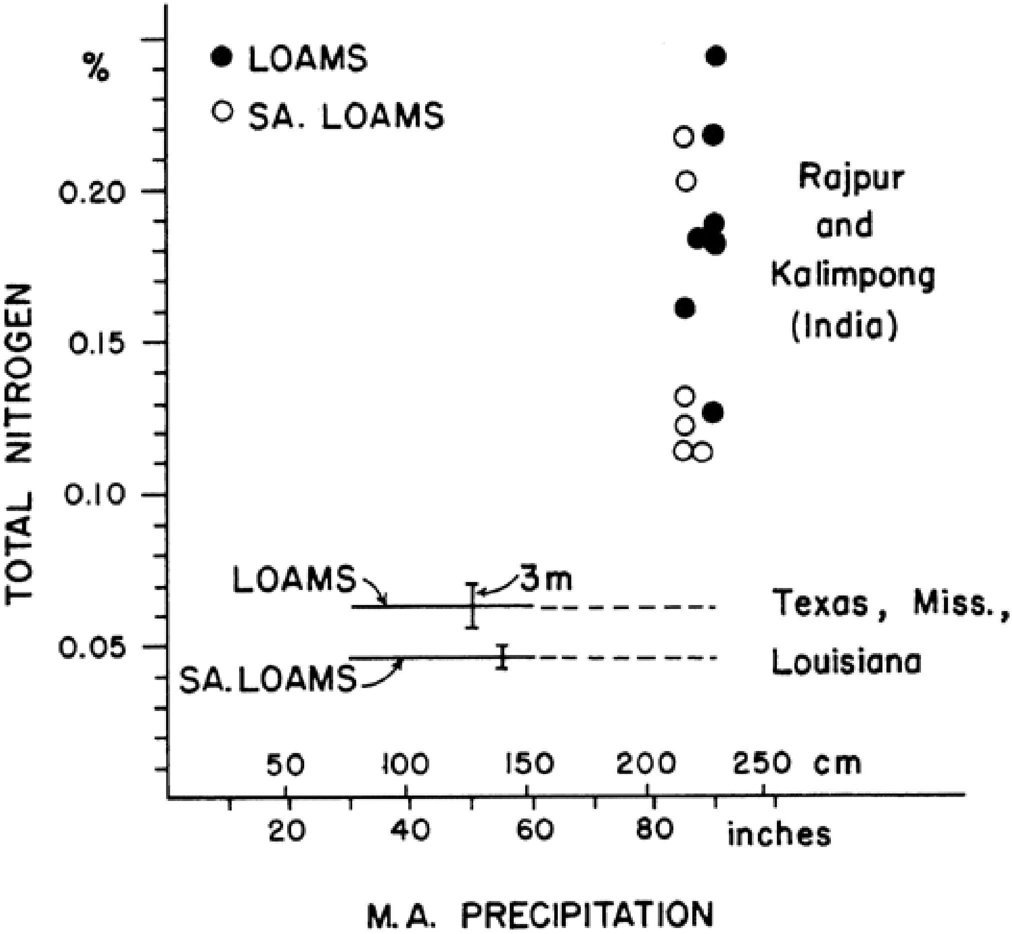


Fig. 10—Comparing areas of equal mean annual temperatures in northern India and in the southern United States (m = standard error of mean). Cultivated loams and silt loams, 0-8 in. depth.

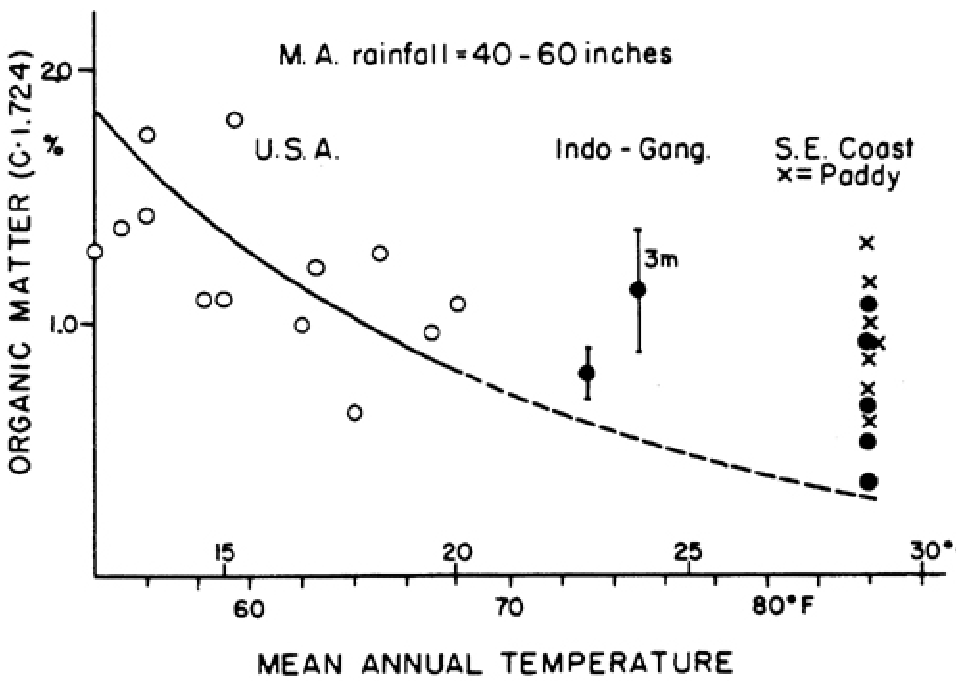


Fig. 11—Extrapolating the organic matter content of Atlantic Coast soils to climates in India.

$[O.M.]_{20}$ mean is 0.83 ± 0.080 percent. The corresponding value for the Atlantic Coast soils, extrapolated to 84° F, is only 0.31 ± 0.076 percent organic matter. Again the difference is highly significant. The superiority of the Indian soils is the more remarkable as they come from lands of great antiquity.

Unmistakably, Indian soils, virgin and cultivated, are richer in organic matter than North American soils, provided we compare sites having similar mean annual temperatures and precipitations.

EXAMINATION OF GAINS OF ORGANIC MATTER IN TROPICAL SOILS

It is instructive to examine the entire profile inventory of nitrogen and carbon of equatorial and temperate soils, as is done in Table 6. On the average the Colombian soils contain nearly five times as much nitrogen and nearly three times as much carbon as the California soils. The Indian profile also is higher.

TABLE 6-NITROGEN AND ORGANIC CARBON CONTENTS OF COLOMBIAN AND CALIFORNIA FOREST PROFILES
(Forest floor plus mineral soil)

Locality	Depth of Profile in.	Nitrogen		Organic Carbon	
		g/m.^{2}	lbs./A.	g/m.^{2}	lbs./A.
Colombia					
Calima	30	2,502	----	36,681	---
Chinchina	50	3,521	----	45,196	---
Average		3,012	26,867	40,939	365,176
California					
Shaver-oak	50	633	----	11,606	---
Shaver-pine	50	650	----	17,317	---
Average		641	5,718	14,461	128,992
India					
Siliguri (Bengal)	40	1,000	8,920	-----	---

Helpful insight is provided by considering these profiles as steady-state soils. The annual net gains (α) of nitrogen are then equal to the annual losses, that is

$$\alpha = kN$$

where N is the total nitrogen content of the entire profile, including the forest floor, and k is the loss or decomposition constant, that is, the fraction of nitrogen lost. Specifically,

for Colombia: $\alpha_e = k_e N_e$, and

for California: $\alpha_t = k_t N_t$

Division and inserting the nitrogen means from Table 6 yields:

$$\frac{N_e}{N_t} = \frac{3,012}{641} = 4.7 = \frac{\alpha_e}{\alpha_t} \cdot \frac{k_t}{k_e}$$

Thus, to account for the 4.7-fold nitrogen superiority of the Colombian profiles, either their annual nitrogen gains α_e must be much larger than in California, or their loss constants, viz. decomposition constants, must be much smaller. As the latter seems unlikely—though no crucial experiments have as yet been conducted—the explanation, at this time, rests with high annual net gains of nitrogen in tropical forest ecosystems.

The nitrogen gains α_e must come from the nitrogen reservoir outside of the ecosystem, as ammonia and nitrates in precipitation, and as symbiotic and non-symbiotic nitrogen fixation by legumes, bacteria, and algae, and perhaps by other mechanisms. Much research remins to be done (16, 30, 34).

The same sort of reasoning may be applied to organic carbon:

$$Q = K(C + Q)$$

where C denotes the carbon content of the entire profile, and Q the soil's annual gross-gain of carbon, which is related to the annual photosynthesis of the ecosystem. For the profiles under consideration Q is to be identified with the annual litter fall A plus the annual root turn-over R. Though there is no way of measuring the annual root growth R at steady state, it is presumably proportional to A. Considering ecosystems containing diversified plant species one may set for the entire system:

$$Q = rA$$

where r is a proportionality factor.

Accordingly:

$$rA = K(C + rA)$$

For Colombia: $rA_e = K_e(C_e + rA_e)$

For California: $rA_t = K_t(C_t + rA_t)$

Dividing, and inserting the mean A values from Table 2 and the mean C values from Table 6:

$$\frac{A_e}{A_t} = \frac{K_e}{K_t} \cdot \frac{C_e + rA_e}{C_t + rA_t} \quad \text{or}$$

$$\frac{400}{119} = \frac{K_e}{K_t} \cdot \frac{40{,}939 + 400r}{14{,}461 + 119r}$$

We do not know r precisely. It must be greater than 1, it could be 2, but hardly 3. Substituting these values, we obtain:

for $r = 1$, $K_e/K_t = 1.186$

for $r = 2$, $K_e/K_t = 1.184$

for $r = 3$, $K_e/K_t = 1.182$

Clearly, the ratio of the loss constants K_e (Colombia) and K_t (California) is insensitive to r, which is really not surprising, since C is over a hundred times greater than A.

Most important, K_e is about the same as K_t, being only 18 percent greater; in other words, the higher carbon content of the equatorial soils as compared with those of the temperate region (California) is the result of higher photosynthesis, rather than slower decay of humus.

There is a decided parallelism in these profiles between build-up of nitrogen and build-up of carbon. The one may be the cause of the other, but which one is which, cannot be established from the data now available.

INFLUENCE OF MAN IN INDIA, COMPARED WITH U.S.A.

In the Missouri work (14, 15) cultivation effects on soil organic matter were assessed by dividing the nitrogen content of virgin soils into that of adjacent cultivated soils, multiplied by 100. The resulting cultivation index is here designated as N_x for nitrogen and C_x for organic carbon.

In the central part of the United States, after 30-60 years of cultivation, the indices vary from 73 percent down to 40 percent, more or less regardless of the initial nitrogen or carbon content of the soil (8).

For India, comparisons of cultivated fields with nearby forest areas are listed in Table 7. The figures are highly instructive.

TABLE 7-CULTIVATION INDICES N_X, C_X, IN INDIA

$$N_X \text{ or } C_X = \frac{\text{N or C of cultivated soil}}{\text{N or C of forest soil}} \times 100$$

Locality or Region	N_X per cent	C_X per cent
Humid West Coast, paddy	>100	>100
Bengal, Sukna, paddy	86.8	94.4
Bengal, Bellakoba, paddy	84.1	87.0
Dehra Dun-Rajpur	69.8	59.8
Tista plains	66.2	58.2
Mussoorie (Hill station)	63.4	73.8
Gauhati-Lumding (Assam)	63.1	65.9
Kodaikanal (Hill station)	61	66
Pathri (near Hardwar)	57.7	43.6
Darjeeling (Hill station)	56.0	50.4
Humid West Coast	50.6	54.2
Pur (near Meerut)	50.5	44.7
Coromandel Coast	40	32
Mysore Plateau	38.7	31.0
Mohan (near Roorkee)	30.7	22.8

Focusing attention on nitrogen values, N_x ranges from over 100 percent down to 31 percent. The group of high values, 84 to 100 percent, is found in paddies (rice fields) of high rainfall areas. The high figures attest to excellent systems of soil management as far as maintenance of soil organic matter is concerned. Farmers fertilize their fields with animal manure, forest litter, compost, and town refuse.

The group of low values, about 40 percent and less, are from non-paddy fields in regions of antiquity, such as the Coromandel Coast and Mysore Plateau. The lowest value, at Mohan, near Roorkee, occurs in sandy soils in which quite generally soil organic matter is readily oxidized and lost.

The majority of N_x indices lie between 50 and 70 percent, apparently regardless of length of cultivation. The mountain fields (Darjeeling, Kodaikanal, Mussoorie) are perhaps a century old, or even less, and have values from 56.0-63.4 percent. The older, historic regions northeast of Delhi, near Hardwar (Pur, Pathri) have indices of 50.5 and 57.7 percent.

This uniformity of N_x and C_x magnitudes suggests that a new steady-state condition has been reached in these cultivated soils, at 50-70 percent of the original forest state. Interestingly enough, this percentage range parallels that of the midwestern soils in U. S. A. which—though not yet stabilized—are expected to reach steady-state condition within a few decades.

ORIGIN OF INDIA'S AGRICULTURAL NITROGEN PROBLEM AND ITS SOLUTION

The present Indian survey, based on 500 soil samples, carefully collected according to modern pedologic standards, discloses that the drier, densely populated lowlands (Indo-Gangetic plains, Coromandel Coast) and the central plateaus are low in total nitrogen. This is in full accord with the many observations made by Indian soil scientists. The means, which are accompanied by C/N ratios of 9.5-10.5, vary from 0.040 to 0.050 percent nitrogen.

For the sake of clarification, these areas occupy the left-hand quarter of the Indian climatic field in Fig. 9. As is readily seen, this Indian sector lies directly below the U. S. A. field.

As to the origin of this agriculturally deplorable situation the consensus of opinion holds that longtime, exhaustive practices of soil management are to be blamed. But, as seen in the preceding chapter, the cultivation indices reflect good rather than poor practices, as judged by conditions in the United States.

In the light of the temperature functions, as in Figs. 7 and 8, the primary cause of the low nitrogen status of the aforementioned Indian soils must be attributed to climate, particularly high temperatures, which "burn up" soil organic matter and keep the soil's supply of nitrogen at a low level. Admittedly, nature's unfavorable balance has been further depressed by man, but that is a factor of secondary importance.

While it is true that for sameness of state factors—especially annual temperature and precipitation—the Indian soils are richer in nitrogen than the U. S. A. soils, it is nevertheless a fact that the agriculturally crucial areas are nitrogen-starved because of their high mean annual temperatures which exceed those of, say, New Orleans by 10-15° F.

Indian crop potentials may be assessed by employing the equation which relates mean yields (y) of corn (*Zea mays*) to mean soil nitrogen (N), as derived in the United States (13, 15):

$$y = 224.6N - 3.3 \qquad (r = 0.995)$$

Inserting the average nitrogen content of the soils of the northwest Indian plains, namely 0.050 percent, the formula predicts a corn yield of only 7.9 bushels per acre, or 440 lbs./A. The yields actually observed in Uttar Pradesh (32) are in the neighborhood of 11 bu./A., or 600 lbs./A. Clearly, the American corn yield—nitrogen dependency—established prior to the hybrid age—produces for India the correct order of magnitude of corn yields. Should the difference, 8 versus 11 bushels be statistically significant—which cannot be ascertained now—the interesting conclusion would follow that a unit of soil nitrogen is slightly more productive in India than in U. S. A.

Indian agriculturists have made heroic efforts (34) to increase the humus content of their soils by green manuring, composting, and incorporating carbohydrates to stimulate photo-fixation of nitrogen (4). But these approaches, the only ones possible now, have proved inefficient and they must eventually give way to massive fertilization with artificial nitrogen compounds.

In the light of similar situations in the southern United States, crop production in many areas of India could—in a technical sense at least—be doubled if not tripled.

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Microorganisms and Soil Structure[1]

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INTRODUCTION

A desirable soil structure is important in allowing water to penetrate the soil and in allowing an exchange of gases, such as oxygen and carbon dioxide, between the soil and the atmosphere. Plants need a soil sufficiently granular to allow root penetration and adequate soil aeration. Many beneficial micro-organisms, such as the nitrifying micro-organisms, attain maximum activity only under aerobic conditions, and such conditions cannot be maintained in the absence of a favorable structure. Furthermore, the structure of a soil is highly important in determining the resistance of the soil to erosion by wind or water. From an agronomic standpoint, it is difficult to overemphasize the importance of soil structure.

In order to evaluate the role of micro-organisms in influencing soil structure, some understanding is necessary of the ways in which structure is developed and maintained in the soil. Generally, we think of structure as involving (a) formation of soil aggregates, either by combination of primary particles of sand, silt, clay, and organic matter into characteristic units, or by subdivision of relatively large units of the soil mass; and (b) stabilization of the aggregates. Both aspects of structure reflect the complex interaction of various physical, chemical, and biological forces. A further brief discussion of the two aspects follows.

Formation of Aggregates. Flocculation and sedimentation of soil particles in an aqueous suspension, as a result of a change in charge of the particles, can account for the bringing together of primary particles of colloidal size (less than two microns). However, flocculation and sedimentation are of limited importance in aggregation under natural conditions in the soil. Drying of a wet soil tends to bring primary particles together, since the attractive charges are brought closer together when the water films between the particles are reduced. On the other hand, drying of the soil may result in the development of unequal stresses which may break the soil into particles. Other physical forces, such as freezing and thawing, also may cause fragmentation of the soil mass into smaller units.

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[3]The material reported in this paper is a summary of the work and philosophy of the authors, developed over a period of years. Specific papers and journal articles are cited throughout the paper, as listed in the references.

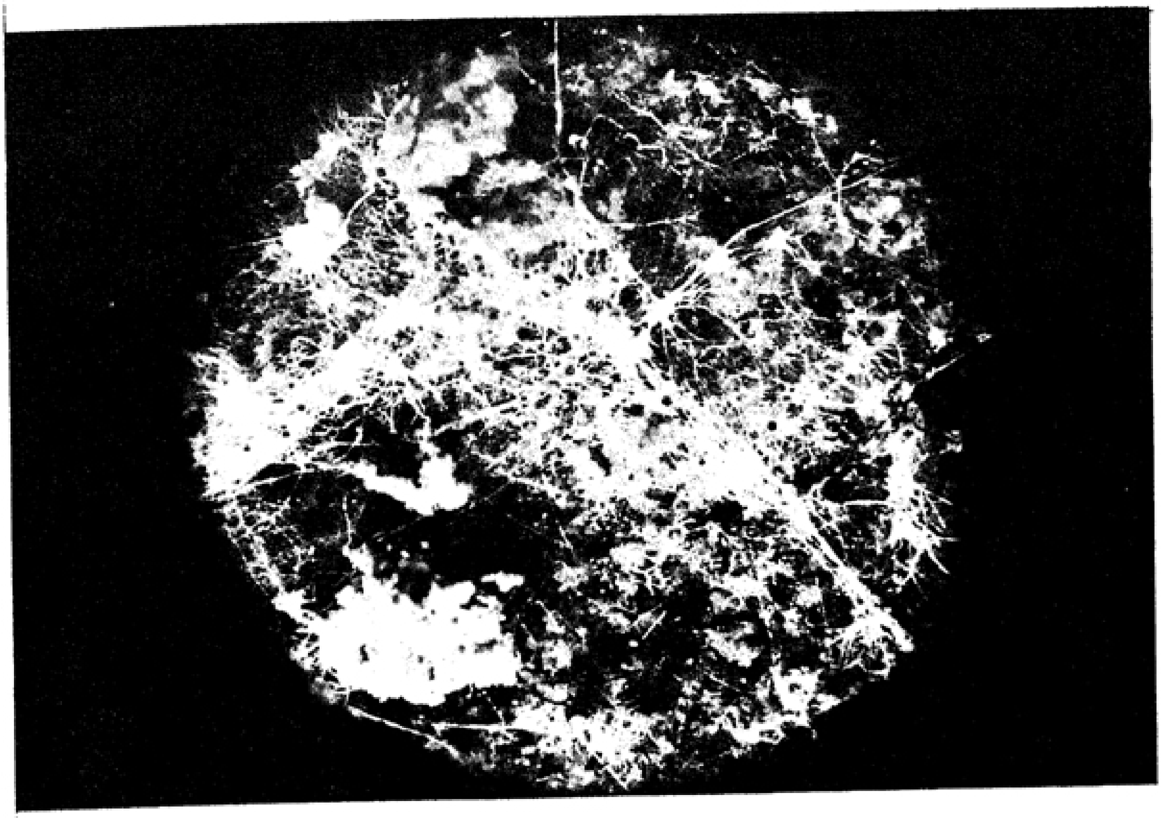

Fig. 1—Mycelia from fungi growing in this soil have bound the individual soil particles together. Note large clump at lower left. Magnified 12X (9, 10).

Tillage may break up the soil mass into various units such as clods, fragments, crumbs and granules. Plant roots certainly tend to push primary particles closer together to form aggregates or structural units in the soil, as do the mycelia of certain fungi (figure 1). Earthworms, crayfish, ants, and many insects form aggregates and, in many cases, may stabilize them. Certain bacteria, through the production of gums, may have similar effects. Burrowing animals, such as moles, separate the soil mass into units. Thus in nature there are numerous ways in which lumps, granules, clods and other aggregates are formed from the soil mass into the many-sized units that are found in the soil.

Stabilization of Aggregates. Once the soil units are formed there are numerous ways in which they may be stabilized. Inorganic cementing materials, such as iron, may give extreme stability such as occurs in the Latosols. Also colloidal materials, such as clays and organic matter, through their chemical and physical effects stabilize the soil units.

Micro-organisms, during the decomposition of plant and animal remains, produce numerous organic compounds and release inorganic substances that affect stability of the soil units (4, 7, 10, 13, 14). Some of the compounds produced and released exert a tremendous effect on stability. Other compounds have little or no effect. Some of the natural products produced by micro-organisms are more effective per unit weight than are the synthetic stabilizers that have been produced (1). In addition to the foregoing microbial effects, the physical influence of certain fungal mycelia in holding together the soil units should be mentioned (figure 1). Micro-organisms vary greatly in their ability to stabilize the soil (2, 3, 6, 12).

The soil fauna is also important in influencing soil stability. For example, the earthworm secretes slimes that render the cast several times more stable than the original soil. Under some mulching treatments, as much as 40 tons per acre of earthworm casts were produced and deposited on the surface of the soil (10).

Thus there are many factors involved in forming soil structure units and in stabilizing them. The kind of soil structure will depend upon type of soil and all aspects of its chemical, physical, and biological makeup.

The purpose of this paper is to discuss the role of micro-organisms in determining soil structure and to consider ways in which soil micro-organisms may be used to improve soil structure stability.

GENERAL CONSIDERATIONS

Kinds of Organisms in the Soil

In order to understand the role of soil micro-organisms in determining soil structure, let us first look at the number and kinds of soil micro-organisms and their activity in the soil.

There are many kinds and quantities of organisms in the surface foot of soil, as shown in table 1. Each kind of organism plays some significant role in

TABLE 1-AVERAGE POPULATIONS AND WEIGHT CONTRIBUTIONS OF VARIOUS KINDS OF MICROORGANISMS IN THE SOIL (10, 11).

Kind	Average Number per Gram of Soil	Average Weight in Pounds per Acre-Foot of Soil
Bacteria	500,000,000	600 - 1200
Actinomycetes	10,000,000	900 - 1200
Fungi	500,000	1400 - 1800
Protozoa	500,000	100 - 500
Yeasts	500	---
Algae	75,000	150 - 350
Worms and Insects		900 - 1200

the decomposition of plant and animal residues, liberation of plant nutrients, or in the development of soil structure. Many groups are dependent on each other. Thus, one kind may tend to follow another, both resulting from and causing an organized sequence of reactions in the soil. In size, the organisms vary from forms invisible with the ordinary microscope but visible with the electron microscope, to those that can be seen with the naked eye. In shape they vary from tiny spheres to weird twisted forms. The organisms have the capacity to digest the materials in the soil because they produce enzymes which form a gigantic, complex enzymatic system that extends throughout the soil. There are few things in the soil—even such resistant materials as hair and horn—that escape digestion.

Percolation

Influence of Sucrose. When micro-organisms are grown in the soil, they typically decompose organic substances and produce various byproducts, such as polyuronides, waxes, and gums, which may affect the stability of the soil granules. This effect, in turn, may influence the movement of water through the soil (5, 8). It is conceivable that when organic substances decompose in the soil, the decomposition products and microbial tissue might plug up the soil pores so that water penetration would be reduced. Rapid penetration could possibly be obtained by stirring this mass of soil, micro-organisms, and decomposition products into a lumpy mixture. Particularly rapid percolation might be expected if good stability of the soil units had been achieved.

To test these points, sucrose was added to air-dry Peorian loess (5) at a concentration of 4 percent of the weight of the soil, and ammonium nitrate was added at a concentration of 100 p.p.m., which approximates a field application of 200 pounds per acre. The mixture, contained in shallow pans, was inoculated with a pinch of surface soil, and moisture content was brought up to 26 percent. After 5 days of incubation at room temperature of about 28° C, the material was stirred and then packed into percolators, after which rates of percolation were measured. In another treatment, air-dry Peorian loess inoculated with a pinch of surface soil was packed directly into the percolators. Sucrose and ammonium nitrate, at the concentrations previously given, were added in sufficient water to wet the layer of Peorian loess. Percolation tests were made after an incubation period of 5 days. Results (table 2) indicate that when sucrose was mixed with the soil, incubated, and the soil stirred prior to testing, the total percolation for an 8-hour period was 69.30 inches. This value represents an increase of 66.13 inches over the control value. If the mixture was incubated in the percolator without stirring, on the other hand, the total percolation for the 8-hour period was reduced by 2.10 inches. Thus the data support the suggestions made in the preceding paragraph. It seems probable that soil plugging of the sort observed in this experiment may be responsible for some of the problems encountered in attempts to replenish underground water supplies by applying water to the surface of the soil.

Another effect of micro-organisms and their decomposition products may be the coating of soil particles so that the surface will not wet. The result may be an increase in runoff.

Influence of Cotton Gin Waste and $HgCl_2$. Three treatments, each in triplicate, with Hesperia sandy loam soil were used in large percolators (8). One set of percolators was left untreated and flooded with distilled water. Another set was mulched with a 2-inch layer of cotton gin waste and flooded with distilled water. A third set was flooded with distilled water containing 10 p.p.m. of

TABLE 2-INFLUENCE OF SUCROSE DECOMPOSITION ON THE PERCOLATION RATE OF DISTURBED AND UNDISTURBED SAMPLES OF PEORIAN LOESS (5).

Treatment of Peorian Loess	Percolate - Inches per Hour								Total for 8 Hours
	1 hr.	2 hrs.	3 hrs.	4 hrs.	5 hrs.	6 hrs.	7 hrs.	8 hrs.	
None	0.00	0.46	0.46	0.58	0.58	0.37	0.36	0.36	3.17
4% sucrose (undisturbed)	0.04	0.14	0.14	0.14	0.12	0.15	0.16	0.18	1.07
4% sucrose (disturbed)	18.37	12.68	5.36	4.26	10.18	9.26	6.41	2.78	69.30

$HgCl_2$. The water was maintained at a constant head and allowed to percolate continuously for a 50-day period. The mean hourly rate for each day was calculated. Certain of the data are shown in table 3.

TABLE 3-INFLUENCE OF MERCURIC CHLORIDE AND COTTON GIN WASTE ON THE CONTINUOUS PERCOLATION OF WATER THROUGH A LAYER OF HESPERIA SANDY LOAM IN THE LABORATORY (8).

Time in Days	No. Treatment	Cotton Gin Waste Mulch	10 ppm of $HgCl_2$ in Water
	(ml of percolate per hour on day shown)		
1	467	411	446
2	489	295	556
4	380	193	485
6	336	128	525
8	320	81	480
10	305	60	470
12	283	51	458
14	251	44	457
16	231	36	448
18	191	30	444
20	163	28	438
25	114	26	418
30	84	21	427
40	43	15	382
50	23	13	352

The percolation rate of the untreated soil was gradually reduced from an initial value of 467 ml. per hour to 23 ml. after 50 days of incubation under submergence. When the soil was mulched with a 2-inch layer of cotton gin waste, the percolation rate on the first day was 411 ml. per hour, and the rate dropped to 13 ml. per hour at the end of 50 days. Reduction in percolation rate was more rapid in the gin waste-treated soil than in the untreated soil. Thus, by the 10th day the percolation rate with cotton gin waste had dropped to 60 ml. per hour, while the rate for the untreated soil was 305 ml. per hour. As in the case of the sucrose experiments, the evidence indicates plugging of the soil pores as a result of the decomposition of organic matter.

Mercuric chloride, added to the water at the rate of 10 p.p.m., maintained a high intake. However, since $HgCl_2$ is both a disinfectant and an electrolyte, it is difficult to determine which effect is predominant. Quite possibly both effects are important.

AGGREGATION

Aggregating Effect of Different Cultures. Thirty-three fungi and one actinomycete, isolated at random from plates made from field soil, were inoculated into sterile Peorian loess with straw or sucrose as energy material (12). The soil material was brought up to 25 percent moisture and incubated for 2 weeks at 24° C. Aggregation was then determined by a wet-sieving method (2). The results are shown in table 4.

TABLE 4-VARIATION IN AGGREGATION OF PEORIAN LOESS BROUGHT ABOUT BY 34 SOIL ISOLATES WITH STRAW AND SUCROSE AS ENERGY MATERIALS IN 1% CONCENTRATIONS (12).

Energy Material (1% Concentration)	Aggregation Range1/ %	Number of Cultures
Straw	10 or less	19
	11-20	8
	21-30	4
	31-40	1
	41-50	2
Sucrose	30 or less	2
	31-45	3
	46-60	7
	61-75	18
	76-90	4

1/ Based on weight of material retained on a 0.2 mm screen after wet-sieving for 5 minutes. Value for uninoculated control = 4%.

These results show that sucrose is a better source of energy for these randomly isolated micro-organisms than is straw. The degree of aggregation was high with sucrose. Only 3 cultures produced aggregation greater than 30 percent with straw as a source of energy material. These results also show that soil micro-organisms do vary greatly in their aggregating ability. If it were possible to have all the crop residue decomposed by only the few micro-organisms with superior aggregating ability, soil structure might be changed greatly. The problem then appears to be that of utilizing only the superior soil structure stabilizing micro-organisms for decomposing the available crop residues.

Selecting and Testing Superior Micro-organisms. In a search for a new, superior soil structure stabilizing micro-organism, 12 cellulose-decomposing fungi were compared with respect to their ability to promote the aggregation of sterile Peorian loess with ground wheat straw (1 percent concentration) as the source of energy material (2). Following inoculation, Petri plates (in duplicate) were incubated at 24° C for 14 and 28 days with moisture levels at 15, 25 and 30 percent. Results of the 14-day incubation are shown in table 5.

It is clear from the results that *Stachybotrys atra* is the most effective aggregator of the 12 fungi tested. The aggregation brought about by *S. atra* ranged from approximately 2 to 30 times that effected by the other soil fungi. The appearance of Peorian loess before inoculaion and after inoculation with *S. atra,* and incubation for two weeks, is shown in figures 2 and 3.

Factors Influencing the Aggregation of Peorian Loess by Stachybotrys atra. Further studies with *S. atra* were designed to furnish information on the environmental conditions under which this organism is most effective in aggregating Peorian loess (2). Except as noted, the following conditions were used

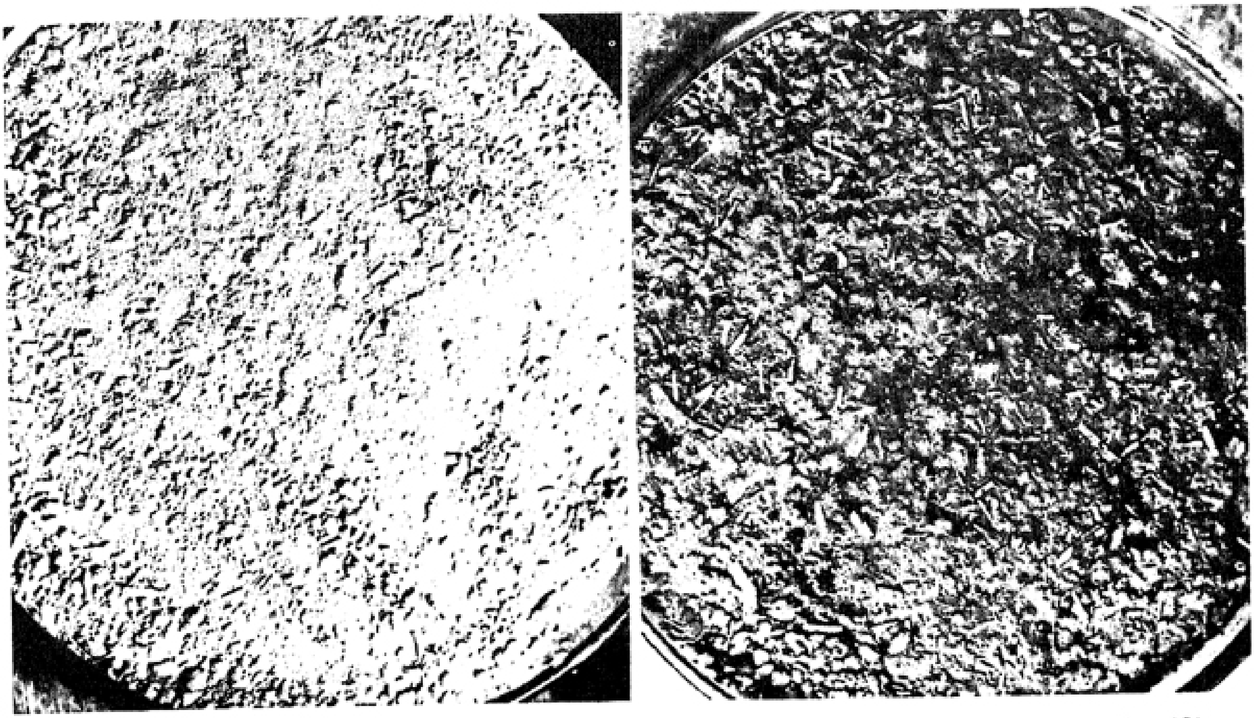

Fig. 2—The appearance of Peorian loess with ground wheat straw at 1 percent concentration (2). Left: Uninoculated, at beginning of experiment. Right: Inoculated with *stachybotrys atra* and incubated for 2 weeks at 24° C.

Fig. 3—A portion of the inoculated plate shown in figure 2 magnified 5X. Note the mycelial growth on the particles of straw and Peorian loess (2).

TABLE 5-AGGREGATION OF PEORIAN LOESS WITH FUNGAL CULTURES INCUBATED FOR 14 DAYS, USING WHEAT STRAW IN 1% CONCENTRATION FOR ENERGY MATERIAL (2).

	Percent Moisture		
Organism	15	25	30
	Percent Aggregation (Average)1/		
None	2.6	2.2	2.1
Monascus purpureus	3.1	2.3	2.2
Aspergillus terreus	3.0	3.5	3.3
Aspergillus flavipes	4.5	3.9	3.4
Aspergillus fumigatus	4.1	6.1	2.8
Thielavia basicala	3.8	3.7	6.9
Myrothecium verrucia	4.0	5.8	8.0
Helminthosporium	4.4	5.4	11.8
Memnonilla echinata	4.5	7.3	10.4
Cephalothecium roseum	3.6	14.7	6.7
Chaetomium globosum	7.0	10.0	10.2
Curvularia	16.6	19.4	10.2
Stachybotrys atra	28.5	54.0	60.6

1/ Based on weight of material retained on a 0.2 mm screen after wetsieving for 5 minutes.

in all experiments: carbon source—ground wheat straw, 1 percent concentration; initial moisture level, 25 percent; incubation temperature, 24° C; incubation period, 2 weeks. Thirty-five grams of sterile Peorian loess were used in each of triplicate Petri dishes and duplicate aggregate determinations were made from each dish. The following variables were studied: Incubation time, incubation temperature, moisture level, nature and concentration of carbon source. In all experiments, calculations of aggregation percentages were based upon the dry weight of material retained on a 0.2 mm. screen after 5 minutes of wet-sieving.

Incubation Time: Results of a comparison of incubation periods of 1, 2, 4 and 8 weeks are presented in table 6 (2). The data indicate the attainment in

TABLE 6-INFLUENCE OF INCUBATION TIME ON THE AGGREGATION OF PEORIAN LOESS BY STACHYBOTRYS ATRA (2).

	Time in Weeks				
Organism	1	2	3	4	8
	Percent Aggregation (Average)				
None	3.9	5.7	---	---	10.5
S. atra	48.8	50.8	60.9	58.8	66.3

L.S.D. (0.05) = 9.5 for comparison of means of time within S. atra.

one week of a relatively high degree of aggregation. The incubation periods above one week and up to 8 weeks increased the degree of aggregation to some extent, but the increase was small.

Incubation Temperature: Incubation temperatures of 20°, 24° and 28° C are all favorable for aggregation by *S. atra,* as shown in table 7 (2). Under the conditions of the experiment, essentially equivalent aggregations were attained at the three temperatures.

TABLE 7-INFLUENCE OF INCUBATION TEMPERATURE OF AGGREGATION OF PEORIAN LOESS BY STACHYBOTRYS ATRA (2).

Organism	Temperature (Degrees Centigrade) 20	24	28
	Per cent Aggregation (Average)		
None	3.1	2.5	4.6
S. atra	62.3	60.2	59.0

L.S.D. (0.05) = N.S. for Comparison of means of temperature within S. atra.

Moisture Levels: Results of an experiment dealing with the effect of initial moisture level on aggregation are presented in table 8 (2). It is apparent that moisture levels of 10 percent and 15 percent are suboptimal for aggregation by *S. atra,* and that increasing the initial moisture content from the 20 percent level to 30 percent is without effect on the aggregating ability of this organism.

TABLE 8-INFLUENCE OF INITIAL MOISTURE LEVEL ON AGGREGATION OF PEORIAN LOESS BY STACHYBOTRYS ATRA (2).

Organism	Percent Moisture 10	15	20	25	30
	Per cent Aggregation (Average)				
None	3.8	7.5	2.9	3.3	3.1
S. atra	24.6	36.8	52.8	50.0	52.1

L.S.D. (0.05) = 11.6 for comparing moisture levels within S. atra.

Nature and Concentration of Carbon Source: In an experiment comparing carbon sources, ground wheat straw, ground alfalfa, and a 1:1 mixture of the two were used at levels of 0.25, 0.5, 1.0, 1.5 and 2.0 percent (2). The results presented in table 9 demonstrate that, within this concentration range, there tends to be increased aggregation in response to increased concentration of energy material. It is also apparent that, on a weight basis, alfalfa is superior to straw for the promotion of aggregation by *S. atra.*

TABLE 9-INFLUENCE OF CARBON SOURCE ON THE AGGREGATION OF PEORIAN LOESS BY STACHYBOTRYS ATRA (2).

Carbon Source	Per cent Energy Material 0.00	0.25	0.50	1.0	1.5	2.0
	Per cent Aggregation (Average)					
Straw	--	32.8	41.7	46.7	56.8	58.9
Alfalfa	3.3	46.8	55.9	58.2	70.9	65.7
Straw-alfalfa*	--	32.8	46.1	62.8	65.6	64.8

L.S.D. (0.05) = 8.4 for comparing concentration of energy material within a treatment or treatments within a concentration.

*Equal weights of both straw and alfalfa added to each Petri dish.

Establishing Superior Soil Structure Stabilizing Micro-organisms Following Soil Sterilization Treatments. As has been shown by the previous results, certain micro-organisms such as *S. atra* are highly effective in aggregating the soil. However, when *S. atra* is added to an unsterilized soil, no increase in aggregation is obtained (table 10) (13). It therefore becomes necessary to reduce the existing soil microbial populations before introducing an organism such as *S. atra.* Soil can be effectively sterilized by autoclaving, but this procedure would be impractical on a field scale. However, the use of chemicals to eliminate the soil populations might be feasible.

TABLE 10-INFLUENCE OF AUTOCLAVING ON THE MICROBIAL POPULATION OF PEORIAN LOESS AND ON THE AGGREGATION EFFECTED BY SUBSEQUENTLY INTRODUCED S. atra.

Treatment	Percent Kill		Percent Aggregation	
	Bacteria	Fungi	No. Inoculum	S. atra
None	0.0	0.0	8.2	7.7
Autoclaved	100.0	99.7	2.6	48.7

In order to determine the influence of chemicals for eliminating or reducing soil microbial populations prior to introduction of superior soil structure stabilizing micro-organisms such as *S. atra,* chloropicrin, pentachlorophenol, urea-formaldehyde, and biuret-urea-formaldehyde were added to Peorian loess (13). Following fumigation, the Peorian loess was inoculated with *S. atra,* soil flora, or no culture. Data on reduction in the microbial population and on aggregation are given in figure 4. The figure also includes information on autoclaved Peorian loess.

From the results with autoclaving, which reduced the microbial population essentially to zero, it can be seen that subsequent introduction of *S. atra* inoculum, soil flora, and blank inoculum, resulted in aggregations of approximately 50, 15 and 3 percent respectively. In the nontreated controls, aggregations of around 5 to 10 percent were achieved regardless of the inoculum used. These results again demonstrate the low degree of aggregation in sterile Peorian loess and emphasize the inability of *S. atra* inoculation to bring about any marked increase in aggregration unless the bacterial and fungal populations are reduced.

Apparently this reduction in native microflora must be quite drastic before inoculation with *S. atra* can produce substantial aggregation. Thus, low levels of chloropicrin produced marked reductions in microflora, but the degree of aggregation brought about by subsequently introduced *S. atra* was still increasing somewhat at the highest level of fumigant which was used. At this level the degree of aggregation produced by inoculation with *S. atra* was approximately two-thirds of that which was attained following autoclaving.

Pentachlorophenol was quite effective in reducing microbial numbers but, apparently through residual toxicity to the inocula, this fumigant produced an unfavorable effect on aggregation. In other experiments, the soil was found to be essentially sterile after the incubation period. It is necessary, therefore, to consider possible residual effects of the fumigation treatment, as well as the effectiveness of the treatment in reducing the soil microflora to a low level.

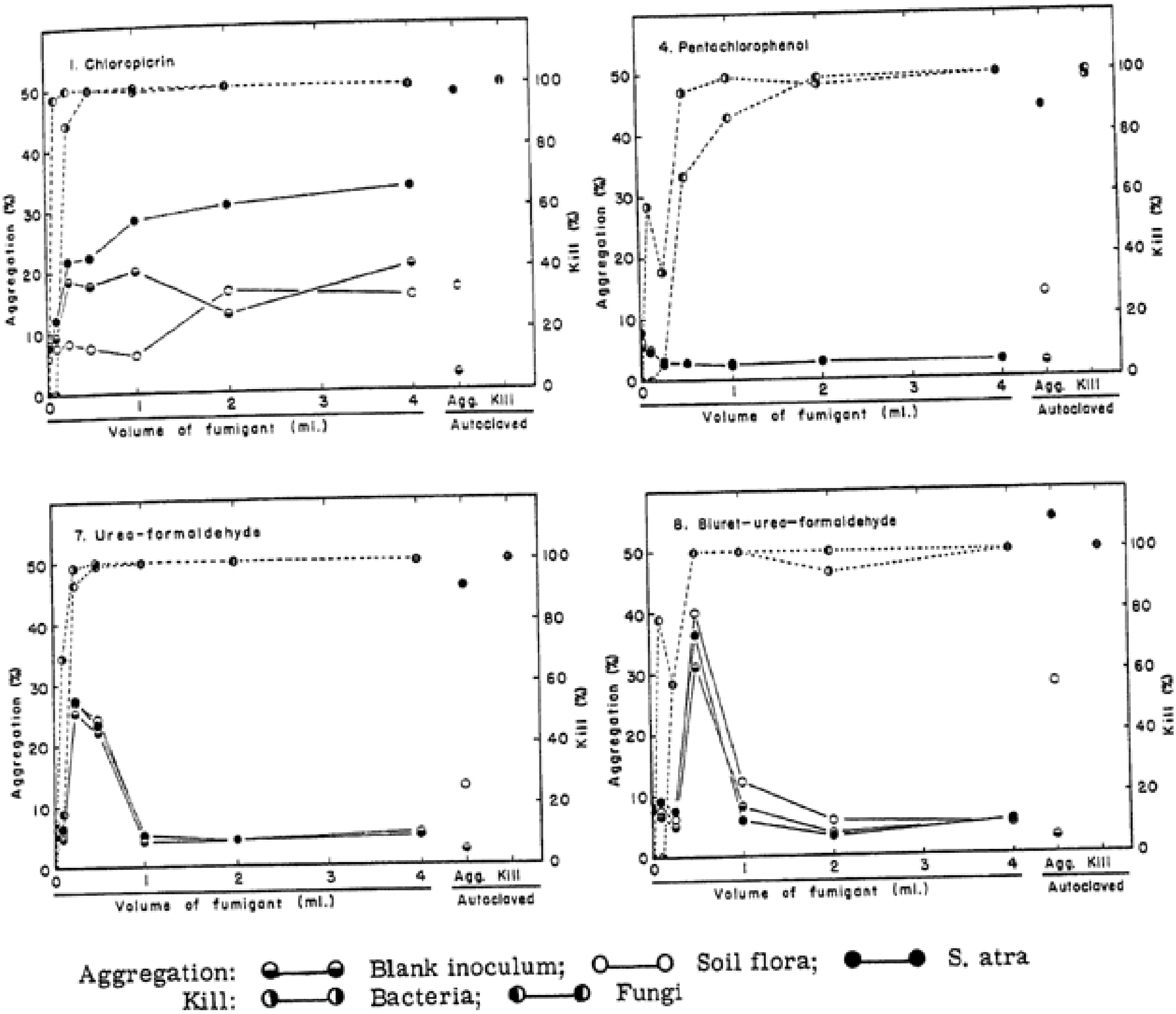

Fig. 4—The effect of different amounts of fumigant upon numbers of microorganisms in Peorian loess and upon subsequent aggregation of the loess by 3 inocula. In each case the volumes shown were added to 500 g of Peorian loess, and following a fumigation period of 7 days at a moisture content of 20%, microbial numbers were determined and portions of the fumigated material were supplemented with wheat straw and were then inoculated with *S. atra,* soil flora, or a blank inoculum. Aggregation was measured after an incubation period of 2 weeks. Data on aggregation and reduction in the microbial population in autoclaved Peorian loess are presented at the right of each graph (13).

The urea-formaldehyde and biuret-urea-formaldehyde treatments resulted in good kills of bacteria and fungi. Similar aggregation patterns were produced following inoculation of the fumigated soil material; that is, aggregation was relatively high at the 0.25 ml. or 0.5 ml. rate, and lower at the other rates; and aggregation seemed not to depend on the nature of the inoculum used. From these observations it was initially supposed that the aggregations noted resulted directly from action of these two fumigants on the soil material (13). Subsequent experiments, however, have demonstrated the presence of organisms resembling *Fusarium* in those treatments where good aggregation was obtained. Evidently the two formaldehyde-containing fumigants are selective in their action, and the organisms that are able to survive the indicated levels of fumigant happen to be capable of effective aggregation. This observation suggests the possibility of obtaining improved aggregation without artificial inoculation of the soil.

DISCUSSION

It is evident that soil micro-organisms affect the stability of soil structure to the action of water. Also, the movement of water through the soil is influenced by the action of soil micro-organisms. Furthermore, micro-organisms vary greatly in their ability to utilize crop residues, such as wheat straw, in the improvement of soil structure stability. In sterilized Peorian loess with wheat straw as an energy source, the aggregation resulting from the introduction of ordinary soil flora was about 15 percent. When an efficient aggregator, such as *S. atra,* was used under the same conditions, aggregation was increased to about 50 percent or about 3 times as high as that obtained with soil flora. If a superior soil aggregator such as *S. atra* was used to decompose the available crop residues in the field, it appears that a much improved soil aggregation could be obtained.

In order to obtain good aggregation, it is first necessary to reduce the existing soil flora to a low level. When this reduction is followed by introduction of a superior soil aggregator, improved stability of the soil results.

At the present time, as an integral step in the production of some crops, an attempt is made to eliminate organisms such as nematodes, certain pathogenic fungi, and insects, by means of soil chemical treatment before planting the crop. It may be desirable to go a step further and destroy all soil micro-organisms with a broad spectrum fumigant such as chloropicrin. Then the desirable soil micro-organisms could be added to the soil to do a particular job. In addition to superior soil structure stabilizing micro-organisms, there are superior nodule producing micro-organisms. It is also possible that many other groups of micro-organisms, such as cellulose decomposers, nitrifying bacteria, or non-symbiotic nitrogen-fixing micro-organisms, may include individuals superior for a particular job. Management of micro-organisms by controlled introduction and directed activity through chemical, physical, and biological manipulation of the environment, conceivably could exert considerable influence on crop growth or, in the case of superior soil structure stabilizing micro-organisms, could result in improved soil and water conservation.

It is also possible to improve soil micro-organisms through selection and genetic manipulation. Only through control of the micro-organisms in the soil, such as that exercised for the crop above the ground, will maximum crop yield be achieved. On the basis of the work done with superior soil structure stabilizing micro-organisms, as reported in this paper, it appears possible in the laboratory to exercise control over soil micro-organisms and their activities. There is reason to believe that, in the future, such control on a field scale will be a highly important factor in our agriculture.

SUMMARY

Good stable soil structure is valuable for promoting the growth of plants and micro-organisms by permitting enhanced aeration and water penetration, and by decreasing erosion under some conditions.

Micro-organisms influence water percolation through the soil. They may plug up soil pores with byproducts of growth and reduce water percolation. On the other hand, if a soil containing a large amount of microbial products is stirred and allowed to dry, then the percolation may be high.

Micro-organisms are involved in stabilizing soil structure by their products of decomposition and their cellular binding material, such as mycelia. Micro-organisms differ greatly in their ability to stabilize soil structure. Restricting the microflora to superior soil structure stabilizing micro-organisms materially increases soil structure stability. This restriction is accomplished under laboratory conditions by first eliminating the indigenous soil flora and then introducing the desired micro-organisms. Indigenous flora can be eliminated by autoclaving or by the use of a soil fumigant such as chloropicrin. Some fumigants, such as urea-formaldehyde and biuret-urea-formaldehyde at certain critical concentrations, selectively eliminate soil micro-organisms, leaving only effective soil aggregators. Physical and chemical factors, such as temperature, moisture, and amount and nature of energy material, affect the growth and effectiveness of soil structure stabilizing micro-organisms.

The use of superior micro-organisms for changing nutrient availability, nitrogen fixation, and soil structure stabilization may permit a degree of control over plant growth which heretofore has been impossible.

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Soil and Livestock Production

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I appreciate the opportunity to join with our distinguished visitors in this program on the broader implications of the soil. Those of you who have taken any of Dr. Albrecht's courses have been exposed to the many stimulating ideas on this subject which he has proposed. It is not my purpose to review his lecture notes for you; you can do that at home, or you can recall Mr. E. M. Poirot's testimonial of his increased site value after applying treatments recommended by Dr. Albrecht.

Today I want to indicate some of the livestock producer's problems and to illustrate how soil or what you and your colleagues do to soil affect these problems. In the discussion which follows, I will consider soil as the vehicle for supporting and nourishing plants. Obviously, other soil effects which have been previously discussed will have a bearing on the performance of the animal.

The animals I will relate this to are ruminants. Perhaps you will forgive my prejudices long enough to allow me to assume that the plants grown by United States farmers are intended as animal feed. Animal investigators hope to have plants available which are "tailor made" for our animal's needs. We can, of course, change our animals to a certain degree by breeding and by altering environment, but I hope to convey the extent of our need for nutritious forage by the discussion which follows. The major points are built around examples from the literature which was not exhaustively reviewed.

I believe that the most important contribution of the soil to animal production is to determine which plant species will grow on a given soil. Consider the stimulating effect of calcium or molybdenum on legumes and nitrogen on grasses as well as the disappearance of sharp boundaries in the climax vegetation after soil deficiencies are corrected.

Let me illustrate the change in vegetation that has been obtained in Australia and New Zealand by appropriate soil treatments. (See also Kline, C. H., Reclaiming Acres With Ounces. J. Ag. and Food Chem. 2:404-408) The slides which follow illustrate the "before" and "after" vegetation of

The Ninety Mile Desert
The Tablelands of New South Wales
Western Australia
The Rotorura area of New Zealand

If any of you think that you know of 6 million acres of similar land within a few hours of Columbia, you are right. What will you do about it?

That certain plants are indicators of selenium in soils is also well established. The type of plant determines the trace mineral content forage as shown below.

TRACE ELEMENTS IN PLANT SPECIES GROWN IN FIELD UNDER IDENTICAL CONDITIONS
(In parts per million, on dry-weight basis)

	MO	Fe	Mn	Zn	Cu	Co
Sassafras gravelly loam			200	16	2	0.6
Alfalfa, 1st. cutting	0.9	261	27	27	8.3	0.14
Kentucky Bluegrass	2.8	503	40	43	10.4	0.20
Timothy	2.7	144	34	36	6.9	0.06
Corn	0.5	64	4		1.8	0.01
Oats	3.2	178	38	37	6.8	0.02
Soybeans	5.1	108	32	42	16.0	0.20

Bear, F. E. J. Ag. And Food Chem. 2:247, 1954.

Of course the composition of the species varies depending on where it was grown. Our studies show that alfalfa is very different in its content of the alfalfa ash factor.

The second major effect of soils is to determine yield. The advances, mostly since World War II, in soil testing and fertilizing have greatly increased the amount of feed which is available to livestock. The gains in Missouri and bordering states indicate that relative rates of efficiency in crop production have been at least 5 times as fast as those in livestock. Unfortunately, most of the gains are in cereal grain production. The same progress has not been made with other forages or in the utilization of cereals.

If the increased yield of roughages is to be used by livestock it must be palatable and rapidly and efficiently digested. If a grazing animal will not consume the forage, it is of little value to the producer. Both plant species and nutrient content are factors and other effects will probably be established. Studies from the Kentucky station illustrate the species effect. Table 1 shows the intake and nutrient value of forages consumed by grazing wethers, table 2, the value of forages for fattening steers, and table 3 the persistency rating of several pasture plants, as evaluated with dairy cows. Since the amount of feed eaten and the efficiency of its digestion and metabolism are the factors determining the total nutrients available from a day's ration, you can appreciate the importance of evaluating soil treatment as was done at California. The results are shown in Table 4.

Assuming that the animal readily eats the forage offered, let us now examine the nutrients which are most important to the animal and see where we need to direct our research in the years ahead. Unfortunately, we do not have available all needed information on the animal's requirements at different stages of their life but generalizations are possible. The illustrations which follow indicate that most forages are likely to be deficient in the energy yielding nutrients, primarily carbohydrates, and that soil adjustments which favor the production of plants yielding the greatest amount of net energy should receive additional attention from investigators who are interested in supplying the animal's needs from pasture or forage. Table 5 shows the requirement of a high-producing dairy cow and illustrates how the roughage portion of her diet meets her needs for all nutrients except energy, phosphorus, and salt. Protein may look deficient, but any grain given to correct the energy deficiency will provide more protein than is needed to balance the ration. Table VI shows similar calculations for a beef steer on mixed pasture.

Protein is usually the second most expensive ingredient in animals' rations. Our ideal forage should meet the quantitative and qualitative needs for this nutrient. Many past experiments which were interpreted as showing a stimulating effect from protein additions were not properly designed. Any experiment which shows a favorable effect from one pound of protein supplement cannot be properly interpreted unless the controls received energy and minerals and vitamins equivalent to that in the protein feed.

We know of many cases where favorable responses to protein are actually responses to additional energy and/or phosphorus. A beautiful example of the phosphorus deficiency is found in the case of the Ash Creek cattle.

The forage should be nontoxic. This is an extremely important requirement which will receive much attention in the future. The buildup of toxins may be related to imbalance but at the present time it seems impossible to design experiments which will enable us to study simultaneously all of the combinations of minerals which are needed under all the various climatic conditions. Perhaps I can illustrate the scope and diversity of the problem from three locations in the world. In Australia, animals grazing on *Phalaris tuberosa* develop a disease known as Phalaris staggers. The addition of cobalt to the rumen of these animals will prevent the occurance of this condition and yet on the basis of plant analysis these plants contain adequate cobalt. In Germany, in the latter part of the 1800's, lupins were planted in large areas and grazed for several years without any serious loss of livestock. Later, severe cases of lupinosis developed and lupins are no longer fed. The same sequence of events has recently been found in West Australia. In north Missouri, our attention has recently been called to a condition of scouring in sheep on pasture in which one producer lost 300 lambs. This condition did not exist on his farm ten years ago. During the dry year of 1954, he experienced no trouble. Since that time, losses have increased. Animals that are removed from his farm and sent to other locations are reported to do well. It is now advisable and may become imperative that any fertilizer treatment used on forage producing land be evaluated in terms of animal production for a minimum of five years.

If the soil is capable of producing a high yielding, palatable, nontoxic, readily digestible species with an adequate energy content, we would normally accept it as being a likely livestock feed. If it does not meet all of the mineral requirements, we would hope to supply these in a supplement, as we now do with iodized salt and phosphorus. However, we should not forget that nature may produce more of her experimental deficiencies in the future, and, as in the past, wide areas will be unable to support livestock until these new deficiencies are corrected. Plants grown in many parts of the world are deficient in iodine and restrict livestock production. The addition of iodized salt has essentially eliminated this problem in the temperate zone.

The next large area trace mineral deficiency to be encountered was copper. This problem still requires study. What was once believed to be a simple copper deficiency has been shown to be a complex interrelationship involving, in some instances, excess molybdenum and sulfur, manganese, and protein ratios.

Many parts of the world were at one time thought to be cursed. A good example is reported from New Hampshire where, after having been double crossed, a dying Indian delivered a curse on the white man's house. The curse was effective for many years and caused cattle to die. The pronouncement of the curse happened to coincide with the depletion of the limited amounts of cobalt which were originally present in the soil. Cobalt salts can counteract this and other similar curses. We can expect more of these in the future especially in northwest Missouri where Dr. Picket's studies indicate borderline deficiencies now exist.

Iron, zinc, and manganese have not been shown to limit ruminant production. However, we should always be alert to the effects of treatment which change the pH of soil and the subsequent uptake on these nutrients. An experiment by F. Bear illustrates the changes that can take place.

	Soil pH			
	4.6		7.0	
Trace minerals in soybeans:	Trace Elements Added			
	0	+	0	+
Mo ppm	0.3	49	0.6	109
Mn	189	399	135	191
Zn	332	775	228	212
Cu	8.6	14.4	11.3	12.4
Co	.08	3.8	0.06	0.38

One of the most active areas in nutrition research today is the attempt to determine if those trace minerals which we have regarded as essential are the only ones which are required. It has been shown recently that selenium, usually listed in the toxic table, can be a useful nutrient for sheep in areas where white muscle disease is a limiting factor. Molybdenum, which came into prominance as a toxic element prevents the formation of xanthine calculi in the South Island of New Zealand and may be a useful supplement to the rations of growing lambs. As, Ni, Hg, Au, Ag, V, are other toxic elements. Some of these may be shown to be required in small amounts.

As more of our fertile land is inundated by water from our large dams or taken out of production to make highways, airports and surbubia, livestock production will be forced into the less productive areas. In the productive areas today's new technology has changed the established order of livestock production. My assignment was to show a relationship between soils and livestock production, and this has been possible especially in the world wide areas of phosphate deficient pastures, the 90 mile desert of South Australia, the coastal plains of Florida and many eroded areas. Unfortunately, it is much easier to show a relationship between no soil and no livestock as exists in the highlands of Scotland, on the "rock bound coasts" and in certain parts of the Ozarks than it is to show a favorable correlation between good soil and good livestock. In fact, on much intensively farmed fertile land in the United States today, the correlation seems to be good soil and no livestock. This may be an artificial situation developed in part by the price support program for cereals, but the tremendous differential which exists between the advanced technology with crops and that with animals is also responsible. Russia and Australia will take over a lot of the world's food production unless we strive for maximum efficiency. In order to compete under these new conditions, our animals must eat more of fewer varieties. A steer or dairy cow becomes dependent upon businessmen for his total nutrition. Can animals adapt to the new conditions rapidly enough to meet the change? I would like to quote from an experiment by Brumby which indicated a need for identical experimental farms and twin farm managers to make a final evaluation of this problem.

HOW MANAGEMENT AND FARM AFFECT MILK PRODUCTION
Ruakura Annual Report 1957-58

	# milk	% fat
Heifers reared at Ruakura		
from good herds	5846	5.22
from poor herds	5883	5.04
Identical twins reared in farmers, herds		
Twin A in good herds	5541	5.2
Twin B in poor herds	3572	5.2
Farmers, two year olds		
good herds	5728	5.4
poor herds	3908	5.1

Last night we heard the familar quotation, "The spirit is willing, but the flesh is weak." Recently this was translated into Russian and back to English. The new rendition was, "The wine is good, but the meat stinks." If animals continue to be a food reserve and the source of our high quality foods, we will need more efficient and productive lines to keep our meat from stinking. The feeding value of tissues from animals grown under several conditions of management has not been determined. This should be done. We will hope that soil scientists will be able to tell us how to conserve and manage the soil to make available all the necessary nutrients which encourage the production of large amounts of highly nutritious feeds; that the plant scientists can breed better varieties free from disease and capable of using the nutrients which have been placed in the soil; that our animal husbandrymen will be able to understand those conditions which influence acceptability and metabolizability of feeds so that we can make some of the same gains in efficiency that have been made in poultry production. We hope to establish livestock in new areas and to control the diseases and parasites now existing in intensive areas. If all of us are successful, our animals will be able to convert the superior plants grown on balanced soils into the "main course, providing the nutrients that keep man a truly healthy omnivore and incidentally well pleased with his lot.

If we don't do this job some other basic industry will take over to supply the need. Our choice is to provide meat efficiently and economically or to be replaced by algae husbandry or people in other countries.

Suggested Reading: Intersociety forage evaluation symposium Agron. Journal 51:212-45 (1959)

TABLE 1-INTAKE AND NUTRITIVE VALUE OF FORAGES CONSUMED BY GRAZING WETHERS

Forage & number of observations	Intake of Digestible Protein	Intake of Digestible Organic matter
	lbs/day	lbs/day
Ky. 31 fescue	.18	1.10
Orchard grass	.20	1.24
Bluegrass	.39	1.53
Ky. 215 red clover	.37	1.56
Lincoln bromegrass	.34	1.58
Birdsfoot trefoil	.33	1.58
Redtop	.20	1.59
Kenland red clover	.41	1.67
Timothy	.18	1.68
Alfalfa	.56	2.09
Ladino clover	.65	2.35

Only Ladino clover and alfalfa were consumed in sufficient quantity to meet the daily digestible organic matter requirement of approximately 1.8 pounds needed for fattening lambs of the size used. All forages, with the exception of Ky. 31 fescue and timothy, provided at least 0.20 pound or what is considered to be an adequate intake of digestible protein.

TABLE 2-THE VALUE OF SOME PASTURE FORAGES FOR FATTENING STEERS

Forage and Number of Observations	Intake of Digestible Protein	Intake of Digestible Organic Matter
	lbs/day	lbs/day
Ky. 31 fescue	1.24	7.1
Bluegrass	1.50	9.0
Orchard grass	1.82	9.6
Alfalfa	2.84	11.9
Ladino clover	4.44	14.8
Lincoln bromegrass	2.86	18.8

Since fattening steers of this size requires approximately 1.4 pounds of digestible protein per day, all forages with the exception of Ky. 31 fescue were satisfactory in meeting the protein requirement. However, under the conditions imposed in these trials, only alfalfa, Ladino clover and Lincoln bromegrass met the daily requirements of approximately 12 to 14 pounds of digestible organic matter needed for satisfactory gain.

KENTUCKY AGRICULTURAL EXPERIMENT STATION
Lexington, Kentucky

TABLE 3-PASTURES FOR KENTUCKY

Persistency ratings:	
Orchard grass Ladino	97.2
Bluegrass	94.4
Orchard grass	90.6
Fescue	70.8

TABLE 4-PHOSPHATED ALFALFA FEED VALUE

	Low P	High P
5 steers/lot		
Init. wt.	558	543
Av. daily gain (91 days)	0.53	2.19
Av. daily cons.	11.24	20.58
Feed/cwt. gain	21.30	940

Persians took alfalfa to Greece - 500 BC
Al-faefaeah - the best of fodder

TABLE 5-EXCEPT FOR ENERGY AND SALT, GOOD FORAGE MEETS A CHAMPION DAIRY COW'S REQUIREMENTS

Requirement	Dig. protein lb.	TDN lb.	Ca lb.	P lb.	Carotene Mg.	Co Mg.
1700 lb. cow	1.03	12.6	.037	.037	100	2
100 lb. 4% milk	4.5	32	.220	.152	500	1
Total	5.53	44.6	.247	.189	600	3
Supplied by:						
Alfalfa hay, 28	3.58	14.76	.450	.07	280	2.4
Grass legume silage, lb., 50	1.35	7.7	.275	.06	500	.8
Total	4.93	22.46	.725	.13	780	3.2

TABLE 6-

Requirement	DP	TDN	Ca gm.	P gm.	Na	Mg
700 lb. fattening steer	1.4	13.5	20	18	50	20
Supplied by 80 lb. brome alfalfa pasture	2.6	11.1	90	29	18	29

Reciprocal Relationship of Soil, Plant and Animal

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What is soil? Soil is basically fragmented rock ground down by the action of streams, by erosion from rain, by wind, by the mechanical breakdown from animal life, by the chemical action of growing elements within it, by the expansion and contraction of freezing and thawing, by the action of energy from the sun, by the trituration of rock by glaciers, by growing vegetation, by the action of bacteria and molds, by the acids and bases that are created by growing organisms, by the minute root systems that help to break it down, such as the microrhizomes that find their way into the smallest crevices of rocks to cleave them by the force of growing and dissolve the exposed surfaces by the chemical elements which they contain.

Good soil is teeming with fungi, bacteria, protozoa, earth worms, beetles, crustacea and larvae of insects, as well as reptiles, and even small animals. The root systems of our crops and their productivity are actually altered as the population within the soil changes. Man alters these by the addition of organic and inorganic elements, by governing the moisture, varying the temperature, and controlling radiant energy.

What does man remove from the soil? Man removes plants and animals and their products. He removes much of the plants, the animals and the excrements without returning them. These are considered of organic nature. Of what do they consist? Primarily they are proteins, fats, carbohydrates, minerals, and water. Plants and animals are produced from a living soil. Their return to the soil constitutes the completion of the ecological cycle. They are basically made from inorganic rock, the water of the ocean, the gas of the air, and the energy of the sun.

Some students of ecology argue that only the proper combination of the mineral elements needs concern us for water is obtainable, air is all about us, and radiant energy can even be produced artificially. Others hold staunchly to the theory that it is the return of organic elements to the soil that is all important to the production of the most beneficial crops for man's use. They further believe that true plant and animal health comes only with a large return to the soil of the organic wastes, manure, garbage, carcasses of animals, and the plants themselves that have been broken down into humus by the action of bacteria, molds, and the earthworm.

Though hydroponic solutions of water, inorganic elements, air and radiant energy, produce plants, they ask, "What is the effect of consuming such plants as food on the optimum development of animal life, not only for the present, but for the generations of future animals?"

There are those who feel that there is the middle ground where soil not only needs the mineral element, but that activators from organic material returned to the soil enhance plant growth, either through making the mineral elements more readily available or also by actually being incorporated into the new plants. They recognize that the leaf is a great chemical factory for transforming water, mineral, organic materials from the soil, gasses from the air, and radiant energy from the sun into the nutrients for growth and reproduction of root, stem, flower, leaf, and seed.

Modern man measures the value of his soil by the bushels per acre, and, with the exception of those technically interested, pays little attention to the composition of the crop. To him a bushel of corn is a bushel of corn, and should give him feed for his children or his animals in the light of its quantity. To the ecologist the fact that X-bushels of corn equal Y-pounds of pork on the farm, or Z-rabbits in his laboratory is not sufficient. To him the question is "Was there a difference in X-bushels of corn from soil A, B, C, D, and E?" "Was there a difference in the ear as to size, to shape, to natural resistance to pest," and many other questions. If there were differences, why did soil A differ from B and C? Can his chemists detect the differences? If not, how can he explain? Through painstaking experiment, long after the original crop from these soils had been forgotten except as statistics, his experiments may produce some of the answers. But in the meantime, the rats in the granary have long since disclosed that they had a preference for one of the lots of corn over the others. Such an observation would frequently go unnoticed except by the curious such as the care-taker who was piqued by the spoiled photographic films in Roentgen's Laboratory, and an alert scientist. But why did the rats prefer one corn over the other? Will corn A produce a strain of animals that differ from the animals raised on corn B? The question has to be answered in the mind of the ecologist. So he chooses the rabbit and conducts a "controlled experiment." (Table 1). First he grows Korean Lespedeza on the five soil types: the Eldon Sandy loam, the Putnam silt loam, Clarksville gravelly loam, Grundy silt loam, and the Lintonia fine sandy loam. In each instance he uses both fields treated with lime and phosphorus and untreated fields. First, he studies the character of the hays. He describes the hays from the treated and untreated plots. He describes the rabbits, how they looked, how much they gained in weight, how much hay they had to eat to gain a gram, how much hay he obtained from an acre of soil and how many pounds of rabbits he could produce on each soil. He found a rather close correlation between rabbit gain, hay yield, and pounds of rabbits per acre. However, his curiosity did not stop there.

He wishes to know something about what the hays did to the physiology of the animal as well as to their weight. I am sure he would like to know about the offspring of these animals and their physical efficiency in other respects, but he has to satisfy his curiosity by looking at their bones. (Table 2). These he prepares, weighs and measures as to length and diameter, thickness of cortex, their

TABLE 1-NITROGEN AND CARBON ASSAY OF AN ALPINE SHRUB TESSERA, 315 YEARS OLD

Description of Layer or Horizon	Thickness and Depth cm	Grams of Nitrogen in Layers of 1 m^2. Area	Grams of Organic Carbon in Layers of 1 m^2. Area	C/N
Vegetation	23	25.0	1308.7	52.2
Litter layer	0 - 2.5	43.8	1029.0	23.5
Humus horizon	2.5 - 9	67.8	1477.0	21.8
Light-gray horizon	9 - 20	5.9	131.5	22.3
Brownish horizon	20 - 34	37.3	783.3	21.0
Brownish-gray horizon	34 - 60	16.9	235.9	14.0
Dark-gray horizon	60 - 95	27.4	178.7	6.5
Dark-gray horizon	95 - 100	0.0	0.0	---
	123	244.1	5144.1	22.9

TABLE 2-PROPERTIES OF THE BONES OF RABBITS FED ON HAYS FROM DIFFERENT SOIL TYPES WITHOUT AND WITH SOIL TREATMENTS.

Soil Type	Weight gm.	Length, cm.	Diameter, cm.	Thickness, mm	Breaking Strength, lbs.	Volume cc	Specific Gravity	Retained From Feed in Grams per Pen of Animals P	Ca	Ca/P
					Without Soil Treatments					
Eldon	2.26	6.88	0.520	0.70	22.8	3.11	0.71	25	163	6.4
Putnam	2.02	6.77	0.525	0.59	18.9	2.65	0.76	36	171	4.6
Clarksville	2.09	6.77	0.520	0.58	22.1	3.03	0.69	20	165	6.3
Grundy	3.07	7.24	0.570	0.84	30.0*	3.94	0.77	58	225	3.8
Lintonia	2.59	6.95	0.530	0.73	27.6	3.31	0.78	43	22.7	5.2
Average	2.40	6.92	0.533	0.69	24.3	3.21	0.74	36	190	5.3
Maximum difference,%	52.0	6.9	9.6	44.8	58.7	48.7	13.6	189	39	66.6
					With Soil Treatments					
Eldon	2.96	7.20	0.560	0.72	25.2	3.48	0.85	44	261	5.8
Putnam	2.35	6.88	0.540	0.77	26.4	3.21	0.72	34	179	5.2
Clarksville	2.63	6.93	0.548	0.71	24.2	3.29	0.79	37	165	4.3
Grundy	2.85	7.20	0.530	0.95	30.0*	3.63	0.78	60	201	3.3
Lintonia	3.26	7.33	0.565	0.82	30.0*	3.79	0.86	79	379	4.7
Average	2.81	7.11	0.549	0.79	27.2	3.48	0.80	51	237	4.7
Maximum difference, %	38.7	6.5	6.6	33.8	19.1	18.1	18.4	131	129	74.0

*In these cases the bones withstood the limit of pressure possible on the testing machine.

(From Biological Assays of Some Soil Types Under Treatments, Soil Science Soc. of Am., Vol. 8, 1944; McLean, Eugene O.; Smith, G.E.; and Albrecht. Wm.A.)

volume and how heavy they are when weighed in water. Then he breaks them and measures how much force they require to fracture. Here he finds that the soil treatment improves all bones in strength and they approach closer a 3 to 1 calcium-phosphorus ratio.

So it is that our friend, W. A. Albrecht, studies soils. He wants to know *what kind of animals and men it will produce, not just how many tons and bushels per acre.*

In our own laboratory, while Dr. Albrecht was working on soils, we found by accident that in the cooking of meat and milk unidentified heat labile factors were altered. Without this unidentified fraction in the dietary of cats, imperfect health in the older animal and imperfect development in the kitten ensue. We also found by accident that the excrement of animals on such diets does not promote normal plant growth. Furthermore, we found that adult cats can exist on a total cooked food diet for a maximum of one year seven months, most dying in less than a year. However, they pass deficiency on to their kittens even though they are returned to the normal uncooked diet, and that it takes four generations of animals to restore the strain on normal dietary.

The diets used were basically carcass meat, including muscle and viscera, especially brain, liver, and intestines, some skin and glands, milk and cod liver oil. In all experiments the control animals were fed raw meat from all parts of the animal and milk unheated, plus cod liver oil. In the meat experiments where cooked meat was studied, raw milk was used. Several grades of raw milk were investigated including commercial raw milk from cattle receiving only dry feeds as well as raw milk from cattle on green pasture or green cut feeds, pasteurized, evaporated and sweetened condensed milk. In the milk studies the animals were given ⅓ of the diet as raw carcass meat and ⅔ of the milk under study.

Our first purpose was to standardize experimental adrenal extracts on the totally adrenalectomized animal. In so doing we unexpectedly began to find out what heat treatment of meat did to adrenalectomized cats. The original observations were that animals fed cooked meat did not stand adrenalectomy well. Adrenalectomy was reported by others to affect mineral metabolism. We therefore studied the calcium and phosphorus of the femurs of 18 adult cats who died in the pens. Two raw meat fed cats had had no operative procedures, dying from disease. Four cats fed cooked meat and two fed raw meat had had one adrenal removed and two fed cooked meat and eight fed raw meat had had both adrenals removed. In the cooked meat fed group, the calcium range was from 11.8% to 14.8%, and the phosphorus from 5.9% to 6.8%. In the raw meat fed animals the range of calcium was 11.5% to 18.6%, while the phosphorus varied from 5.1% to 8.3%.*(2)

*Method of preparation of bones. Calcium and phosphorus were determined on whole bone. Upon death of the animal, the femurs were removed and placed in an ice chest at −25° C. for 24 hours. At the end of this time, all fat and muscular tissue could easily be peeled off the bones. Organic matter was destroyed by oxidation with nitric and perchloric acids.(3) Calcium was determined by titration with permanganate, a modification of the method used for serum calcium being used.(4) Phosphorus determinations were carried out by a modification of the method of Fiske and Subbarow.(5) The amounts of calcium and phosphorus found are expressed in terms of percent of the whole femur.

Two cats, acting as controls, died of other causes than surgery. The trend of calcium and phosphorus was higher in the raw meat fed cat than the cooked meat fed animals.

We had previously noted many differences in the appearance of the raw and cooked meat fed cats. This showed especially in their fur, which, in the raw meat cat, was sleek with a good sheen. These animals had a good disposition and were active. They reproduced normally and their viscera had good tone. In contrast, the cooked meat fed animals were riddled with fleas, sickly, lacked energy, reproduced poorly and passed their deficiencies on to the next generation, regardless of whether they had been replaced on a good diet before breeding.

There were marked differences in the mouths of the animals. Cats raised to adulthood on a normal dietary, when put on a cooked meat diet, developed gingivitis, pyorrhoea, loss of teeth, and their kittens showed poor skull development resulting in crooked teeth.

In Table 3, 18 adult cats comparable as to size and background and general development were studied. Of 12 raw meat fed and 6 cooked meat fed animals,

TABLE 3-CALCIUM AND PHOSPHORUS CONTENT OF FEMURS OF ADULT CATS

Cat Number	Normal or Deficient	Sex	Weight of Cat Grams	Weight of Femur Grams	Weight of Femur Body Weight Per cent	Calcium in Femur Per cent	Phos-phorus in Femur Per cent
1	N	M	2947	11.44	0.39	11.22	5.26
2	N	F	1503	9.37	0.62	11.60	5.17
3	D	F	1531	5.14	0.33	11.74	5.86
4	D	F	2370	10.47	0.44	11.80	5.55
5	D	F	1490	6.51	0.43	12.99	6.38
6	N	M	2745	12.40	0.45	13.25	6.39
7	D	M	3120	15.40	0.49	13.36	6.73
8	N	M	1025	3.78	0.36	13.70	6.94
9	D	F	----	10.78	---	14.00	6.35
10	N	F	3300	12.29	0.37	14.30	6.66
11	D	F	2754	8.24	0.30	14.70	6.70
12	N	M	----	11.26	---	15.49	7.31
13	N	M	2390	7.80	0.26	15.67	8.15
14	N	F	1950	6.86	0.35	16.08	7.50
15	N	F	2295	9.58	0.42	16.40	7.92
16	N	F	1285	6.16	0.48	16.72	8.00
17	N	F	2650	8.39	0.31	17.02	8.14
18	N	F	3312	9.28	0.28	18.37	6.25
Averages	N		2309	9.05		14.98	6.91
	D		2253	9.42		13.10	6.26
	N	C/P 2.1					
	D	C/P 2.09					

the average weight was 2253 grams compared with 2309 grams for the raw meat fed adult cats alone. The femurs of the cooked meat fed cats showed an average weight of 9.42 grams to 9.05 for the raw meat fed cats. The calcium was 14.98 percent for the raw to 13.10 percent for the cooked; phosphorus, raw, 6.91 percent to cooked, 6.26 percent. The calcium-phosphorus ratio was constant, N–

2.1 and D– 2.09, but the total weight of these minerals was greater in the bones of the raw meat fed animals.

In Tables 4, 5 and 6 the kittens were maintained on the respective diets of their mothers, who, when fed cooked meat, were on the diet at least six months before conception and throughout pregnancy. Of the 21 raw meat fed and 20 cooked meat fed kittens, their ages ranged from 1 day to 14½ months. They were comparatively equally spread as to age. The marked superiority of the raw meat fed kittens as to weight of body and femur is evident—1008 grams, raw meat fed; 638 grams cooked meat fed average weight of body; and 4.23 grams raw meat fed to 3.35 cooked meat fed for the femur. Also the calcium content of raw meat fed, 9.48% to cooked meat fed, 5.53%, and phosphorus of the raw meat fed, 4.58%, and cooked meat fed, 2.63%, favoring the raw meat fed cats. The calcium-phosphorus ratio was found to be, raw meat fed, 2.07, to cooked meat fed, 2.63. The higher calcium-phosphorus ratio in cooked meat cats has been noted in other studies.(6)

The calcium percent of the bones analyzed was plotted on the abscissa and logarithm of age as the ordinate. (Fig. 1) Kittens showed a variability with age. However, it is to be noted that the peaks and dips are comparable in the two curves. Each of the major dips corresponds to periods of eruption of teeth.

When the experiment is repeated using milk as the test food, there is an equally profound change in the bones, the fur, the viscera, the strength, and the disposition of the animals.

TABLE 4-CALCIUM AND PHOSPHORUS CONTENT OF FEMURS OF RAW FOOD KITTENS

Cat Number	Sex	Age	Weight of Cat Grams	Weight of Femur Grams	Weight of Femur: Body Weight Per cent	Calcium Per cent	Phosphorus Per cent
1	---	1 da.	---	0.1091	---	10.06	6.02
2	---	5 das.	129	0.1305	0.10	12.23	5.78
3	F	5 das.	115	0.1451	0.12	14.25	7.15
4	---	3 wks.	---	0.75	---	5.31	2.26
5	M	5 wks.	335	0.98	0.28	7.04	3.89
6	F	5 wks.	393	1.06	0.27	7.50	3.74
7	M	5 wks.	377	0.79	0.21	10.59	5.28
8	F	8 wks.	965	4.77	0.49	4.73	2.25
9	M	8 wks.	977	5.21	0.53	5.97	2.85
10	F	8 wks.	715	4.25	0.59	6.48	3.10
11	F	12 wks.	1085	5.63	0.52	7.64	3.66
12	F	12 wks.	800	5.67	0.71	8.55	4.21
13	F	12 wks.	1062	5.87	0.55	8.61	4.09
14	M	12 wks.	1277	6.95	0.54	8.69	3.95
15	F	12 wks.	900	4.89	0.54	8.83	4.08
16	F	12 wks.	1300	6.17	0.62	9.45	4.31
17	M	12 wks.	1275	5.01	0.39	11.59	4.93
18	M	14 wks.	1117	4.53	0.41	15.03	7.35
19	F	10 mos.	1503	9.37	0.62	11.60	5.17
20	M	13.5 mos.	2732	8.48	0.31	12.40	6.02
Averages			1008	4.23		9.48	4.55
	C/P 2.08						

TABLE 5-CALCIUM AND PHOSPHORUS CONTENT OF FEMURS OF DEFICIENT KITTENS

Cat Number	Sex	Age	Weight of Cat Grams	Weight of Femur Grams	Weight of Femur: Body Weight Per cent	Calcium Per cent	Phosphorus Per cent
1	F	1 da.	112	0.0829	0.074	10.79	5.49
2	---	1 da.	---	0.1330	----	11.92	6.15
3	---	3 wks.	261	0.75	0.28	5.32	2.53
4	F	7 wks.	310	1.84	0.59	5.14	2.41
5	M	7 wks.	261	0.97	0.26	6.76	3.24
6	F	8 wks.	400	1.93	0.48	4.49	2.42
7	M	9 wks.	565	2.91	0.51	3.19	1.61
8	M	9 wks.	514	2.83	0.55	3.37	1.73
9	F	9 wks.	434	1.94	0.45	6.27	2.29
10	M	12 wks.	335	2.15	0.64	4.32	2.20
11	F	12 wks.	523	3.28	0.62	3.51	1.79
12	M	14 wks.	1120	5.25	0.46	2.88	1.53
13	M	14 wks.	610	4.39	0.72	4.12	1.84
14	M	15 wks.	890	6.31	0.71	3.95	1.73
15	M	16 wks.	730	5.29	0.72	2.44	1.24
16	F	16 wks.	885	2.65	0.29	7.45	3.64
17	F	16 wks.	915	4.94	0.54	6.74	3.22
18	M	18 wks.	915	4.24	0.49	4.80	2.03
19	F	8 1/2 mos.	1009	2.85	0.28	4.77	2.42
20	F	14 1/2 mos.	1335	5.97	0.45	8.52	4.22
			638	3.35		5.53	2.63
	C/P 2.63/1						

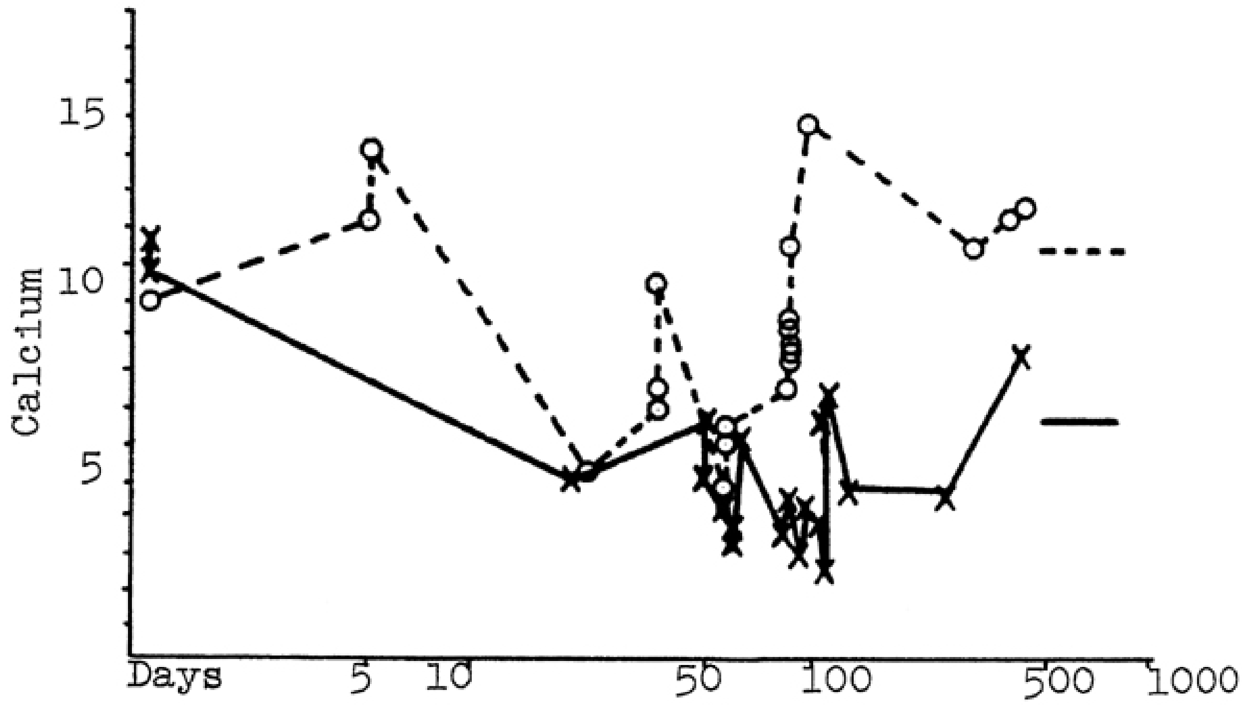

Fig. 1—Calcium content of femurs of raw food and deficient kittens.

TABLE 6-CALCIUM AND PHOSPHORUS CONTENT OF FEMURS OF NEW-BORN KITTENS AND THEIR MOTHERS

Cat Number		Type of Cat Diet	Sex	Age	Weight of Cat Grams	Weight of Femur Grams	Calcium in Femur Per cent	Phosphorus in Femur Per cent
A. Kittens:	a	Raw	---	1 da.	---	0.1091	10.06	6.02
	b	Raw	---	5 das.	129	0.1305	12.23	5.78
	c	Raw	F	5 das.	115	0.1451	14.25	7.15
	d	Cooked	---	1 da.	---	0.1330	11.92	6.15
		Cooked	F	1 da.	112	0.0829	10.79	5.49
B. Mother Cats:	a_I	Raw	F	13 mos.	3200	7.74	10.04	4.83
	c_I	Raw	F	14 mos.	1957	8.09	12.43	5.60
	d_I	Cooked	F	6 yrs.	4600	10.78	14.00	6.35

Mother of corresponding kitten indicated by subletter. Mother cats b, and e, are still alive.

We pursued the study of the health of raw fed and cooked fed cats to their effect on the soil. In 1939 we planted navy beans in each of three plots: (a) one in which the beans were fertilized with the non-composted excreta of cats fed raw meat, (b) one with the excreta of cats fed cooked meat, and (c) one in which no fertilizer was used. This was the control plot. Observation were made on the rate of growth, color and structure of the plants and beans produced. The beans were harvested and part of them analyzed for their various chemical constituents.

The following year, 1940, the experiment was repeated. The seed harvested from the plants fertilized with the excreta of cats fed raw meat, was planted and the plot treated with composted manure from raw-meat cats. This was repeated for the cooked meat and no-fertilizer groups. Two new plots were added. Some of the seed of the nonfertilized beans grown in 1939 was planted and one plot fertilized with the composted excreta of cats whose main diet consisted of pasteurized milk and the other fertilized with the excreta of cats whose main diet was certified raw-vitamin D milk. This made five plots, namely (1) pasteurized milk, (2) certified milk, (3) raw meat, (4) cooked meat, and (5) no fertilizer. The growth of the plants was again observed. The beans, plants, and pods harvested were subjected to chemical analyses.

In the 1939 experiment no apparent difference was noted in the size, color, or shape of the beans grown on the three different types of fertilizer.

The germination of the beans was graded as follows: no-fertilizer group, 96%, raw meat, 88%, cooked meat, 72%. Two weeks after planting, the no-fertilizer plants were the tallest; the raw meat and cooked meat were about equal in height. The plants on raw-meat fertilizer had the best form and color. Three weeks after planting, the cooked meat group of plants was the tallest, the no-fertilizer was next, and the raw meat, the shortest. This rate of growth obtained throughout the experiment. The plants on cooked meat fertilizer were pale green in color, had many more stems and leaves, and their stalks were thinner than the plants of the other two groups. Plants on raw meat fertilizer were short and squat, had a much deeper color, and were sturdier than the plants on cooked meat fertilizer. The no-fertilizer plants were intermediate between the raw and cooked meat groups with respect to the above mentioned features. The leaves of the plants on cooked meat fertilizer were flabby and thin and felt much like tissue paper, those on raw meat fertilizer were firm and heavy in texture, while those on no-fertilizer fell a little below the raw meat. The beans were transplanted to larger plots a month after planting. It was found that the roots of the plants on raw meat fertilizer were at least twice as numerous, tougher and longer than those of the others. The no-fertilizer plants were intermediate, while the roots of the cooked meat plants were less numerous, soft, and mushy.

The beans were analyzed for their moisture, ash, calcium and phosphorus content. The results of the analyses are given in Table 7.

TABLE 7-ANALYSIS OF NAVY BEANS. FIRST GENERATION.

	Type of Fertilizer	Moisture per cent	Ash per cent	Calcium mg. per 100g.	Phosphorus mg. per 100g.
Navy Beans	Raw Meat	11.56--11.82	4.15--4.08	148--140	377--389
	Cooked Meat	11.52--11.50	3.92--3.85	118--121	371--377
	No-fertilizer	13.21--13.49	3.48--3.55	153--155	396--392

In 1940, the observations made on the growth of the plants were similar to those of 1939. In the two plots fertilized with the excreta of cats on the milk diets, the beans of the certified milk group germinated ahead of, and the beans formed earlier than, those of the pasteurized milk group. The beans grown in the plot fertilized with the excreta of cats fed raw meat were by far the best. These plants were sturdier, their color better, and the texture of the leaves superior to any of the others.

Pasteurized Milk. The beans had a hard, smooth white surface. The most noticeable features were the flatness of the beans and their oblong shape.

Certified Milk. These beans exhibited the same general features as those of the pasteurized milk group.

Raw Meat. These beans also had a hard, smooth, white surface. Uniformity of size and plumpness of the beans distinguished them from the beans of all other groups.

Cooked Meat. In this group one-fourth of the beans were shriveled and yellow in color; the remainder were smooth and white. They also were more plump than the milk beans but they were not as plump as the raw meat beans. They also exhibited the peculiar oblong shape of the milk beans.

No-fertilizer. These were smooth and white. They were more plump than either of the milk beans but not as plump as the meat beans.

There was marked variation in the size and weight of the different groups of beans. Of the pasteurized milk beans, the variation in weight was from 72.2 milligrams to 198.5 milligrams with an average of 117.9 milligrams. In the certified milk group, the variation was from 74.5 milligrams to 203 milligrams with an average of 121.7 milligrams. For the raw meat beans, the smallest was 107 milligrams and the largest 210.4 milligrams with an average of 166.2 milligrams. For the cooked meat, the smallest was 35.8 and the largest 201.9 milligrams with an average of 146.7 milligrams. The no-fertilizer beans varied from 62.1 to 194.6 with an average of 113.5 milligrams. (Fig. 2)

A portion of the beans and the dried plants and pods was subjected to chemical analysis. The results obtained on the beans are given in Table 8, the plants in Table 9, and the pods in Table 10.

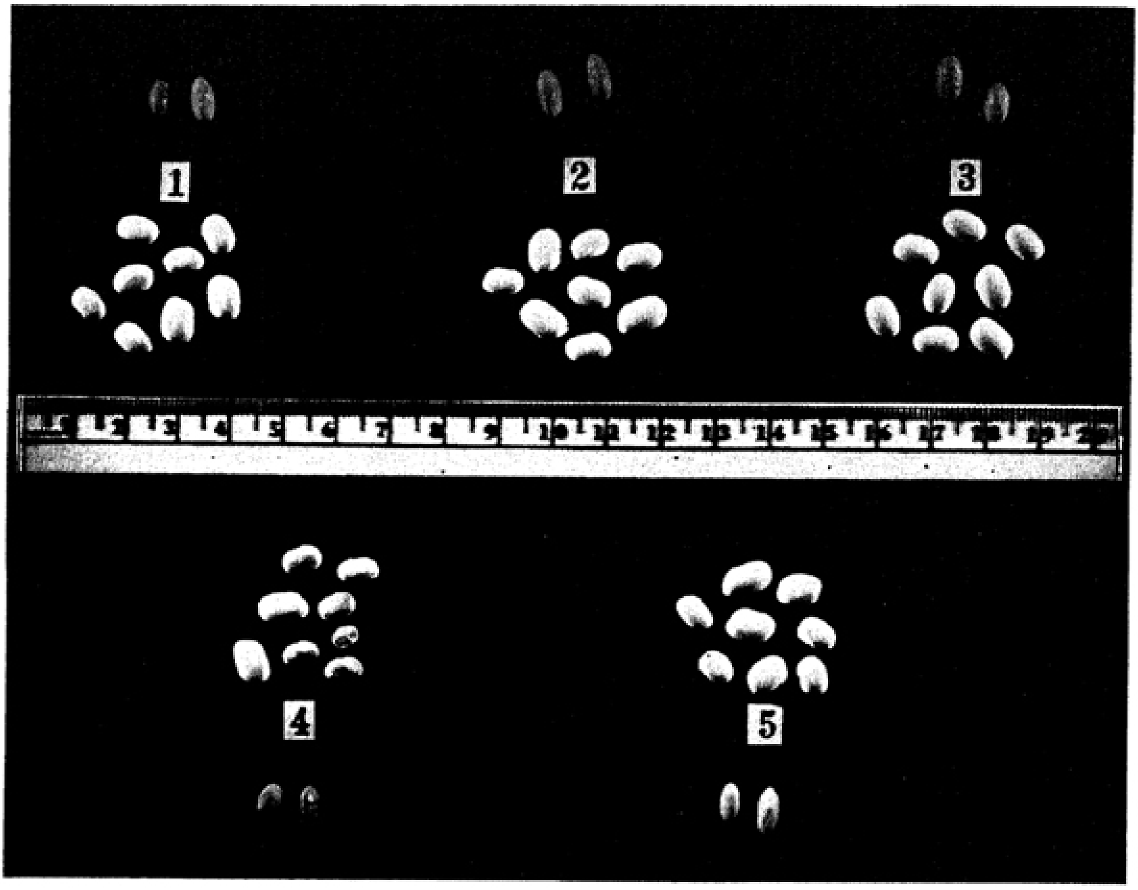

Fig. 2—Beans fertilized by composted cat manure and control. 1. Pasteurized milk beans. 2. Certified milk beans. 3. Raw meat beans. 4. Cooked meat beans. 5. No fertilizer beans.

TABLE 8-ANALYSIS OF NAVY BEANS; SECOND GENERATION

Type of Fertilizer Used on Beans	Moisture per cent	Ash per cent	Calcium mg. per 100g.	Phosphorus mg. per 100g
Pasteurized Milk	12.78 -- 12.97	4.33 -- 4.30	80.2 -- 78.8	489 -- 478
Certified Milk	12.22 -- 12.39	3.82 -- 3.81	67.4 -- 68.5	411 -- 412
Raw Meat	12.91 -- 12.97	4.14 -- 4.12	131.0 -- 130.0	448 -- 449
Cooked Meat	12.54 -- 12.61	3.94 -- 3.92	87.5 -- 89.0	455 -- 457
No Fertilizer	12.51 -- 12.66	4.15 -- 4.03	83.1 -- 86.3	490 -- 487

TABLE 9-ANALYSIS OF NAVY BEAN PLANTS; SECOND GENERATION.

Type of Fertilizer Used on Beans	Moisture per cent	Crude Fat per cent	Crude Fiber per cent
Pasteurized Milk	8.90 -- 8.92	5.11 -- 5.21	35.84 -- 35.44
Certified Milk	8.58 -- 8.43	5.28 -- 5.36	33.71 -- 32.88
Raw Meat	8.68 -- 8.56	5.82 -- 5.54	35.81 -- 35.74
Cooked Meat	7.70 -- 7.71	9.21 -- 9.73	27.01 -- 26.92
No Fertilizer	8.88 -- 8.71	5.81 -- 5.80	27.50 -- 27.67

TABLE 10-ANALYSIS OF NAVY BEAN PODS; SECOND GENERATION.

Type of Fertilizer Used on Beans	Moisture per cent	Crude Fat per cent	Crude Fiber per cent
Pasteurized Milk	9.61 -- 9.73	14.15 -- 14.43	26.89 -- 27.33
Certified Milk	8.75 -- 8.81	17.69 -- 17.96	28.63 -- 28.91
Raw Meat	11.29 -- 11.57	15.29 -- 15.39	28.54 -- 28.27
Cooked Meat	7.19 -- 7.16	24.81 -- 25.22	29.89 -- 30.31
No Fertilizer	11.04 -- 10.81	13.64 -- 13.37	26.70 -- 27.05

DISCUSSION

Definite conclusions cannot be drawn from this experiment, but it suggests the possibility that excreta of diseased and healthy animals contain principles which affect plant growth, and that the health of the animal determines to some degree the effect on the vitality of the plant and its seeds, as well as the chemical constituents of the plant, seed and pod of the beans studied. In view of the fact that some of the beans from the cooked meat fertilizer were smaller and more irregular than those beans not receiving fertilizer, elements toxic to plants may be present in the manure of deficient animals.

In 1942 we made a further simple observation which linked the health of animals to the condition of the soil. We had built the cat pens on land which had never served as a home for any animals. Each pen had an open air enclosure 12 feet long and 6 feet wide. A trench 18 inches deep was dug in this enclosure and filled with fresh washed sand from a common sand pile. A roofed area four feet deep, with a wooden floor, was built at the back of each pen to act as a shelter for the animals in inclement weather. The animals spent much of their time in the open part of the pen. They buried their excreta in the fashion normal for cats. The caretaker removed bones and uneaten portions of meat daily, and cleaned and refilled the water containers. Periodically, he screened the sand, composting the excreta into marked piles for future studies of soil.

Apart from the studies on beans we performed with the composed manure from the various pens, we observed the following circumstances in the pens which lay fallow for five months at the conclusion of the experiment: volunteer weeds came up in each pen. (Fig. 3 & 4) The number of weeds and their hardiness were in direct proportion to the health and vigor of the animals that had lived in the pens. The accompanying illustrations of these weeds also indicate that male and female cats on the same feed contributed a different degree of hardiness to the weeds.

Following the harvesting of the weeds, we planted navy beans in the pens. (Figs. 5, 6 & 7) The growth of these beans, in number, outward appearance, and in other respects (Table 11) bore the same distinct relationship to the health and vigor of the animals that had lived in the pens as did the volunteer weeds.

The following chart will indicate the principal observations. These beans were studied weekly and results of texture, state of growth, were all recorded.

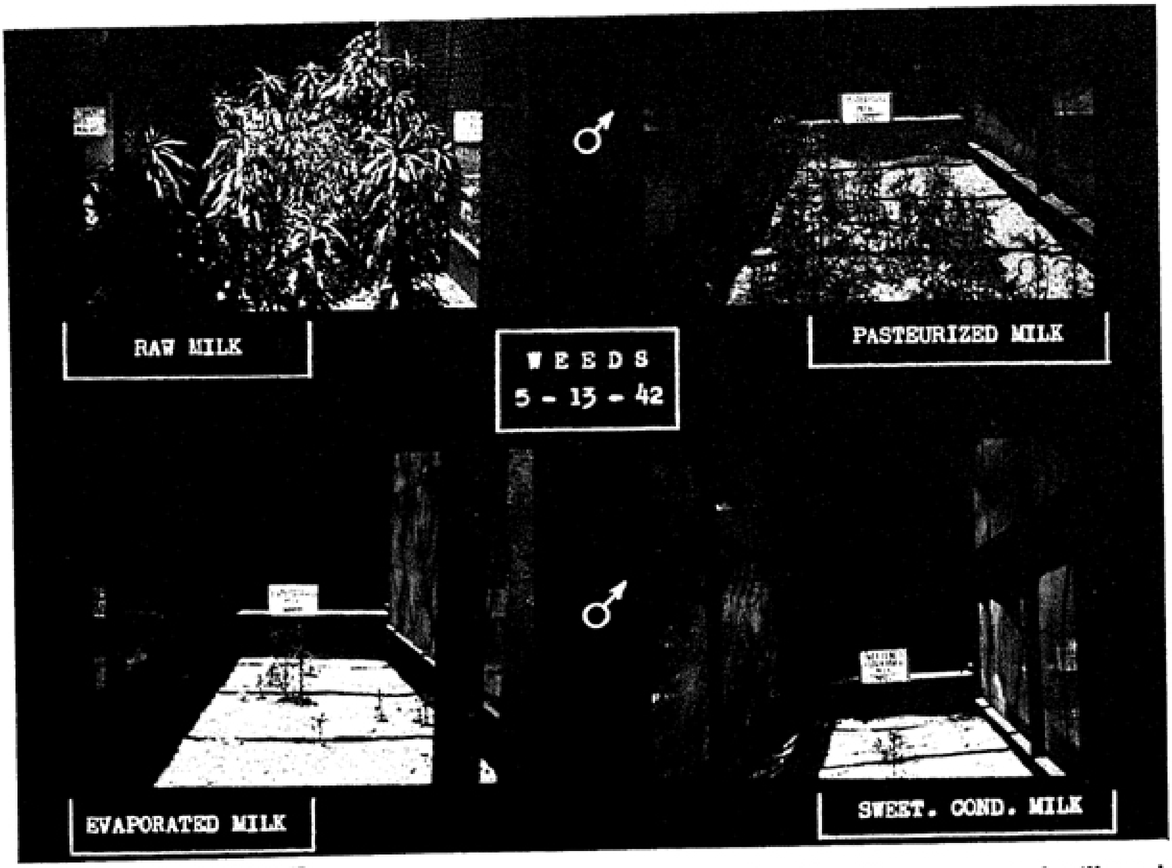

Fig. 3—Pen 18—raw milk-males. Pen 20—pasteurized milk-males. Pen 22—evaporated milk-males. Pen 24—sweetened condensed milk-males.

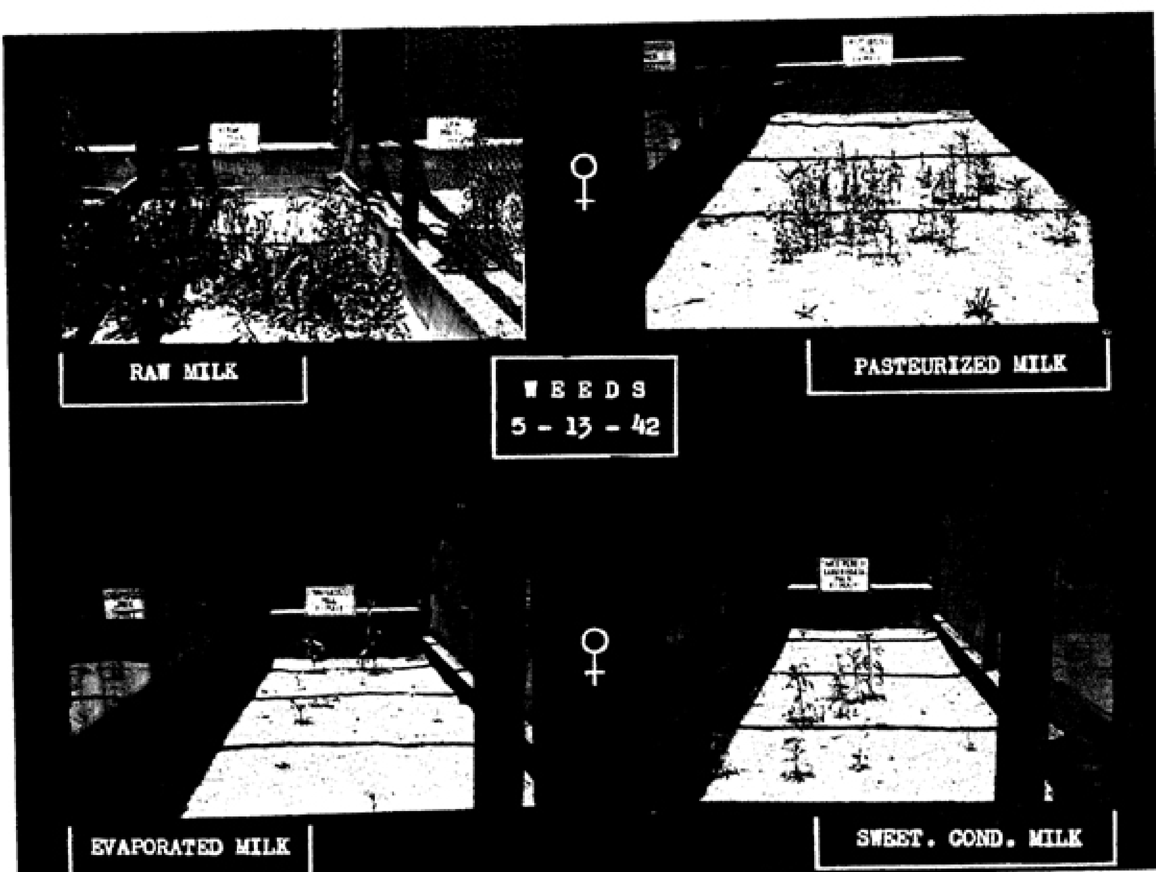

Fig. 4—Pen 17—raw milk females. Pen 19—pasteurized milk females. Pen 21—evaporated milk females. Pen 23—sweetened condensed milk females.

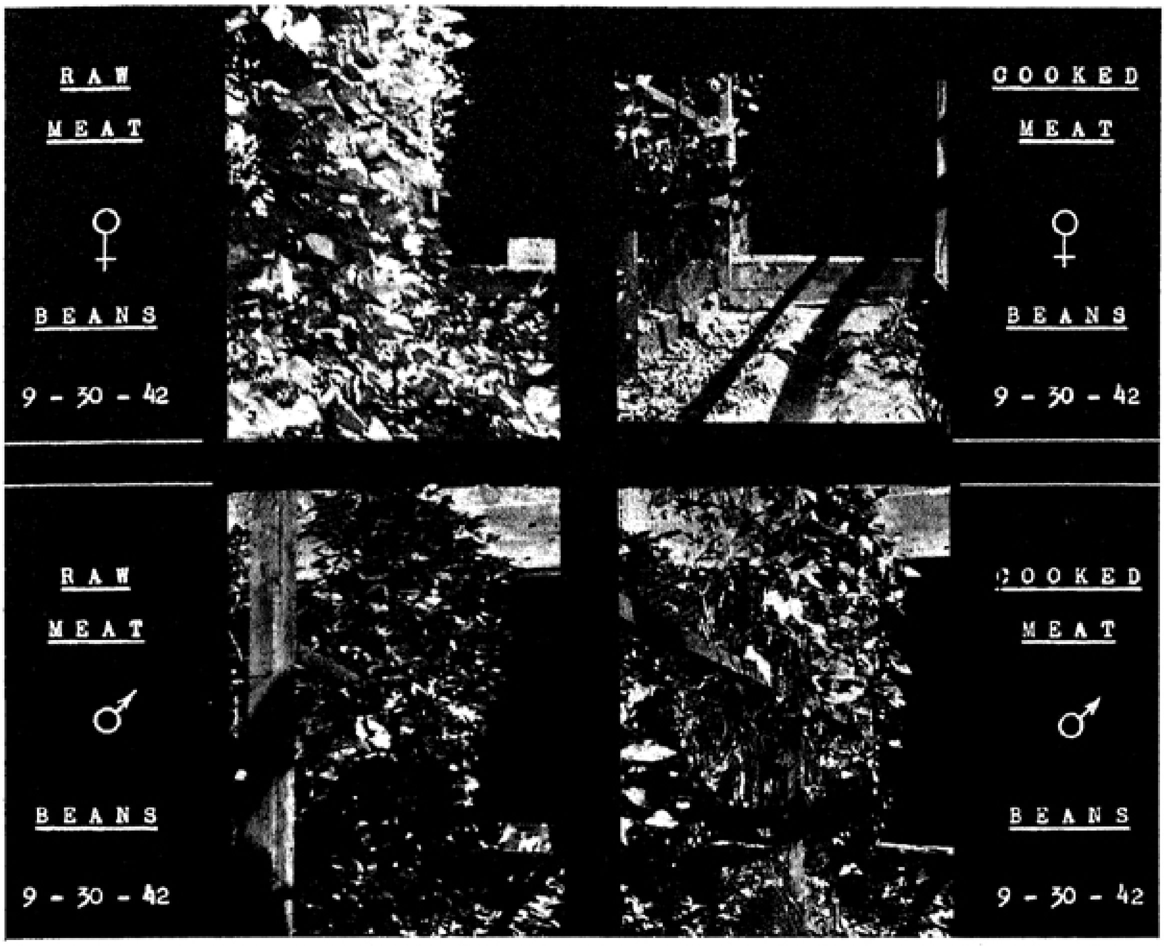

Fig. 5—Pen 13—cooked meat females. Pen 14—Cooked meat male. Pen 15—raw meat males. Pen. 16—raw meat females.

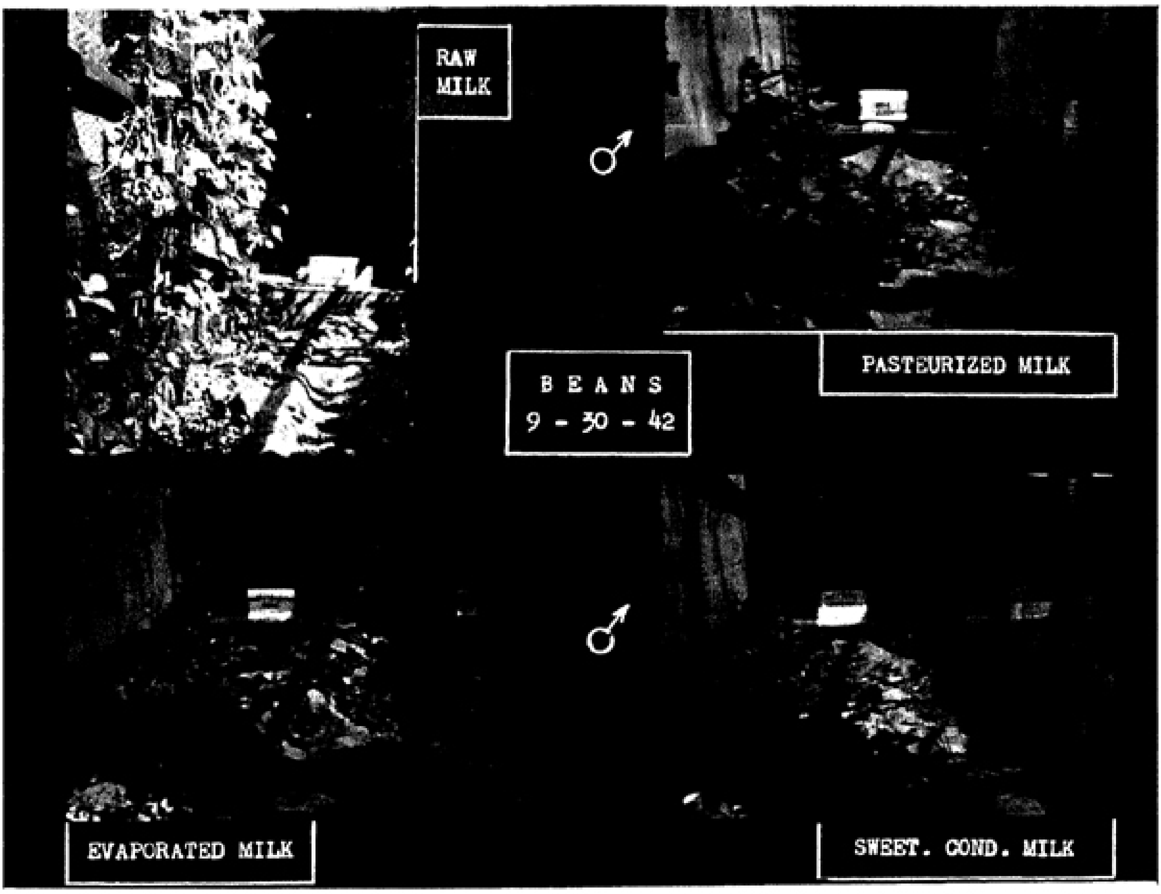

Fig. 6—Pen 18—raw milk males. Pen 20—pasteurized milk males. Pen 22—Evaporated milk males. Pen 24—sweetened condensed milk males.

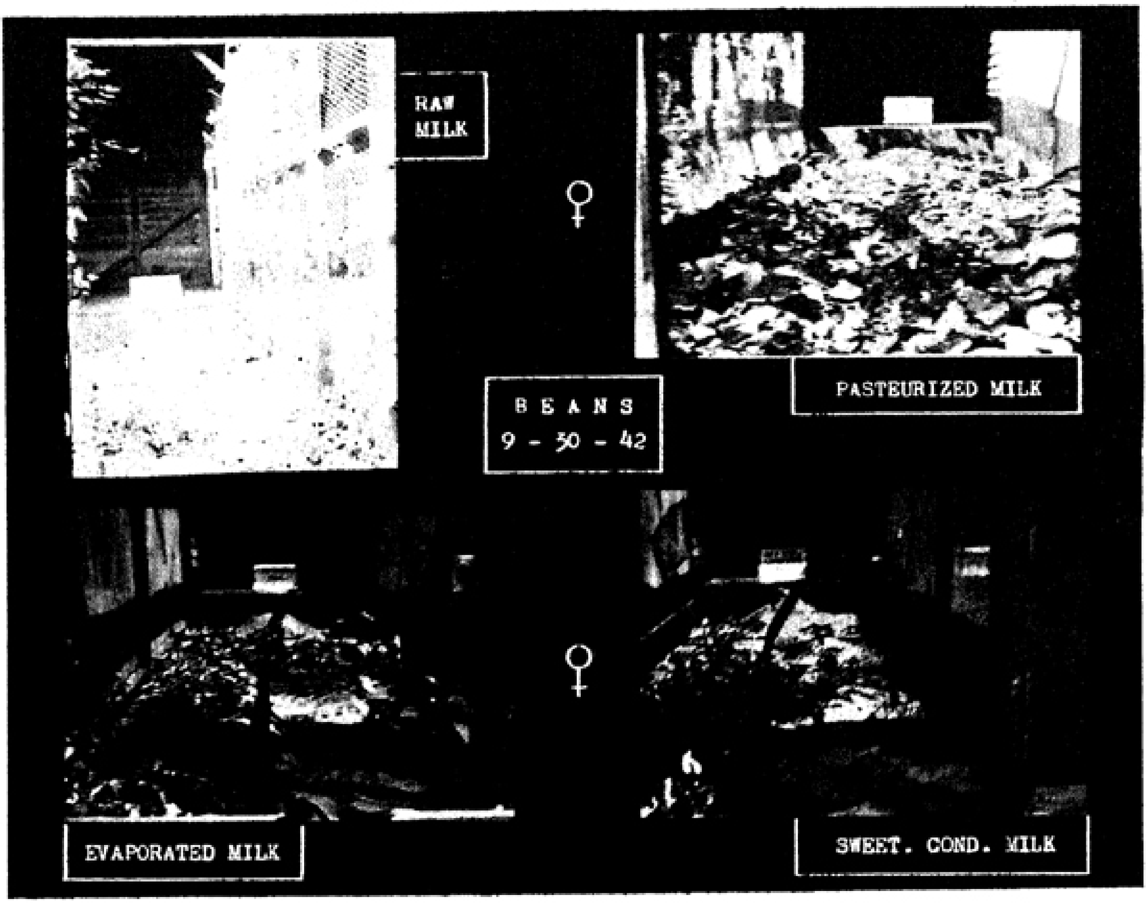

Fig. 7—Pen 17—Raw milk females. Pen 19—Pasteurized milk females. Pen 21—evaporated milk females. Pen 23—sweetened condensed milk females.

We wish to note that pens 13 and 14 had been used for breeding purposes, though pen 14 more frequently housed male cats alone and pen 13, female cats alone. This fact may have some bearing on the results.

The minutiae of the studies we made on the composted manures from the individual pens is unsuitable for inclusion in this report. However, the bean plants which grew on the composted soils behaved in almost identical manner to the volunteer weeds in the same pens.

We believe that the healthy animals in our pens returned to the soil materials which, in turn, raised healthy plants; that the sick animals returned to the soil materials inadequate or even toxic for the growth of the plants. The male cat likewise affects the soil with greater growth stimulation than the female for the navy bean and the volunteer weeds.

Though ecology is usually divided into parts and subparts, it is only as we look at the relationship of soil, plant, animal, and man, with environmental factors such as wind, humidity, clouds, sunshine, rain, and the hand of man as he applies inorganic and organic material for fertilizer, weed and pest control to the soil, and contaminates the atmosphere with gases of combustion from his

TABLE 11

	Pen	Color	Growth	1st Blossoms	No. of Blossoms	Period of bloom	No. of Beans	No. of Pods	Beans per pod	Life of plant (days)
Cooked meat-0 Males & females	13	good sl.yel.	mixed poor & excellent	70 days	500	49 days	700	134	5.2	147
Cooked meat-# Males & Females	14	good sl. yel.	mixed poor & excellent	63 days	2500	49 days	1886	451	4.2	147
Raw meat Males	15	deep green	Ex. thick stems	77 days	2000	70 days	1142	357	3.2	161
Raw meat Females	16	deep green	excellent	91 days	1800	56 days	684	220	3.1	161
Raw milk Females	17	bright green	good	63 days	550	49 days	1092	328	3.3	126
Raw milk Males	18	bright green	good	63 days	1200	49 days	3487	659	5.3	147
Past. Milk	19	poor	weak	63 days	500	42 days	615	146	4.2	126
Past. Milk Males	20	fair	fair	63 days	600	35 days	1045	298	3.5	126
Evap. Milk Females	21	fair	weak fine stems	63 days	300	49 days	120	42	2.8	126
Evap. Milk Males	22	fair	weak sprawled	63 days	300	49 days	339	126	2.7	126
Sweetened Cond. Milk Females	23	fair	poor	63 days	350	49 days	190	69	2.7	112
Sweetened Cond. Milk Males	24	fair	poor weak stems	63 days	350*	42 days	1252	407*	3.0	119

*Counts were made weekly. Some blossoms were probably missed.
O- Breeding pen normally housed female cats.
- Breeding pen normally housed male cats.

engines and manufacturing plants, or the aresols and dusts from agricultural practices, that we get a total picture of the ecology of modern times.

The ecologic cycle has always been variable. The plant and animal population including man, has been physically modified as natural forces have altered environment. The simple factor of rainfall is continually changing. The rainfall may be gentle, evenly stretched over the so called rainy season, or it may fall all at once in the space of a few hours leaving catastrophe to animal, plant, and soil. When rain comes as a deluge, the total precipitation for the year may be high, but because of the short space of time involved the summation of the effects may be similar to those found in years of serious drought. There are years of cyclonic winds, sometimes accompanied by driving rains in a given area, altering the ecological pattern. In other years not only may the rainfall vary but variable humidity may be experienced; or a dust storm may be tragic to one area where the soil surface is eroded, yet may be a blessing to another where the soil is deposited.

The effect of weather on the living elements in the basic soil of a given region may alter its water retention and fertility. In turn the pattern of vegetation may be completely changed, the wild life pattern redistributed. The large animals may migrate. The lesser may die off in large numbers and those remaining become scrawny. It may be years before the former environmental factors return, if ever.

Man has been pointed to as the perpetrator of the greatest disasters to fertility and potential agricultural resources by ignoring the relation to each other of forests, soils, and the animals that dwell in them.

Marco Polo recounts the abundance of forests and animal life of China, but by modern times these have largely disappeared. Lack of conservation practices in the water sheds of the Tigris and Euphrates destroyed the fertility of the valleys and their civilization. In the desert areas of North Africa where shifting sands have swallowed the fertile fields of past civilizations, the adventurer finds the olive press and other evidence of human habitation in a vast sea of waste, again credited to the misunderstanding of total ecology by the men of that day.

Similarly, extensive areas of our own country have been transformed as the ecological pattern of soil, plant, animal, and human life have been altered.

Students of bionomics find today that the primordial life cycle from the soil to the plant, through the animal and back to the soil is frequently disrupted. Man fails to return to the soil much of his crops, his animals and excrements, thus breaking the natural cycle of life. So, in striving to maintain his economy, man must artificially return to the soil that which he removes.

In Japan and China it is reported that the human exrement from the well-to-do is considered more valuable than that from poorer populations. With the "honey bucket" the ecological cycle is only partially complete, since much of the produce of the soil is exported not only from the rural sections to the cities but to other countries as well.

It is a great pleasure to be asked to contribute to this testimonial Soils Conference in honor of Dr. William Albrecht. It is a privilege to pay tribute to an intrepid man whose interest is not confined to the ionic exchanges in the clays of the soil but what these ionic exchanges mean in the production of plant life, animal life, and man. Dr. Albrecht is not merely interested in the bushels per acre but believes that plant life must be interpreted in nutritive value, using its protein content as an index of quality. Again, he appreciates not just the protein of the plant but the quality of the protein. And finally, he knows how the quality of the plant will reflect on the health of the animals who consume the plant, and thus on to man. I owe my own debt of gratitude to Dr. Albrecht's discovery of these relationships.

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