Soils and Their Relationship To Food Production

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Response of corn to 1000 pounds 8-8-8 fertilizer applied 6 inches deep at planting time on right

Effect of copper sulfate on onions grown in organic soil

Left. Copper sulfate 100 pounds per acre
Right. No copper sulfate
Both received 1000 pounds 0-10-30 per acre

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THE RELATION of soils to food production is of vital importance and concern to every country in the world. The influence of the quality of soil and the effects of soil nutrients and fertilizers on the nutritive quality of crops and the health of animals and men, has been the subject of broad and vigorous differences of opinion.

Soil, atmosphere, plant, animal, and man are related in a cycle in which the materials are used over and over again. Man is dependent on animals and plants; animals upon plants; plants upon soil; soil upon rocks, minerals, and the materials that are returned to it. Thus, a great "wheel of life" (Figure 1) is established in which the forces of construction balance those of destruction.

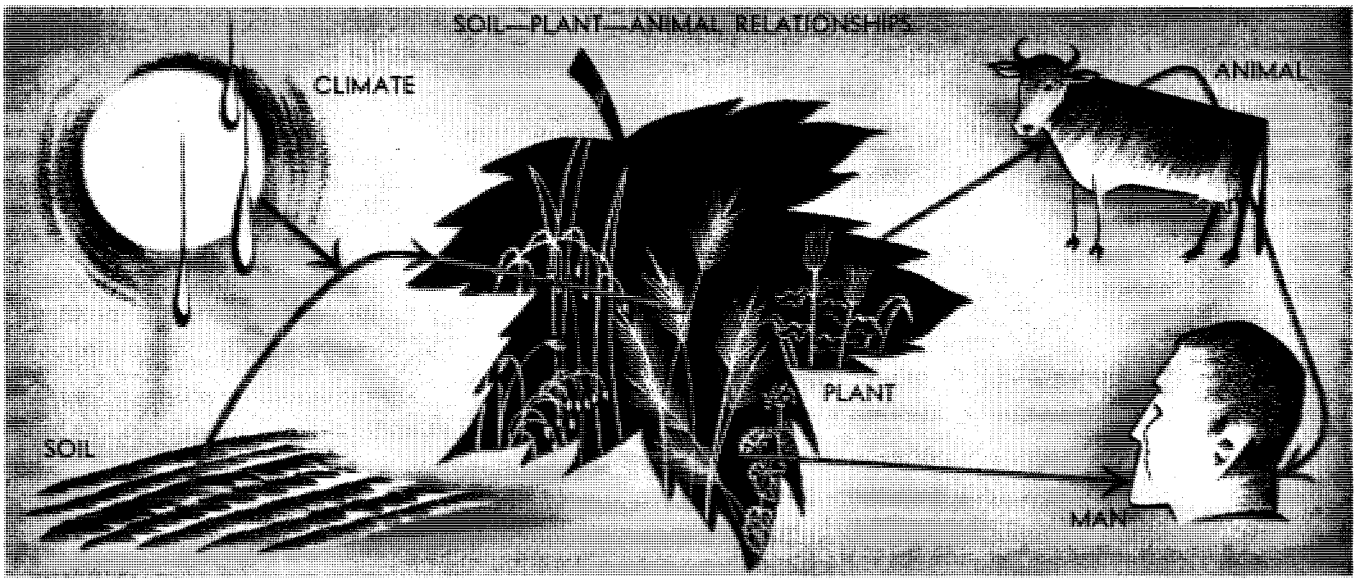
As the same materials are used over and over again in this cycle, the sum total of the elements in the world remains relatively fixed, but there is continuous movement of these elements from one position to another. For each one of the chemical elements required by animal, man, or green plants, the cycle varies in complexity.

Factors Affecting the Nutritive Value of Crops

The principal factors affecting the nutritive quality of crops are: (1) the soil and its management, (2) climate, and (3) genetic factors inherent in any specific plant.

The soil is a highly complex dynamic system of minerals, organic and inorganic compounds, living organisms, air, and water. It may exert a marked influence not only on the yield but also on the mineral content of the crop. There are two general types of nutritional troubles in animals for which certain conditions in some soils clearly have been shown responsible. These two general classes are: (1) nutritional troubles brought about by natural deficiencies of one or more chemical elements in the feed produced on deficient soils, resulting in bone disorders or diseases, and (2) nutritional troubles resulting from toxicities due to a natural excess of certain chemical elements in the soil and consequently in the plants grown on such soils. For example, a disease of great economic importance in animal production in the western part of the country is caused by excessive quantities of selenium in some soils and plants growing in them.

It is of interest to point out that all plants need the same mineral elements as humans (Table I), excepting sodium, cobalt, chlorine, and iodine, and in addition they need boron and molybdenum.



If techniques of sufficient precision were available, it is possible that the essentiality of many other elements might be demonstrated.

Distribution of Nitrogen And Minerals in Soils

It is well known that soils vary in their content of the important nutritive elements. Climate is a factor in producing this variation as is indicated in Table II showing nitrogen variations.

It is observed that the average total nitrogen content of soil shows a 10-fold variation. In regions of comparable temperature, the nitrogen content increases with increasing soil moisture and in regions of comparable soil moisture, nitrogen decreases with increasing temperature. These relationships reflect themselves in crop yields, especially corn yields.

The calcium content of soils varies greatly. Two main factors which govern its distribution: (1) the amounts of calcium, as oxide in the rocks from which it comes, varies from more than 50% in limestone to near zero in some sand and clay deposits; (2) the climate—effects of rainfall on the calcium content of soils in Nebraska is presented as an example (Figure 2).

Because of the decrease of calcium with increase in rainfall, soils tend to be acid and low in lime in regions of high rainfall.

The make-up of parent rocks also influences the amount of phosphorus in a soil. Phosphorus content is less affected by climate than are many of the important nutrient elements. But phosphates tend to become less available as soil formation proceeds. Because of the nature of the soils, the availability of phosphorus may differ widely in two soils of similar phosphorus content.

According to Beeson [*Am. Plant Food J.*, 5, 6–11 (1951)], "An abnormally low level of phosphorus in the soil and in forage crops is the most widespread and economically important factor in nutritional troubles in grazing animals. Such difficulties occur in many parts of the West, the Northeast, and along the Atlantic and Gulf Coastal Plains."

Iodine is an element widely distributed in nature and very important to human body needs; but, in contrast to calcium and phosphorus, it occurs in amounts so small that it is not determined in ordinary soil analyses. Its presence or absence in the soil was first evaluated by biological tests, namely, the distribution of goitre, an iodine-deficiency malady. The iodine content of soils appears to be closely related to the nature of the original or parent rocks. It also has been shown that soils having an alkaline reaction absorb or retain relatively little iodine.

Cobalt is another mineral element occurring in soils in relatively small quantities. A deficiency of this element in soils and crops is responsible for nutritional disturbances in cattle and sheep in several areas. Some of these animal nutritional disturbances can be prevented by feeding cobalt salts or by adding a cobalt compound in fertilizers applied to deficient soils. There is no evidence to indicate that cobalt is essential to the growth of plants.

Soil Management

Good soil management, including the application of fertilizers and the correct tillage practices, not only increases total production, but also makes possible a wider choice of those crops of higher nutritive value which may be grown on any soil.

From the nutrition point of view, the following aspects of plant growth are important:

(1) Production or total yield per acre
(2) Kind of plant species that will grow on a soil
(3) Composition of species grown
 (a) Mineral content
 (b) Vitamin content
 (c) Protein content and quality
 (d) Hormones present

Production or Total Yield per Acre As pointed out earlier, the yield of a given plant depends on climate and soil, but within regions of uniform climate the soil component may be evaluated precisely. We have numerous illustrations in Michigan and throughout the United States where adjacent soils produce widely different yields.

The variation in the productive capacity of some of our soils in the United States is great. The inherent fertility of our soils and management practices, including the use of fertilizers and lime,

DIETARY ESSENTIALS

From the soil	*Manufactured by plants and animals*
Nitrogen, potassium, phosphorus	Carbohydrates
Calcium, iron, copper	Fats
Iodine, sulfur, manganese	Proteins
Cobalt, magnesium, zinc	Vitamins
Sodium, chlorine, etc.	

Table I. Total Nitrogen Content in Surface Soils of Great Plains Area
(Climatic distribution—Jenny[a])

Annual Temp. °C.	Annual Moisture Index → 100	200	300	400
	Nitrogen Content, %			
0	0.22	0.35	0.43	0.48
5	0.15	0.23	0.29	0.32
10	0.10	0.16	0.20	0.21
15	0.07	0.10	0.13	0.14
20 ↓	0.04	0.07	0.09	0.10

[a] Hans Jenny, "Factors of Soil Formation," 1st ed., p. 172, New York, McGraw-Hill Book Co., 1941.

have a direct relationship to the amount of feed or food that can be produced per unit area.

It has been estimated that we shall need 40% more agricultural production in the United States by 1975 than at present. We have an enormous capacity for increased production on existing farms with practices already known and tried. It has been estimated that if all our farm managers were working as efficiently as are those of the upper 10%, U. S. farmers could produce over 100% more than they did in the period 1935–39. Probably more than one fourth of our total crop production today is directly attributable to the use of commercial fertilizers. Fertilizers, teamed up with good farming practices, can increase crop yields more than any other single factor.

Kind of Plant Species that Will Grow on a Soil

There are many areas in the United States capable of producing fruit trees well, but which require heavy fertilization with phosphate, potash, and lime to produce good vegetable crops. The relationship between soil acidity and lime in the growth of alfalfa and certain other legumes is so well known as to be elementary to farming. Legumes, in general, demand high levels of calcium, phosphorus, and potassium in the soil to produce satisfactory growth.

The use of fertilizers and lime to increase the proportions of legumes in hay and pastures is of definite advantage to the nutrition of animals. These results are related directly with the maintenance of good livestock. Agronomists are familiar with the effect of changes in soil fertility on the botanical composition of permanent pastures as illustrated in Table III. The importance of soil fertility is demonstrated clearly through its effect on the increase or elimination of important plant species. The changes that can be brought about in the mineral content of a plant through fertilization and liming are relatively small in comparison to the difference in composition of different plant species.

Plant Compositition as Affected by Soil Fertility and Fertilizers

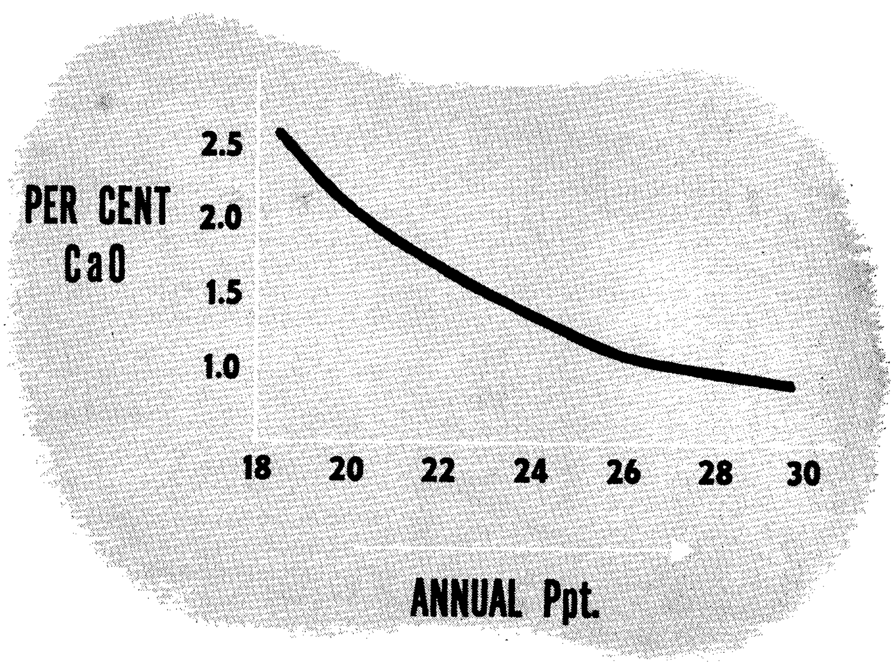
So far as the mineral content of plants is concerned, numerous data exist to show that plant composition is affected by soil fertility. An illustration of this is shown in Table IV. It is observed that as the calcium content of the soil is increased, the calcium content of the plant is increased with a corresponding decrease in the content of potassium. It is interesting to note the relatively constant total content of the cations of calcium and potassium. As the calcium content of the soil is increased, the manganese content is markedly decreased.

The cation-anion relationship in plants is brought out by the data shown in Table IV. In this particular nutrient solution experiment, all factors were kept constant except the potassium content. Here it is observed that there is a decrease in the content of calcium and magnesium as the potassium content is increased. It should also be pointed out that the sum of the cations and the sum of the anions remains relatively constant and thus the ratio of the two is constant.

A generalized picture of the variations in relationships between soil fertility and plant composition is shown in Figure 3 [Discussed by K. C. Beeson, "U.S.D.A. Yearbook of Agriculture," pp. 496–7, 1943–7]. This figure shows that the effect of addition of fertilizers to a soil on the mineral composition of plants may vary greatly, depending upon many associated factors. As illustrated in Figure 3, when the yield under any set of conditions lies between A and A^1, the application of fertilizers should, theoretically, result only in an increase in the yield. Beyond A^1, the addition of fertilizers should result, theoretically, both in an increase in the yield, and in an increase in the concentration of the mineral elements in the plant. At E, no additional yield is obtained as a result of fertilization, but the increase in the concentration of minerals in the plant continues. It is recognized that on different soils other levels, such as B to B^1, C to F, or D to G, may prevail. The important point is that any response to fertilization is a function of the soil characteristics, as well as of the fertilizer itself.

The facts which have been presented so far refer to the composition of leaves and other vegetable parts of the plant. Analysis of seeds and fruits gives a different picture. In general, wide variations in soil fertility do not greatly affect their mineral composition. Plants have a tendency to produce good quality fruits and seeds to the detriment of the vegetable parts of the plant. There are,

Figure 2. Effect of rainfall on calcium content of soils in Nebraska (Jenny)



Lloyd M. Turk, professor and head of the soil science department at Michigan State College, first joined the staff in 1932 as assistant professor of soils. He was then newly graduated, with a Ph.D. degree, from the University of Missouri, and had been an instructor in soil science. In 1945–46 he did research for the U. S. Regional Laboratory at Riverside, Calif. He was co-author of the second edition of "Fundamentals of Soil Science," and has written several bulletins and articles for professional journals. He will become director of the Michigan Agricultural Experiment Station July 1, 1953.

however, numerous data to show that nitrogen fertilizer may markedly increase the protein content of grain.

Present knowledge indicates that soil factors, including fertility, have much less effect on the vitamin content of plants than do climatic factors. The vitamin content may be affected in instances where the supply of some element in the soil is so low that plant growth is retarded.

Relation of Animal Growth and Production to Soil Fertility

As many crops are consumed by meat animals, it is of interest to know the influence of soil fertility on the nutrition of animals and ultimately the health of the consumer of animal food products derived therefrom. Existing knowledge is meager.

A 10-year experiment [S. T. Dexter, et al. "Nutritive Values of Crops and Cows' Milk As Affected By Soil Fertility. I. The Research Problem and Procedures." *Mich. Quart. But.* **32,** 352–9, (1950)] has been in progress since 1945 on a 200-acre farm near Battle Creek, Mich., to gather such information. In this work, Michigan State College and the American Dairy Association are in cooperation. Identical types of crops are being grown on adjacent fields of depleted soil and soil well fertilized with lime, nitrogen, phosphorus, and potassium, and adequate amounts of trace elements. The principal crops are brome grass, wheat, soybeans, corn, and oats.

Yields per acre from the depleted soil have been only about half those from the fertilized soil, but differences in chemical composition of the given crop species have been only slight and inconsistent from year to year. Composition of the grain crop has been particularly unaffected.

Table II. Effect of Fertilizer on Botanical Composition of Pastures

(Penn. Agr. Experiment Station)

Treatment	Frequency of Plant Species, %		
	Weeds	Kentucky Bluegrass	Sweet Clover
Untreated	100	0	0
Lime	87	7	6
Lime plus phosphate	10	70	20

The crops produced have been fed to two groups of cows, as their sole ration, for seven years. No difference in feeding value has been found in favor of fertilization. No differences in herd health, reproduction, or nutritive value of the milk have been observed. We expect biological assay techniques, such as these, to receive increasing attention and to lead to very useful results.

Commercial Fertilizers vs. Organic Compounds

Within recent years considerable publicity has been given to the idea that their contention that inorganic fertilizers disturb the balance of the soil and in turn affect the health of animals consuming the crops. The central theme of the philosophy is that fertilizer drives away earthworms, bacteria, and fungi, the supposed generators of necessary life-giving substances. A full discussion of this question cannot be included here, but it must be stated that there is no evidence which refutes the scientific idea that the ordinary use of chemical fertilizers generally benefits agricultural production and the problem of feeding our people.

On the other extreme there are those who would cure all our aches and pains

Table III. Effect of Lime on Yield and Composition of Bean Plants[a]

Meq. Calcium Added/100 G. Soil	Soil pH	Yield, Grams	Meq. per 100 Grams Dry Material			
			Ca	K	Mn	P
...	5.0	2.3	2	44	15.6	11
1.1	5.8	7.4	19	30	8.6	17
1.5	6.4	11.1	22	27	4.1	18
2.5	6.7	15.6	26	23	2.1	16
6.1	7.5	7.4	31	17	0.1	9

[a] J. Q. Lynd and L. M. Turk, *J. Am. Soc. Agron.*, **40:** 205–215 (1948).

food produced from soil fertilized with chemicals is the cause of increased prevalence of the degenerative diseases of man. The proponents of this concept charge that agriculture's attempt to correct soil exhaustion with chemicals has not been successful and that manure or compost should be used instead of fertilizers. They have cluttered up the literature with a cleverly interwoven mixture of fact and fancy in support of with the liberal use of commercial fertilizers. In recent years, many articles containing exaggerated and unsupported statements on health and soil fertility have appeared in various journals.

Human Health and Welfare in Relation to Soil Fertility

In discussing food consumption in relation to soil fertility, it appears desirable to consider the following ques-

Table IV. Cation and Anion Values and Ratios in Alfalfa in Relation to Changes in Nutrient Solutions Used

(After F. E. Bear)[a]

K Supplied, p.p.m.	Yield Dry wt., G.	Cations in Entire Crop, Meq.				Anions in Entire Crop, Meq.				Cation-Anion Ratio
		Ca	Mg	K	Total	N	P	S	Total	
5.0	10.7	114	33	18	165	261	25	23	309	0.54
19.5	15.0	102	30	34	166	260	22	20	302	0.55
39.0	15.7	76	27	49	152	257	19	18	294	0.52
97.5	16.0	64	21	71	156	270	18	18	306	0.51
195.0	16.5	59	18	89	163	273	16	18	307	0.53

[a] Cation and anion values expressed as meq. per 100 grams of dry matter.

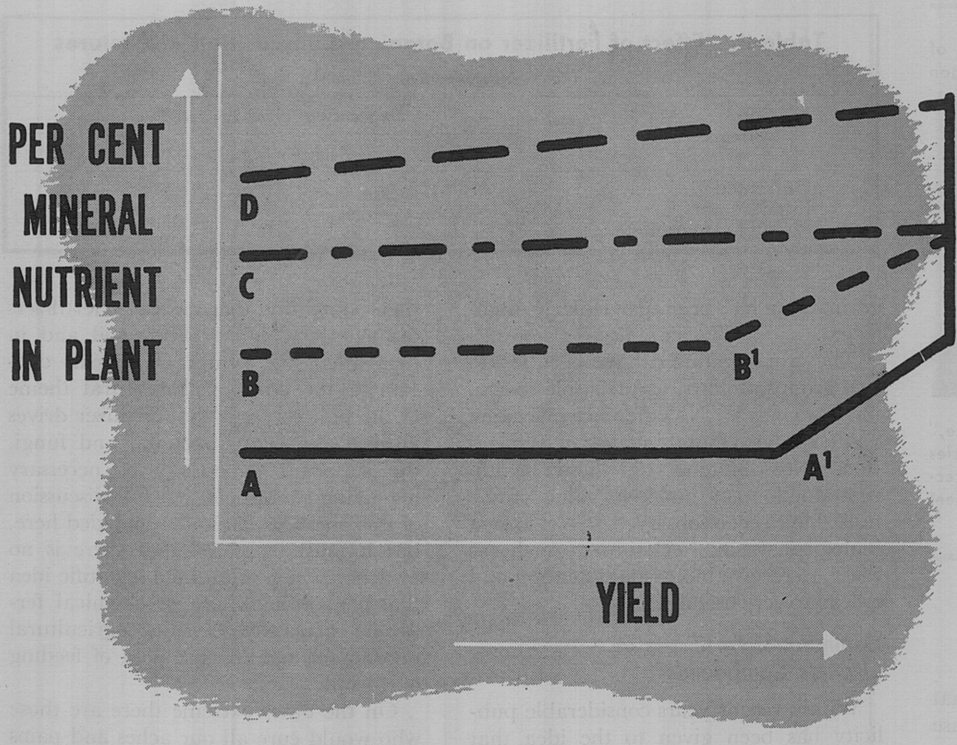


Figure 3. Relationship between yield and mineral content of plants

tions: (1) Is the total food consumed per person dependent on soil fertility? (2) Are the kinds of species (milk, grain, fruit, etc.) of foods eaten related to soil fertility? (3) Is the composition (minerals, vitamins, quality of proteins) of the food species related to soil fertility?

In attempting to answer these questions, we must remember that as a rule we are not confined to one kind of food grown in a limited area. On the contrary, most people have a wide source of supply. As a result of our modern methods of food processing and transportation, the diet in the United States, for the most part, consists of a variety of foods of both plant and animal origin from varied soils, systems of soil management, and climatic regions. Economic factors, such as purchasing power, may limit the ability of people to purchase more costly "protective foods." A lack of information or the choice made in selecting foods enters into the picture. It is further complicated by the fact that processing, handling, and storage may have a profound influence on many food nutrients. There may be qualities in foods grown on good soils which have not yet been assessed and which may be important. In collaboration with nutrition experts, soil scientists are conducting experiments along this line.

To answer the questions asked above, it is advisable to consider some factors with respect to urban and rural areas separately.

In urban areas, the total amount of food consumed bears no direct relation to soil fertility, but is largely a matter of income and food habits. It depends, among other things, on the cost of transportation of food to the store, and in some cases the types of food produced in the area; in other words, on the dependency on local production areas. For example, there may be more limited choice of fresh fruits and vegetables in small towns and villages than in some of the larger cities.

If attention is focused on populations that live directly from the land, on a restricted acreage, the relationships between soil and health may become more striking. Although, as was indicated earlier, transportation improvements are changing availability patterns, low crop production in rural areas could produce low standards of living which in turn could be accompanied by disease and malnutrition. Restrictions in types of crops as a result of infertile soils also limit economic advancements. This may affect the nutritional standards of the rural people directly because of possible lack of essential kinds of food, such as milk and other animal products.

The amount and kind of food available and the prosperity and health of the people in a country will have a direct relationship to its soil fertility. Fertility certainly influences quantity and soil nutrient deficiencies affect the type of crops and animals which can be grown.

The theory that the over-all nutritive value of foods for man is favorably influenced by a fertile soil has not been proved. Indeed, the preponderant evidence is to the effect that *no effect significant in improving human nutrition has yet been demonstrated*, even in the case of plants which are taken directly from the soil to serve as food. With the exception of iodine, which has been shown to vary in foods in relation to the amounts in the soil, no direct relationship between soil and nutritive value has yet been proved which could have any bearing on human diseases or deficiency states.

Animal products, including milk, are even less likely to reflect soil deficiencies than are plant products. L. S. Maynard, whose ideas are the basis of the preceding paragraph, has declared that the nutritive values of animal products, which contribute so greatly to the kind of diet required for health, are not significantly influenced by soil factors.

Many factors enter into the relationship between food and good health. There appears to be no need for alarm concerning the soil factor. With proper management practices, including judicious use of fertilizers, there seems to be no reason to doubt that food of high nutritional quality can be produced in abundance. Soil science still has much to contribute to improvement in the fields of both human and animal nutrition.

Good health requires good food and good soils produce good food in abundance. The opposite assertion, however, that poor health is caused by poor soils, is only partly true. Many factors contribute to poor health and much careful research has yet to be done to trace accurately the role of soil fertility in human health. This will require the unified efforts of workers in many fields of investigation.

The above article is based on a talk presented at the meeting of the American Association for the Advancement of Science in St. Louis, Mo., on Dec. 30, 1952. Approved for publication as Journal Article 1487 from the Michigan Agricultural Experiment Station.