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SOIL ORGANISMS-FACT AND FICTION

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Soil organisms (see table 1) and the soil organic matter with which they are intimately associated are of tremendous importance. Through the action of the soil microbes on organic materials, elements needed for plant growth are released in forms available to the plant. Toxic organic substances from plants and other sources are destroyed. Soil aggregation or structure is improved which reduces water runoff and erosion and favors soil aeration, drainage, and ease of cultivation. Inorganic constituents of the soil are made available to the plant.

These and other beneficial effects of the soil population and organic materials are generally accepted by soil scientists and others, but it is recognized that soil organisms and organic fertilization do not represent the only factors involved in the successful production of crops. An ultra-organic or organic farming group, on the other hand, proclaims that all that is needed for perfect crops is organic manures. It is claimed that inorganic fertilizers (chemical fertilizers), seed dressings, fungicides, insecticides, fumigants, etc., are not necessary, that they poison the soil and the soil population, cause the formation of hard pan, lower the nutritional value of food, weaken the people and animals that eat the food, etc. This group is not made up of trained scientists nor do they use the scientific method in their writings or so-called plant growth tests. Their claims do not stop with the accepted beneficial effects of soil organisms and organic matter but proceed to the absurd. The words "organic" and "biological" represent the divine, while "chemical" and "inorganic" represent all that is bad. In many cities organizations have been formed in which the members agree to purchase only organically grown food. One often finds advertisements in his local newspaper which offer organically grown produce for sale.

It is the purpose of this paper to explain on the basis of scientific research some of the important functions of organisms and organic materials in soil processes and to point out where fact ends and fiction begins.

Organic Matter Decomposition

Probably the main function of soil organisms is the decomposition of organic materials, all of which are composed of plant nutrient elements such as carbon, nitrogen, calcium, magnesium, potassium, phosphorus, sulfur, iron, zinc, and many others. These elements were originally obtained in the inorganic form from the soil or from the air by living plants. The supplies of several of these elements—primarily carbon, nitrogen, and phosphorus—in forms available to plants are limited. In order for life as it is now constituted to continue it is necessary for these nutrients to be returned to inorganic or available forms. This process is carried out primarily by the soil population.

TABLE 1

Estimated numbers of microorganisms found in common agricultural soils

Organism	Number in 1 gm dry soil		
Bacteria	3,000,000	to	500,000,000
Streptomycetes	1,000,000	to	20,000,000
Fungi	5,000	to	900,000
Yeasts	1,000	to	100,000
Protozoa	1,000	to	500,000
Nematodes	1	to	3,000*
Algae	1,000	to	500,000
Bacteriophages	Unknown numbers		
Viruses	Unknown numbers		

*Numbers in 100 gm. soil

As soon as organic residues are returned to the soil, and in the presence of favorable moisture and temperature conditions, they are immediately attacked by soil microbes. Some organic constituents are more readily decomposed than others. These, namely sugars, amino acids, some proteins, certain polysaccharides, and others, are destroyed first. Constituents, such as lignin, are more resistant to decay and tend to accumulate. In addition, several organic substances including polyuronides, nitrogenous complexes, and lignins undergo physico-chemical inter-actions with each other and with the clay particles of the soil which render them relatively resistant to further decomposition. As a result, some of the organic matter remains in the soil and gives rise to what is called "soil humus" (Table 2).

The plant food elements contained in organic materials are given off as waste products during the decay process. Carbon dioxide and water are the main waste products and are first to be released. Nitrogen is liberated as ammonia. If the plant material is high in nitrogen it is quickly released; if low, considerable time may elapse before it is formed. Similarly other elements such as phosphorus and sulfur are released in the inorganic form. As such they are available to new generations of living things.

Effect of Decomposition of Organic Matter On Inorganic Soil Minerals'

The soil organisms affect the availability of inorganic plant nutrients in the mineral fraction of the soil. A constant stream of carbon dioxide from decomposing humus forms carbonic acid in the soil solution. This acidified water has a much greater solvent action on the inorganic minerals than rain water. Organic acids produced during decomposition exert a similar action. In the presence of organic food materials microbes have been shown to exert a solvent action on feldspars, zinc and potassium silicates, calcium and magnesium phosphates and carbonates, and other relatively insoluble soil and rock minerals. Organic materials excreted from or sloughed off growing plant roots can serve as food material for the organisms.

Nutrient Requirements of Soil Organisms

The soil organisms taking part in the decay of organic residues are not intentionally working for the welfare of the plant. They are primarily an independent group which operate according to the law of the survival of the fittest. They compete with one another and even with higher plants for the food nutrient materials which they require for growth just as do other living things. The necessary elements are obtained from the organic materials they decompose and from the soil.

The nitrogen requirements of the soil population are especially high. Bacteria contain from 8 to 15 percent nitrogen and fungi from 2 to 8 percent. Host plant residues contain but 0.04 to 2.5 percent nitrogen. When organic materials low in nitrogen are applied to the soil, the soil organisms compete with plants for the available inorganic supply. This phenomenon explains the temporary retarding effect on plant growth of organic residues such as straw, cornstalks, sorghum, some manures, and other materials low in nitrogen. A similar phenomenon occurs with respect to additional nutrients such as phosphorus. To obtain the beneficial effect of low nutrient organic residues without the temporary retarding effect on plant growth it is necessary to supplement them with inorganic fertilizers, compost them previous to application, or apply them to the soil several weeks or months before plants are to be grown.

TABLE 2

Proximate chemical composition of some organic residues

Constituent	Oak leaves %	Corn stalks %	Alfalfa %	Cow manure %	Soil humus %
Ether soluble portion—					
Fats, waxes, & related substances	6	3	3	2	2
Water soluble fraction—					
Sugars, certain polysaccharides, some proteins, organic acids,					
Hemicelluloses—					
Pentosans, hexosans, and polyuronides	13	20	12	16	23
Cellulose—	15	28	28	19	Trace
Lignins and related substances—	23	11	13	22	44
Nitrogenous complexes—	9	3	11	10	30

Organic Versus Inorganic Fertilization

The strictly organic farming group claims that inorganic fertilizers arc poisoning the soil, including the organisms which inhabit the soil, and that crops grown with chemical fertilizers are less nutritious than those grown with organic fertilizers. Actually there is no difference between a calcium phosphate or ammonium sulfate molecule that is formed as a result of organic matter decomposition and one added to the soil as an inorganic fertilizer. Regardless of how the soil is fertilized the elements used by the plants are the same.

There is no evidence that food quality and health are adversely affected by the use of chemical fertilizers. On the contrary there is abundant evidence that the opposite is true. The amino acid and protein content of plants is increased by chemical nitrogen additions to the soil. The percentage of essential nutrients, such as phosphorus, calcium, potassium and sulfur, in food crops is increased by applying these minerals to the soil by approved methods. Plants grown in chemically fertilized soil or solution culture have been shown to contain just as great a percentage of vitamins as those fertilized with organic materials; for example, at the Citrus Experiment Station in Riverside, California, citrus trees have been grown for years in solution cultures containing only inorganic chemicals. No significant differences can be found in the chemical composition between leaves and fruits of these plants and those grown in soil fertilized with manure only.

The following interesting observation on human health and use of chemical fertilizers has been made: In India, where life expectancy of males is 26.9 years, chemical fertilizer usage on soils per capita *is* but 0.07 kilograms of nitrogen and 0.006 kilograms of phosphoric acid. On the other hand, the life expectancy in the Netherlands is 65.7 years and the per capita usage on soils of chemical nitrogen and phosphoric acid is 10.4 and 12.7 kilograms, respectively.

In most soils there is insufficient decomposing organic matter to meet the nutrient requirements of cultivated plants during the period of maximum growth. Even if organic manures are added it is not certain that sufficient nutrients would be liberated to give optimum plant growth. Certainly if all farmers were forced to rely on organic fertilizer only, the available supply would not begin to furnish the required amount for good crop yields. Our high production is dependent on substituting or supplementing organic with inorganic fertilizer. Further increases in crop production will result largely from increased use of inorganic fertilizer and better soil management practices, which include the use of green manure crops, rotations, and organic manures when available.

With respect to the assertion that inorganic fertilizers poison the soil organisms it can be stated that proper fertilization actually has the opposite effect. By increasing the growth of plants, both roots and tops, chemical fertilizers increase the food supply for the soil organisms and thereby increase their numbers and activity. An example of this phenomenon is presented in table 3.

It is true that improper use of fertilizers can affect the nature of the soil population and possibly lead to soil difficulties. For example, continued use of ammonium sulfate or other acid-forming fertilizers on sandy soils may appreciably acidify the surface of the soil if corrective lime or gypsum applications are not made. This may reduce numbers of bacteria and actinomycetes, increase numbers of fungi, and decrease soil aggregation. Similarly continued use of large amounts of sodium or potassium containing fertilizers in areas where the rainfall and/or irrigation are insufficient to leach the excess bases out of the soil may increase the sodium or potassium to the point where soil structure may be adversely affected and plant growth reduced. This same condition, however, may be brought about by continuous applications of large quantities of manures which are high in potassium or sodium. In this connection many farmers know that it is often difficult to grow good crops where old corrals have stood. The poor growth of plants on such spots is associated with high potassium. Continued use of large amounts of chicken manure may increase the soil potassium to the danger point.

TABLE 3

Numbers of microorganisms in soils of several of the orange tree fertilizer plots at the Citrus Experiment Station, Riverside. (Sept. 1951)

	Numbers in one gm dry soil*	
Treatment	Bacteria plus actinomycetes	Fungi
None	13,000,000	24,000
Winter cover crop	19,000,000	46,000
Calcium nitrate fertilizer	18,000,000	48,000
Calcium nitrate fertilizer and winter cover crop	35,000,000	69,000

*All figures represent averages of 6 samples from each of 4 plots. Soil taken from 0 to 12 inch depth.

A citrus grower near Riverside is having difficulty with too much sodium, potassium, and chlorides in his soil. Steer manure has been used in rather large amounts as fertilizer. An investigation showed that the manure was obtained from animals which had been fed hay and alfalfa grown in a soil high in sodium, potassium, and chlorides. The manure was therefore high in these elements. One must use moderation and common sense whether he uses organic, inorganic, or a combination of fertilizer materials.

The organic cult argues that crops grown with organic fertilizers are more resistant to plant pests than those receiving chemical fertilizers. In the Soils Division at the University of California Citrus Experiment Station, plants have been grown in solution culture containing chemicals only, and in soil receiving chemical or organic fertilizer. Insects attacking these plants do not distinguish between the two root media nor between the two types of fertilizer used. Plant pests have been a problem since the beginning of history. Before chemical fertilizers were used they often destroyed crops completely. It should be mentioned that some soil-borne plant parasites, such as *Phymatotrichum omnivorum,* root rot of cotton, may be partially controlled by the addition of certain types of organic matter to the soil. This phenomenon is a type of biological control in which the added organic matter favors the growth of soil organisms which are antagonistic to the parasite. On the other hand, *Rosellinia arcuata,* root rot of tea, is favored by organic matter. In most instances the addition of organic or inorganic fertilizer has little effect on the activity of the parasite.

Decomposition of Toxic Organic Compounds

One often hears the claim that our soils, the plants that grow on the soils, and the people and animals which eat the plants are being poisoned by insecticides, weed killers, fungicides, fumigants, and similar substances used in modern .agriculture. Regular use of arsenic sprays over a long period of time has had a deleterious effect on soils and plants in certain isolated places. For this reason other materials are being substituted for arsenic. The use of other inorganic pesticides, namely sulfur and copper materials, has not caused damage. At present a very large percentage of the pest control compounds are organic substances. Almost any organic compound known is utilized to some extent by one or more forms of the soil population. For example, microbes have been found to decompose phenol, methane, ethane, oil, gasoline, the hormone weed-killers including 2,4-dichlorphenoxy acetic acid, soil fumigants, hydrogen cyanide, and many other poisonous substances. Some are decomposed quickly, others more slowly. Indeed, some decompose chemically before the soil organisms are able to utilize them.

Plants themselves are adequately supplied with toxic organic substances. For example, the following may be mentioned: hydrogen cyanide in sudan grass and many other plants, nicotine in tobacco, rotenone from trees of the genus *Lonchocarpus,* coniine from the hemlock, strychnine, brucine, and curine from various tropical plants, ergot from a fungus infection of grain, poison mushrooms, botulin, one of the most potent poisons known, from soil bacteria, and many others. Many plants produce toxic metabolic waste products. These substances include coumarin, aesculin, daphnetin, and related substances. Controlled experiments have shown that in the absence of microorganisms some of these materials are stable and remain toxic to plant roots. If soil organisms are introduced the toxic substance is quickly destroyed. Destruction of toxic organic compounds is therefore a very important function of soil organisms.

A toxic organic compound is poisonous whether it is produced by nature or synthesized in a chemical plant. Fortunately, soil organisms destroy them regardless of the source. When applied to the soil they either enhance microbial activity by supplementing the food supply or produce a partial sterilization effect. The latter consists of a brief reduction in numbers or organisms due to the killing of susceptible types followed by a large increase in numbers and activity.

If we were to rely on nature and forbid the use of pesticides, crop production would be inadequate to meet the demand. Thousands of insect pests and disease organisms attack crop plants. Some destroy the plant or its economic product while others reduce the yield. Without pesticides we would have to abandon cultivation of some crops, the quality of others would be intolerable, and that of most would be reduced. To illustrate this point, one need only compare the size, appearance, and quality of apples or pears grown in one's backyard or in a less progressive country where pesticides and fertilizers have not been used, with similar fruit produced in a modern orchard where these practices have been employed.

Decomposition of Organic Micronutrients

There have been frequent assertions that organic manures exert favorable effects on plant growth which cannot be explained on the basis of nutrient elements or improvement of physical condition of the growth medium. Presumably the beneficial effects were attributable to vitamins or plant hormone substances in the organic materials. It has been shown that organic manures do contain plant growth substances. The same materials are also found in the soil. Many soil organisms synthesize them and likewise many decompose them. When artificially applied to the soil they are quickly utilized as a food source by soil microbes. The better controlled experiments on the problem indicate that plants synthesize all the organic micronutrients required for growth and do not respond to added supplies. Stimulation in artificial culture noted by some workers is now considered to have been due to the addition of trace elements by the organic manures which were not added to the checks.

Microorganisms and Soil—the Structure Formation

From the structural point of view the ideal soil is one in which the soil particles are bound together into water stable granules or aggregates. A structure of this type allows ready penetration of plant roots into the soil, good aeration, and rapid infiltration of water.

Various factors are active in the formation of a good soil structure. Alternate wetting and drying, freezing and thawing, plant root action, presence of clay particles, calcium to flocculate the colloidal material, and other phenomena all contribute to the formation of aggregates. In order for these aggregates to become stabilized, however, it is necessary that cementing materials which are relatively stable in water be present. In the best aggregated and best agricultural soils of the world the binding substances are largely organic in nature and are produced primarily through the action of soil microbes during the decomposition of organic residues in the soil.

If organic materials resistant to decomposition are added to the soil, or if organic residues are mixed with the earth and decomposition prevented, the materials do not become an integral part of the soil and do not affect soil structure to any appreciable extent. Under natural conditions organic residues do undergo decomposition in the soil. During this microbial process various waste products, altered plant constituents, and substances synthesized by the microbes undergo physical and chemical interactions with the other soil constituents which result in improved soil structure. During periods of intense microbial activity the bacterial cells and fungus filaments themselves may mechanically bind the soil particles together and thereby improve aggregation.

Polysaccharides (*a carbohydrate decomposable by the addition of elements in water into two or more simple sugars*) synthesized by soil organisms are effective soil cementing substances. (See table 4.) As little as 0.1 gm of a bacterial polysaccharide bound 22 grams of dispersed silt plus clay particles into water stable granules larger than the silt particles in size. Bacterial proteins and certain plant derived substances are undoubtedly just as important as microbial polysaccharides in this respect.

Organic soil binding substances are not indestructible. Some decompose quickly, others slowly. In order to maintain structure it is necessary to have a continuous source of organic food material for the soil organisms. Under natural conditions this is best exemplified by grassland areas. Under cultivation it is supplied by crop rotation with "soil building crops," green manure crops, organic manure applications, plant roots and top litter, and applications of other types of organic residues to the soil. Cultivation accelerates humus decomposition and therefore increases the necessity for a continuous and adequate supply of organic food material for the soil population

TABLE 4

Effect of various bacterial polysaccharides on soil aggregation

Polysaccharide	Concentration %	Aggregation* %
None	Dispersed soil	0
None	Check	28
Fructosan from *Bacillus subtilis*	0.1	44
	1.0	71
Fructosan from *Azotobacter indicum*	0.1	59
	1.0	87
Dextran from *Bacterium* sp.	0.1	70
	1.0	88

*Percent aggregation of silt and clay particles.

Microbial Soil Inoculants

Associated with the organic farming group or on their own initiative many individuals have placed biological or organic preparations and numerous "natural products" on the market. Great claims are made for these preparations. A small quantity of inoculant or other material allegedly brings about an enormous increase in numbers and activities of soil organisms, releases inorganic plant nutrients from soil minerals, improves the structure of both the subsoil and top soil, increases water penetration into the soil, improves the quality of crops growing on the soil, makes the plants resistant to various plant pests and disease organisms, restores the proper nutritional balance to the soil, and/or exerts many other similar effects on the soil. With respect to the microbial inoculants it should be pointed out that the soil is teeming with countless millions of microbes. The types present are there because they are best able to cope with the environmental conditions. When microbes are applied to the soil they rapidly decrease in numbers. They either die or are destroyed by the existing population. If some do survive it is very probable that the same forms are already present. To establish a new type the environment has to be made favorable by changing the acidity or alkalinity of the soil, by applying essential nutrients in required amounts, or by applying a favorable source of organic food material. The only way to appreciably increase the numbers and activity of beneficial soil microbes is to supply them with additional food material. Furthermore, it is soil organisms working as a group or a team which bring about beneficial effects in the soil. No particular species possesses special magical powers.

A liquid biological soil preparation which is sold in this area is now under test in our division at the Citrus Experiment Station. When applied in recommended dosages, 20 gm (less than 1/20 lb.) of solid material containing 50 percent ash is distributed over 1 acre of land. Table 5 illustrates the ineffectiveness of this material on water penetration and microbial numbers which should be markedly improved according to the manufacturer's claims. *Actually the only benefit to be derived from an organic or microbial soil inoculant is that resulting from the organic matter and nutrient content of the product.* If sold on this basis the cost would be prohibitive.

(The biological preparations discussed above should not be confused with the legume inoculants which have a recognized value.)

Microbial Inoculants for Composting

Microbial inoculants and plant extracts for compost piles are rather widely sold. These preparations are supposed to insure a high quality compost in a short period of time. The same phenomena governing the decomposition of organic materials in the soil are applicable to compost piles. The rate of decomposition depends on moisture present, temperature, aeration, available nitrogen and other nutrients, and the organic chemical composition of the residues. In the early stages of composting the physical nature of residues may affect the rate of decay. Materials such as cereal straw, for example, tend to shed water and are therefore difficult to wet.

No magical preparations are needed to obtain a successful product. Crop wastes and dust naturally contain all the microbes that are needed in the rotting process, and these quickly establish themselves under proper conditions for composting. If the materials are low in nitrogen and other nutrients, the addition of this element and possibly phosphorus and calcium in any commercial fertilizer form will speed rotting and produce an end product with a greater fertilizer value. The addition of manure, finished compost material, dried blood, fish meal, and similar organic products, or extracts of these materials, will speed the decay process by furnishing nutrients and also organic colloidal materials which adhere to the fresh organic residues, thereby aiding wetting and providing a "foothold" for the organisms which start decomposition. If one has ample time and is interested only in the improvement of the physical and biological properties of the soil, fertilizer material need not be added to the compost pile but can be applied directly to the soil when and if needed.

Mixing or turning a compost increases the decomposition rate by improving aeration within the pile.

About 10 years ago while at the New Jersey Agricultural Experiment Station one of the authors made two composts from cereal straw[7] according to directions given by a company selling inoculants and extracts. A small amount of commercial fertilizer containing primarily nitrogen and a little phosphoric acid was added to one pile and the inoculants and extracts were added to the other. The one receiving fertilizer decomposed faster and the end product was superior, based on plant growth response.

Earthworms

There has been interest in earthworms since Darwin in 1882 stressed their importance in the soil. They are especially abundant in soils rich in humus. They feed on organic substances and other soil organisms. 'I heir activity in the soil perforates the ground and thus increases aeration and infiltration of water. The action of the digestive juices of the worms increases the soluble nutrients in the soil and humus which passes through their bodies.

Controlled studies have shown that in soils with average structure the presence of earthworms has no effect on plant growth, but in fine textured soils having very poor structure plant growth is stimulated by their activity.

If conditions favorable for the worm population are maintained, they will be active and will reproduce in the soil. On the other hand, if unfavorable conditions exist they will not survive even if added to the soil. Their number and activity in an agricultural soil will depend primarily on the available food

TABLE 5

Effect of a "biological soil inoculant and conditioner" on water penetration and numbers of microbes.

(All figures average of 5 replications)

Determination of	Check	Treated
Water penetration*		
At time of treatment	15½ hrs.	16¼ hrs.
Seven weeks after treatment	14¾ hrs.	15½ hrs.
Numbers of microbes:†		
Bacteria plus actinomycetes before treatment,		
0 to 6 inches	15,000,000	16,000,000
6 to 18 "	7,000,000	8,000,000
Bacteria plus actinomycetes 7 weeks after treatment,		
0 to 6 inches	17,000,000	16,000,000
6 to 18 "	8,000,000	8,000,000
Fungi before treatment		
0 to 6 inches	36,000	44,000
6 to 18 "	7,000	7,000
Fungi 7 weeks after treatment		
0 to 6 inches	41,000	40,000
6 to 18 "	8,000	8,000

*Time required for water in a full basin around orange tree to penetrate into ground.

†Numbers of bacteria and actinomycetes to nearest million and fungi to nearest thousand in 1 gm dry soil.