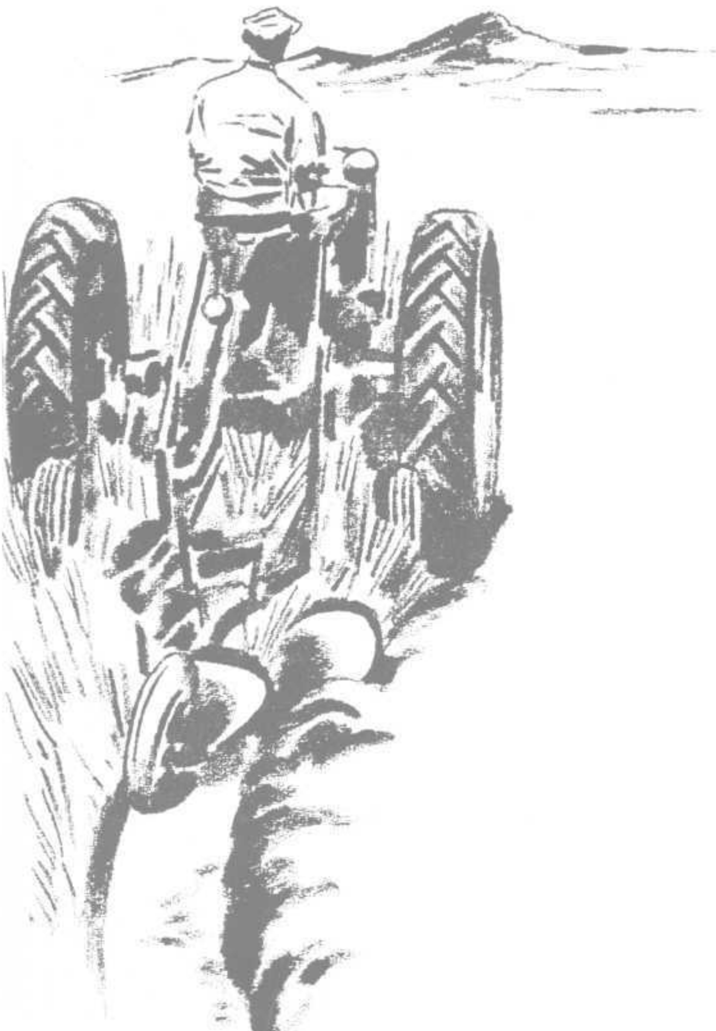
SOIL ORGANIC MATTER



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SOIL ORGANIC MATTER

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Introduction

Organic matter is the life of the land!

Though in calcareous Arizona soils the amounts are small, small amounts of organic matter exert a profound influence on the physical and biological characteristics of a soil. These characteristics control such practical factors in crop production as water penetration, moisture retention, soil structure, plant nutrient supply, and microbiological activity. *The maintenance of this relatively small amount of organic matter in our irrigated soils is essential to high productivity of the land.*

Soil organic matter is one of our natural resources, along with water, timber, and minerals, that has been exploited and dissipated by our modern civilization. Our soils have been injured by systematic depletion. Though less spectacular than soil erosion, the invisible decline in soil fertility caused by intensive cultivation and incessant removal of crops is reaching alarming proportions. The continued productivity of the soils in Arizona will depend largely upon the replenishment and maintenance of the soil organic constituents.

Virgin soils of Arizona contain approximately 0.1 to 1.0 percent organic matter. Compared to 3.0 to 5.0 percent in the prairie soils of the Midwest this is not much. Such a low content is not a serious handicap providing it is replenished and maintained at an economical level.

It is not the purpose of this discussion to plead a case for the maintenance of a fixed level of organic matter in Arizona soils, that is beyond economical circumstances, but rather to point out the values of incorporating crop residues in soils. Such topics as the nature of organic matter, amounts and distribution in Arizona soils, causes of depletion and means of maintenance will be discussed in this bulletin.

Nature of Soil Organic Matter

According to the latest concepts of organic matter, it consists of partially rotted residues of the plants that occupied the land under native and cultivated conditions, and the materials formed by soil organisms. Until quite recently organic matter was considered to be almost wholly of plant origin. Though the nature of organic matter is still somewhat obscure, there is increasing evidence that soil organisms make a substantial if not dominant contribution.

A small percent of the organic matter is living. This requires that the greater part of the soil organic matter is itself derived from the dead tissues of microorganisms and that the remainder is the more resistant part of plants.

Organic matter is formed during the decomposition or rotting of plant material. Decomposition is not an undesirable process but rather one that recirculates necessary plant food elements for additional crops. In addition to the release of mineral elements such as nitrogen, phosphorus, iron, etc., carbon dioxide and water are released.

All plant constituents do not decompose at the same rate. More resistant plant substances as *lignin* undergo relatively slow change by soil organisms because of their complex nature. Carbohydrates such as plant sugars and cellulose, on the other hand, are rapidly attacked yielding carbon dioxide and water. The resistant materials like lignin are not wholly inert nor are they readily identified in the soil. If this were not so organic matter would accumulate until ultimately the surface of the earth would be nearly all organic matter.

A. G. Norman[1] compares the decomposition of organic matter to a fire in his statement, "After the first rapid phase of decomposition when the plant residues are rapidly attacked, biological activity slackens, just as a wood fire dies down from a bright blaze to smouldering embers, glowing for a long time."

The composition of organic matter from different locations is surprisingly uniform despite the wide variations in type of plants and microorganisms that are responsible for its formation. Recent investigations indicate that three classes of compounds form the predominant part of soil organic matter.

(1) Substances produced by the alteration of lignin of plants.
(2) Compounds related to carbohydrates (bacterial gums, slimes and molds).
(3) Material probably derived from proteins. These are possibly the principal carriers of nitrogen.

The *lignin* of the plant material undergoes change when first mixed in the soil. After the initial attack a resistant portion remains that is so greatly altered as not to be properly spoken of as lignin. This portion, although resistant to further degradation, can be further showly degraded.

The *carbohydrate-like* materials in soil organic matter are largely substances of microbial origin, as,

[1] Norman, A. G. Organic matter in Iowa soils Iowa State Agricultural Experiment Station, Popular Bulletin P57; 1943.

slimes, gums and organic salts of uronic, teichoic, muramie fulvic and humic acids.

Between one-tenth to one-third of the total carbon appears to be associated with uronic groups. Considerable research indicates that the soil uronides are prducts of microorganisms rather than plants. The gelatinous materials surrounding the soil microbial cells are in a great part uronic gums. Many fungi are also able to produce uronic constituents.

Microbial gums and slimes are believed to contribute to soil structure formation. The activity and numbers of soil microorganisms have been related to the formation of water-table soil aggregates or crumbs. In this way microorganisms effect water penetration. Threads of mycelia of fungi and streptomycetes are know to fabricate soil particles giving soil structure stability.

The *proteins* are chiefly microbial tissue and cells. Irrespective of their source soil proteins are greatly modified from their original form. The protein fraction contains the nitrogen in the soil.

Soil organic matter also contains *organic phosphorus* compounds. Arizona soils contain as much as one-third of their total phosphorus in this form. Figure 1 shows the relationship between organic matter and organic phosphorus at various depths in three typical soils.

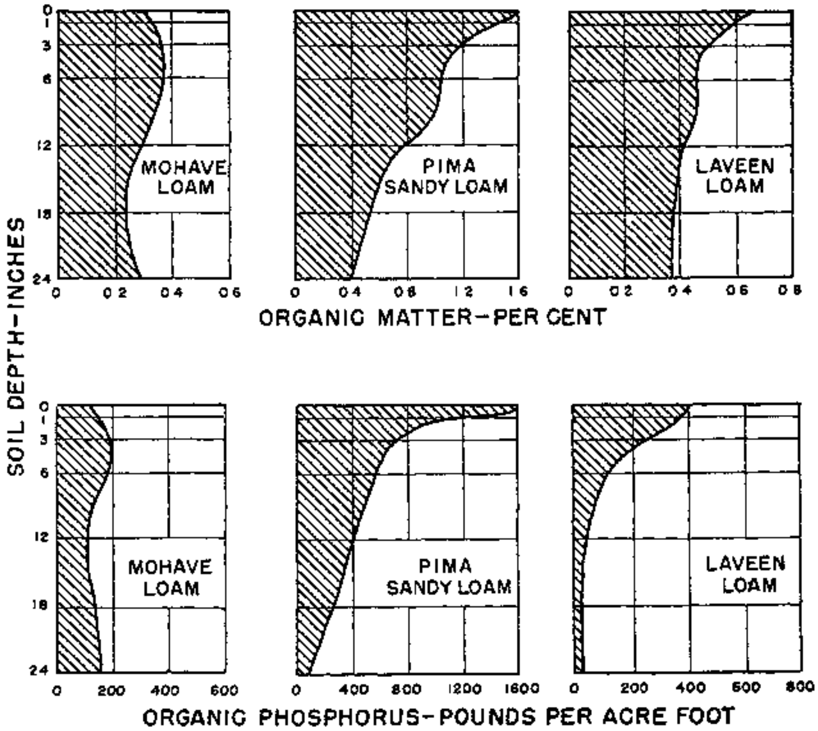

Figure 1. — The distribution of organic matter and organic phosphorus at different depths in three representative soil profiles.

Both the organic matter and organic phosphorus decrease as depth in the soil layer increases.

How do nitrogen and phosphorus carried in soil organic matter become available? There is only one way: namely, by the action of extracellular enzymes from the tiny organisms that live in the soil.

Ensymes are substances made by organisms that, in small quantities, are able to liberate or release nitrogen and phosphorus from unavailable organic forms to mineral forms available to plants. Thus the rate of release depends on the activity of the soil organisms which in turn depend upon the presence of a food source such as plant or crop residues coming in contact with the soil.

Other constituents of the soil organic matter are the trace substances such as the "growth inhibiting" or "growth promoting" substances usually termed *growth* regulators. Antibiotics as bacteriophage, a substance that dissolves the beneficial legume bacteria, thus inhibiting maximum nitrogen fixation by legumes, are found in soils supporting old stands of alfalfa.

Penicillin, patulin, streptomycin, and *actinomycetin* are characteristic antibiotics that are produced by soil microorganisms and may exercise some control over population *Patulin* is a very strong antibiotic, made by many soil organisms, that has been found to assist in the control of fusarium wilt disease of the banana. Manure has been considered to contain plant "growth regulators." Some active materials that apparently enhance the growth of roots have been indicated.

The principal organic compounds in soils are all predominantly acid in nature and thus contribute to cation or base exchange by holding base elements against loss by leaching.

Base exchange is the exchange taking place between the soil bases, ammonium, potassium, calcium, etc., of the soil particles or colloids and other bases in the soil solution, or from plant roots or fertilizers.

Functions of Soil Organic Matter

Organic matter may best be evaluated in terms of its functions in the soil. They are listed briefly as follows:

(1) Direct nutrition for plants
   - (a) To supply major nutrients such as nitrogen and phosphorus.
   - (b) To supply minor nutrients such as boron, manganese, zinc, and others.

(2) Indirect effect of plant nutrition
   - (a) Change in rate of release of potassium and phosphorus from inorganic minerals.
   - (b) Mobilizing plant nutrients such as iron, phosphates, etc.

(3) Food and nutrient supply for soil microorganisms, such as carbon energy supply, nitrogen and phosphorus.

(4) A part played in determining soil structure and thereby water behavior.

(5) Conservation of moisture.

(6) Contribution to base exchange, i.e., exchange of nu-

trient ions from soil colloid particles to the soil solution for plant absorption.

(7) Biotic control in soils through the presence of particular compounds now commonly called "growth regulators" such as antibiotics and growth promoting factors.

A detailed discussion is presented below in order to describe more clearly the manner in which organic matter fulfills the above functions in soils.

Plant Nutrients in Organic Matter

Organic matter contains such major plant constituents as nitrogen, phosphorus, and micronutrients as iron, manganese, copper, and boron. These elements are largely in organic form *i.e.* an integral part of organic matter. *Soil nitrogen is almost wholly in the organic form;* thus it represents the sole natural source for crop production. A rather constant ratio of nitrogen to carbon exists in all soil organic matter.

A ratio of 8 to 10 seems to be common for the organic matter in virgin Arizona soils. The ratio is a little wider, 10-12, in northern regions. The value of organic matter in soils becomes apparent upon the realization that nitrogen is directly proportional to the amount of organic matter in the soil. Soils low in organic matter are notably low in nitrogen.

Small quantities of nitrate nitrogen are also found in the soil, but never at a single time are they ever sufficient for a satisfactory crop, except where fertilizers are used extensively or irrigation waters are high in nitrates. For example, the total nitrogen in Arizona soils may be between 800 and 1,600 pounds N per acre-foot though seldom is there more than but a few pounds of nitrate-nitrogen present at a single time. A crop such as cotton requires 75 lb. of nitrogen for every 1,500 lb. lint and seed. The crop must rely upon the organic matter to supply much of this nitrogen.

Crops are dependent upon the conversion of organic nitrogen to the inorganic nitrate form by soil microorganisms; namely, bacteria. Thus the greater the amount of organic matter, greater is the nitrate formed: the greater the amount of the nitrate formed the higher is the crop yield.

Organic phosphorus is also a part of organic matter. Although the availability of this phosphorus is not known it is believed that it becomes available slowly just as the nitrogen of organic matter. The relationship between carbon and phosphorus is not as constant in organic matter as the carbon nitrogen ratio. In the 3- to 6-inch layer of seven virgin soils of the Salt River and Santa Cruz Valleys the ratio

$\frac{\textit{organic carbon}}{\textit{organic phosphorus}}$ varied from 19 to 38, though an extreme ratio of 120 was found at the 2-foot level in the Laveen loam of the Salt River Valley.

For the most part, the soil organic

matter in Arizona soils is richer in organic phosphorus than that of the black prairie soils of the Midwest.

The value of soil organic matter in supplying minor elements is recognized though an exact evaluation has never been shown. No doubt plant materials release their minor elements for plant use as they undergo decomposition. The observation that many minor element deficiencies may be remedied by addition of organic residues to soils has made the recommendation of organic residues a common practice for this purpose.

Food Source for Soil Organisms

Plant nutrients are released from soil organic matter only as a result of decomposition by the action of organisms in the soil. Plants would starve for nitrogen if it were not for soil organisms. The organisms require food in order to live. *Organic matter supplies the necessary food.*

The size of the microbial population is determined by the amount of organic matter in the soil. Large populations are found in soils high in organic matter and in soils having large amounts of crop residues returned — a soil low in organic matter and receiving little crop residue has small populations of organisms.

Despite the very small size of soil microorganisms, the numbers are so great that many pounds of nitrogen per acre may be tied up in their tissue. As the food supply (organic residues) becomes used up the microbial population diminishes and nitrogen is released from the dead microbial tissue for plant use. In this way a constant supply of nitrogen is provided the plant and nitrogen loss as nitrates or ammonium salts by leaching is lessened. The continuance of this nitrogen cycle is essential to high production by the plant. Briefly this cycle may be put into diagram as seen in Figure 2.

Like living cells the soil organisms take up oxygen (O_2) and give off carbon dioxide (CO_2) just as men and animals do when they breathe. The carbon dioxide is used by the plant in photosynthesis to build cells. Carbon dioxide may also function in the soil to make available to plants mineral nutrient elements such as mineral phosphates.

Organic matter and plant residues are food also for the larger soil flora such as earthworms. Earthworms are considered to benefit the soil by their burrowing action and makes channels for water and air penetration. Moreover, castings of earthworms become a part of the water stable aggregates that are so important to good soil structure.

As much as 10 tons of castings will pass through earthworms from 1 acre in one year. Earthworms, however, create no fertility since they do not fix nitrogen from the air or any other unavailable nutrient.

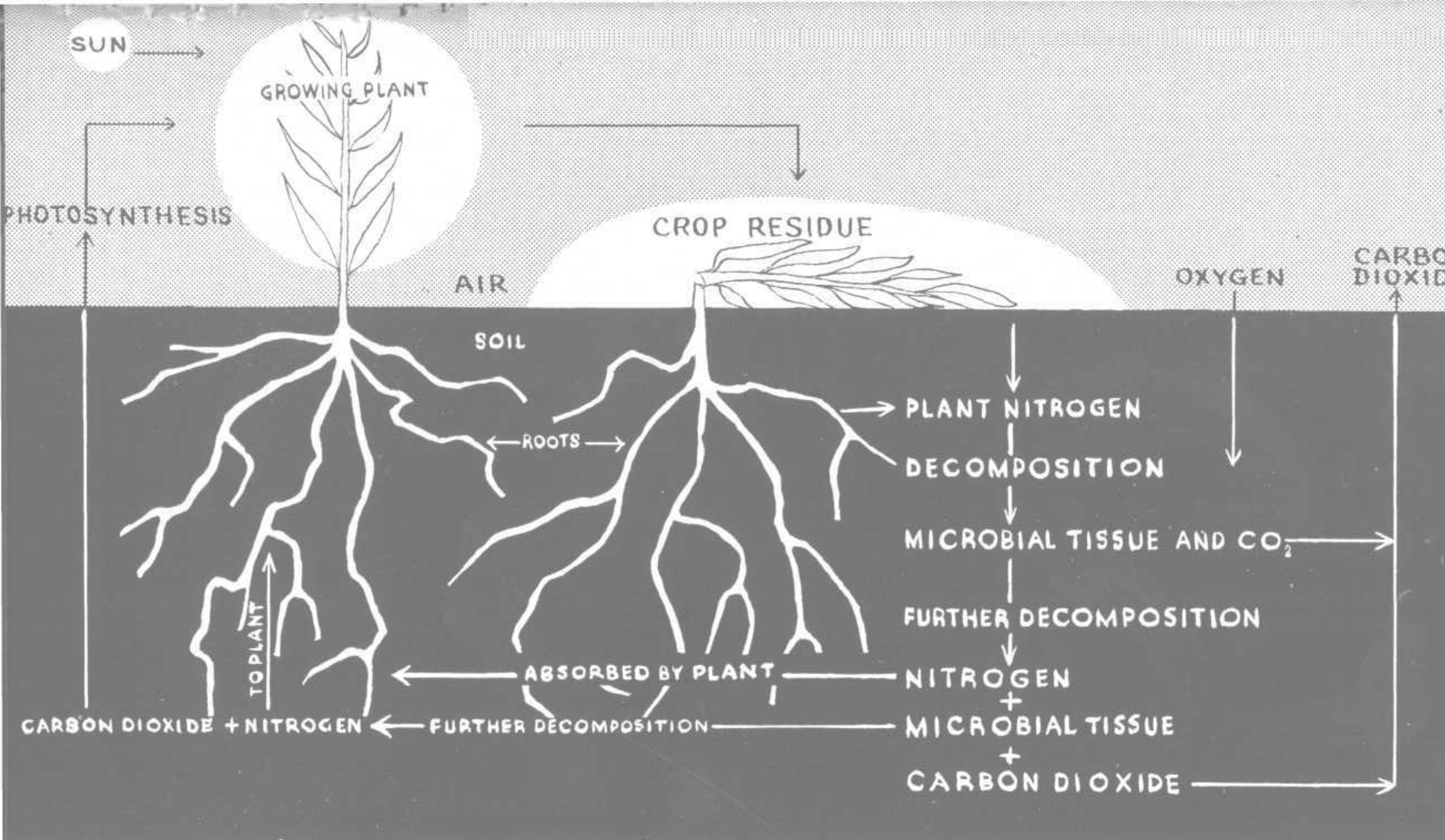

Figure 2. — The transformation of nitrogen and its movement through the soil and into the plant.

Organic Matter Benefits to Physical Properties of Soil

Soils are composed mostly of mineral particles of all sizes ranging from gravel to sand to silt and finally to the very small colloid clay. The arrangement or groupings of these particles into aggregates or crumb-like units is called structure. In the absence of soil structure or aggregation, water penetrates with difficulty or not at all. Air movement, so essential to root growth, is also dependent on channels and crevices of soils of good structure.

A soil with a good structure is easily worked by farm implements and is spoken of as having good "tilth." The photos on following pages show by contrast the desirable effect of crop residues and manures on the development of good soil structure and tilth.

Decline in soil organic matter content is associated with a decline in the desirable physical properties of a soil. Soils remain in hard clods that break up with difficulty when worked with tillage equipment. The soils become compact and hard spots spread and new hard spots appear. Erosion becomes rampant in many soils and water penetration sluggish or completely impeded. Aeration is poor limiting root penetration.

Though the soil may be well supplied with mineral plant food elements, yields may be considerably reduced in soils of poor physical condition. Hard spots in alfalfa fields are good examples of yield reduction due to poor physical condition. The effect of hard spots or

The influence of plowing under barley straw on the physical properties of the soil. Rough tilled barley straw residue turned into the soil. Note the good soil structure and fine condition of tilth.

Influence of steer manure on the physical properties of the soil. Upper: Manure added to the soil. Note that the structure and tilth is better than the field below where no manure was added. Lower: No manure or crop residue added. Note the poor soil structure and the washing of the soil.

Cotton roots crooked and twisted, by inability to penetrate the soil. These plants were grown on a hard compact soil very low in organic matter.

a hard compact layer of soil on preventing cotton roots from penetrating the soil is seen in the photo above.

Uronic acids and other gum-like bacterial products are active structure producing materials. Crop residues and organic materials as food for soil organisms have been shown to create good aggregation. Mere addition of coarse organic matter is generally not sufficient to produce structure. It is rather the continual utilization by organisms with the formation of new products that is important.

Status of Organic Matter in Arizona Soils

Using the foregoing discussion as a background, let us examine the organic matter situation in the arid and semi-arid soils of Arizona.

The most outstanding feature of *virgin soils* of Arizona is their very low organic matter content. Usually the amounts do not exceed 0.1 to 1.0 percent. The peculiar moisture and temperature relationships of this region are responsible for this condition. The scarcity of moisture only permits meager vegetation under virgin conditions whereas the rather favorable temperature conditions permit decomposition to progress rapidly throughout the year when sufficient moisture is present.

The second feature of these soils is the presence of organic matter well distributed throughout the first 2-foot layer. Since organic matter in the arid and semi-arid soils of Arizona moves downward but little this demonstrates the importance of the contribution of roots to the organic fraction of the soil.

Three of the most notable characteristics of *irrigated* or *cultivated soils* in Arizona valleys in regard to soil organic matter are: (1) the astounding rapid rate of decomposition and almost complete disappearance of agricultural residues added to or grown on these soils; (2) the often observed increase in organic matter, under some farming systems, over that of virgin conditions; and (3) the fact that the very low content of organic matter does not particularly inhibit maximum crop yields in irrigated soils as it does in humid sections of the country.

The third characteristic is explained on the basis of an earlier statement that decomposition is all important to the beneficial functioning of organic matter in soil. The next two main sections on rate of decomposition and maintenance of organic matter more fully explain this characteristic of irrigated Arizona soils.

Rate of Decomposition of Farm Crop Residues

Only by *decomposition* can plant residues function to benefit crop production. Only by decomposition can nutrients such as nitrogen, phosphorus and minor elements be released for plant reuse.

The regulation of this rate of decomposition is, therefore, all important to the farmer. If water is limiting, decomposition will stop completely. In the presence of sufficient water, however, the availability of nitrogen regulates the rate with which microorganisms will attack crop residues and consequently the rate of release of the nutrients for plants.

Ordinarily, straws, cotton stubble and other mature crop residues must be supplemented with nitrogen in order to insure rapid decomposition. If no nitrogen has been supplied, it has frequently been observed that non-leguminous crops sown on the land will show extreme nitrogen starvation the first few weeks following the turning under of the residues.

Though many Arizona soils contain an average of 0.04 percent nitrogen or 1,600 pounds per acre-foot of soil, this becomes available only very slowly. Only a small fraction of this is made available to plants at one time by microbial activity. Thus there is a need for supplementing the soil with nitrogen in an available form to meet both the requirements of the microorganisms and those of the plants.

Since the microorganisms control the nitrogen metabolism in the soil, *the plants get only the nitrogen that exceeds their needs for decomposition.* Thus as decomposition proceeds to completion and the number of soil organisms decrease, more and more nitrogen may be made available to plants.

Nitrogen applications have often been associated with organic matter conservation and maintenance. This is due to the added increase in crop residue as a result of increased growth. Root as well at top growth is greatly increased by favorable nitrogen additions.

Increase in Organic Matter

Soils that are low in organic matter under virgin condition often will show an increase in this constituent when put into crops. This is brought about largely by the vast amount of agricultural crop residues incorporated in soils as compared to that under virgin conditions.

It is not likely, however, that the soil organic matter content can be increased greatly or permanently by farm practices that are economically advisable. The favorable moisture conditions under irrigation, the good aeration in Arizona soils and the high temperatures favor rapid decomposition and make any attempt to increase the organic matter permanently above that of virgin soil economically impractical.

Maintenance of Organic Matter

The very *low content of organic matter* in Arizona soils is not to be looked upon in alarm, *if it is maintained.* Though the presence of organic matter in soils is extremely essential to maximum growth, only small amounts are demanded by plants. *It is the maintenance of this small amount that is so critical to a favorable agricultural economy.*

One may use the example of a horse drinking from a trough of water to illustrate this point. It is not the level of the water in the trough that concerns the horse as much as the rate of income of water in relation to his uptake. The trough may be 4 to 24 inches deep, if the water flows in at the rate he drinks it, he will be little concerned about the depth mentioned.

However, if there is no income of water, the 24-inch depth would be the most desirable and would take care of the needs of the horse for some time without replenishment. The exploitation of the first 20 inches would be of little consequence, only if replenishment at a rate equal to the outgo were commenced and maintained at or above the minimum level.

Arizona soils, being lower in organic matter, need replenishment much sooner than soils higher in organic matter. Thus the low organic matter content accentuates the need for good management and replenishment.

There are three main means by which organic matter may be replenished in soil. These involve the addition of organic residues in the form of: (1) animal manure, (2) green manures, and (3) mature crop residues. The suggestion is not that maintenance depends on the use of all three materials or that these are alternatives, but rather that each be used in its proper place and according to its special qualities.

Animal Manures

Animal manure is an excellent source of organic matter. Its value on the farm is often not appreciated. One ton of steer manure for example contains plant nutrients equivalent to 100 pounds of 10-5-10 fertilizer.

Animal manure has three effects when added to soil: (1) an immediate effect to increase yields, (2) a long-time effect on yield due to the slow release of nutrients in the more resistant residues, and (3) effect on structure and moisture-holding capacity. A minimum application of 5 tons per acre is usually recommended for best results for most crops.

Recent research shows manure from stock-yard of pen-fed cattle is seriously high in salts and when excessive may prove damaging in large applications to home plantings.

Green Manures

Legumes are the crops best suited for green manure because of their capacity to support nitrogen fixation and their favorable balance of nitrogen and carbon permitting rapid decomposition without the addition of nitrogen. Furthermore, the roots of legumes are extensive

Sesbania being turned under for green manure.

and penetrate deeper than most roots. (See photo.) This is beneficial from a standpoint of succeeding downward penetration of moisture and aeration.

Non-legumes such as barley and rye have been successfully used as winter catch crops when turned under before May 1. The recommendation of green manure crops for organic matter replacement should be considered from the standpoint of the farmer's economy. Very often such a practice is costly and not advisable where water is extremely limited.

Crop Residues

The renewal of organic matter in Arizona soils is largely dependent upon the utilization of crop residues. Crop residues of all sorts are very valuable not only because they contain plant nutrients but because their decomposition is accompanied by an improvement in the physical condition of the soil and because they supply the food essential for microbial activity. When crop residues are incorporated into soil, the food supply is greatly increased and microbial activity and population greatly increases.

As the food supply is used up, the size of the microbial population diminishes and the nutrients contained in the microbial tissues may be released for plant use. The nitrogen in the plant materials, largely in the form of proteins, is also utilized by microorganisms. As the fires of microbial activity slowly diminish as decomposition proceeds to completion the nitrogen of the bacterial tissues, and this is considerable, is mineralized to ammonium and nitrate available for plant use.

Burning of crop residues, which involves the loss of all nitrogen and of the contribution that the more resistant fraction may make toward organic matter replacement, is definitely an indefensible practice under normal conditions. Only in the case of pest or disease control should it be used, and then perhaps only as a last resort.

In burning-off of crop residues the soils not only are deprived of structure building and moisture conserving materials but are robbed of fertilizer elements. In terms of nitrogen, phosphorus and potassium, crop residues are valuable fertilizer sources. Table I, taken from the "Soil Analysis Handbook" compiled by W. T. McGeorge, indicates the fertility values of certain crop resi-

Table 1. — Pounds nitrogen (N), phosphorus (PO_4), and potassium (K) returned in crop residues if plowed into the soil.

Crop residue	Yield per acre	Nitrogen	Phosphorus	Potassium
Alfalfa	1 ton	47	16	38
Barley straw	40 bu. grain	15	7	17
Flax straw	15 bu grain	20	5	16
Hegari	1,550 lbs. grain	23	8	7
Lettuce	23,000 plants per A	75	32	100

dues. Minor elements have not been evaluated. There is little doubt that crop residues are a very valuable source of minor elements.

Plowing under of crop residues often results in immobilization of nitrogen to such an extent that the succeeding crop may show nitrogen deficiency symptoms. This is due to the great demand by soil organisms for nitrogen in decomposing the carbonaceous crop residue.

Unless the residue contains more than 1.5 percent nitrogen, the organisms will rob the soil to rot the residues. Eventually, however, as the residues become decomposed, nitrogen is released for plants.

A simple and cheap means for avoiding temporary nitrogen starvation following the plowing under of crop residues is to add commercial nitrogen to the land at the time of plowing. Such practice has been helpful in reducing rootrot infestation. For example, a report by The University of Arizona Agricultural Experiment Station shows a yield of 3 bales of cotton per acre was made on land that was 100 percent infested with root rot by using this simple technique.

The need for intelligent utilization of crop residues should be again emphasized. It has been pointed out that crop residues make an essential contribution to the productivity of soils during their process of decomposition. Only by decomposition can organic residues and organic matter function to their maximum extent for the benefit of crops.

Just because Arizona soils are low in organic matter there is no reason to minimize the importance of this constituent as an essential factor in crop production. That crop residues such as barley straw and roots are a valuable source of plant nutrients may be seen in the photo on page 10. By use of a radioactive phosphorus technique, the phosphorus of barley materials is shown to be as available to plants as liquid phosphoric acid.

The irrigated soils of Arizona produce no less crop residues than most soils in the United States, including those of the prairie area, and most have as much residue returned to the land. The obvious difference between the condition in Arizona soils and those of the northern states is not in the route but in the over-all *rate of transformation* of returned residues from whole plant constituents ultimately to carbon dioxide and water and microbial tissue.

Soil organic matter as we know it is only a stage in the complete conversion of plant residues to carbon dioxide and water, though it is in no way similar in composition to that of the original plant material.

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