

# Organic Matter In Iowa Soils



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# Organic Matter in Iowa Soils

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The importance and wealth of any state or country depend in great measure on its natural resources and the extent to which these resources are used. Some states are rich in mineral wealth, others in lumber or oil or water-power. All these Iowa lacks, yet she is not poor but fabulously rich in the most vital of all resources, the soil. Within her boundaries, north and south, east and west, lies one of the most concentrated of fertile areas of the northern hemisphere. Her climate, though one of extremes, is well suited to agriculture. Corn yields abundantly, and directly, or indirectly through livestock, is the source of much of her wealth. More than one-fifth of the corn raised in the United States is grown within the state of Iowa. The farm value of Iowa corn has for a number of years been in the neighborhood of 250 million dollars annually. This abundance of corn is due to the productivity of her soils, which in turn is largely an expression of their high organic matter content. Their continued productivity depends on proper management, and maintenance of this vital component of soil.

Modern civilization has exploited and wantonly dissipated many natural resources. Forests have been cleared and hillsides denuded, coal seams have been exhausted and the countryside despoiled. Our land is scarred by the wreckage of depleted resources. The soil has not escaped. Almost as serious as the visible ravages of erosion, however, is the invisible decline in fertility that may be caused by intensive cultivation, single-cropping and the absence of rotations that tend to replenish the supply of organic matter within the soil. The purpose of this bulletin is to review the role played by organic matter in soil fertility, to examine the causes of depletion of organic matter, and to consider the means by which maintenance can be accomplished.

## THE NATURE OF SOIL ORGANIC MATTER

The organic matter of the soil primarily consists of extensively decomposed residues of the vegetation that occupied the land under virgin conditions. Supplementing this, but far less in amount in Iowa soils, are residues from crops grown on the land since it came into cultivation. The decomposition of the plant materials that gave rise to these residues is brought about by the activity of the microorganisms of the soil. These microorganisms themselves make a contribution to the organic matter in the form of living and dead cells and residues from the latter. Soil organic matter is therefore predominantly plant-derived but extensively transformed by microorganisms.

The natural decomposition of plant materials that occurs in and on the soil is not an undesirable process but one that keeps continually in circulation the raw materials needed for plant life and crop production. The materials of which plants are built are carbon dioxide from the air, water, nitrate and other nutrients from the soil. In the process of decomposition of plant residues, the microorganisms again release the carbon dioxide and plant nutrients, so making them available for further plant growth.

Some of the constituents of plants are readily and quickly used as food by the soil microorganisms; others are more resistant and are attacked only comparatively slowly. It would be incorrect to regard soil organic matter as just an accumulation of wholly unusable, unavailable or inert residues from plants. It is instead an accumulation of material that is not readily used by the microorganisms, and which in consequence ordinarily undergoes only slow change. 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 soil organic matter may be expected to depend mainly on the nature of the plant materials giving rise to it. It will also be influenced by the conditions under which they decompose, because the latter affect the activity of the organisms bringing about the decomposition. For example, the organisms developing on forest litter are very different from those that would be responsible for the organic matter transformations in a poorly drained soil or bog. The variations in composition between soil organic matter of one origin and those from other sources

must not be overstressed, however, because the composition of one mature plant material is not so widely different from another. The same general constituents are likely to be present, though they may be there in different proportions.

There are reasons for believing that the nitrogen content and the lignin content of plant materials may particularly affect the amount and composition of the organic residue ultimately remaining. Nitrogen is present in plants as protein. Lignin is a substance that is deposited on the cell walls of plants as they mature and get woody. Soil organisms can apparently utilize lignin only very slowly so that it tends to accumulate in the decomposed residues.

Young plants may contain large amounts of easily available constituents and protein but are usually low in lignin. Such plant materials decompose readily and rapidly. Almost all of the nitrogen in the protein is liberated, and the quantity of relatively resistant residue that remains to add to the organic matter supply in the soil is small.

Mature plants, on the other hand, contain less of the quickly available constituents and protein, but often contain 15 percent or more of lignin. Accordingly their rate of decomposition is less, and little or no nitrogen is freed. A larger quantity of residue remains, containing most of the lignin, that undergoes further change only slowly.

Both organic carbon and organic nitrogen are characteristically present in soil organic matter. Indeed the organic matter content of soils is conventionally arrived at by heating the soil to a high temperature to burn the organic matter completely, and determining the carbon dioxide given off. The amount of organic carbon which must have been present is then calculated and multiplied by 1.72 to obtain a figure for organic matter. This factor is based on the fact that soil organic matter contains approximately 56 percent carbon. The nitrogen content of the organic matter usually falls between 4.5 and 5.5 percent.

The ratio of carbon to nitrogen in the organic matter of surface soils is generally found to vary only within narrow limits.

The average  $\frac{\text{carbon}}{\text{nitrogen}}$  ratio of the surface samples of many soil types in Iowa is 12.1/1. This figure is somewhat higher than that found for the soils of the South and East, which are regions

where the mean annual temperature is higher and the winters less severe. As a result the activity of the soil organisms in such regions can continue throughout the year, so that the residues remaining are smaller in quantity and more extensively decomposed. The fact that the soils of Iowa are in effect in cold storage for about 4 months every year contributes considerably to the relatively high organic matter contents found.

### THE SOURCE AND AMOUNT OF ORGANIC MATTER IN IOWA SOILS

The virgin vegetation of Iowa was of two general types: tall, deep-rooted grasses on the prairies, and deciduous trees in the forested areas along the river valleys and on the adjacent rolling land in the more humid east and southeast portions of the state. Today the prairie-derived and forest-derived soils are clearly distinguishable because the distribution of organic matter within them is quite different. The soils of about 85 percent of the state are prairie-derived.

The prairies were covered with a sod, predominantly but not exclusively composed of grasses, the fibrous roots of which were particularly dense in the top foot, with many roots extending down for 3 feet or more. Wild legumes, both annual and perennial, were common. By early summer there would be profuse growth which as the season progressed matured to form a mat of dry vegetation, later beaten down by fall rains and the snows of winter. Early in the spring this mat decomposed fairly rapidly, and the liberated nutrients on reaching the soil were readily utilized again by the grasses, since the roots of grasses form a very effective absorbing system. Within the soil also, the roots of annual plants and some of those of perennial plants died each year and more slowly decomposed in place. The organic matter within the soil was largely derived from these roots, and its distribution, therefore, more or less parallels that of the root system of the prairie sod. Some little downward movement of the soluble or dispersible part of the organic matter may have taken place through the action of percolating water, but this is believed to have been relatively small. In fig. 1 is plotted the organic matter distribution in several prairie soils all of which had been in cultivation and of which, therefore, the plow layer had been turned over and mixed repeatedly. The

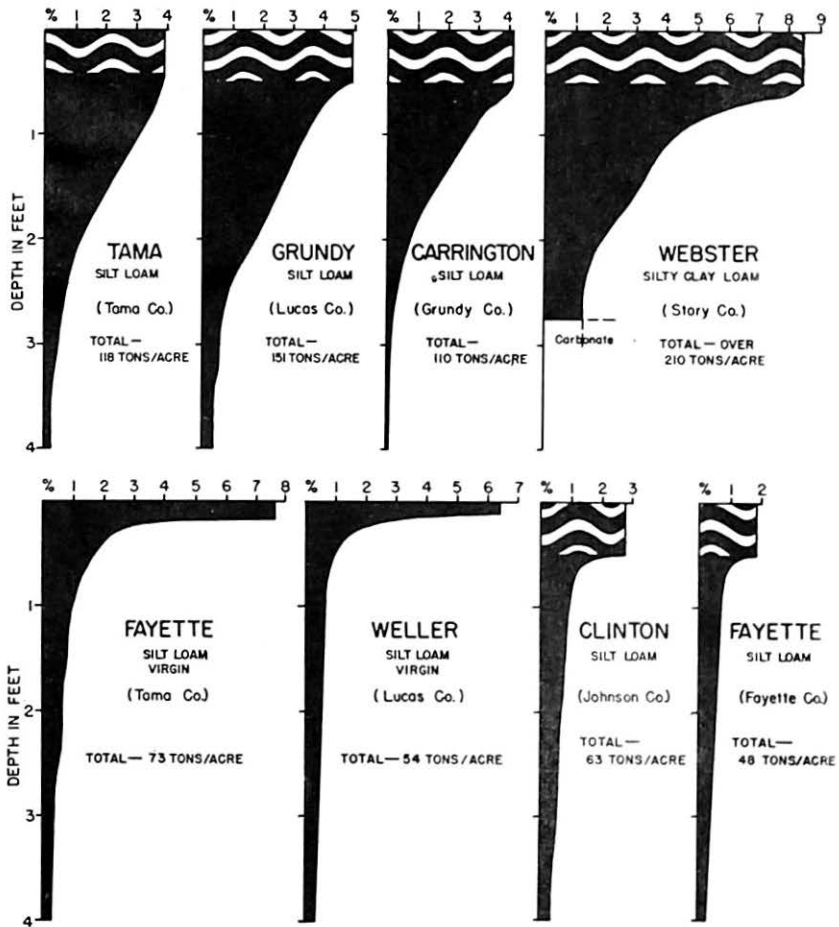


Fig. 1. Distribution of organic matter in typical prairie- and forest-derived soils in Iowa (plow layer indicated by wavy shading).

characteristic feature is the deep distribution with no abrupt changes in amount at any particular depth.

In forest-derived soils, on the other hand, the main organic matter additions to the soil came from the litter accumulating on the surface, which was composed mainly of leaves, but consisted also of twigs, small branches and fruiting bodies such as nuts and acorns. The forest litter decomposed slowly on the surface and lost its structure to give a dark, fluffy residue that only gradually became incorporated in the soil. Some was transported downwards by the percolation of water through the soil. The organic matter of the deeper layers of forest soils is largely

brought in from above in this way, but that in prairie soils arises largely from decomposition of roots in place. In a forest the cycle of growth and return to the soil is more or less similar to that under grass, but is less rapidly completed. Part of the annual growth in the branches, trunks and roots of the trees is only returned at intervals as the trees are damaged by storms or die. The organic matter distribution of forest soils under virgin conditions is characteristically one of shallow distribution, very high at the immediate surface but decreasing rapidly with depth. In fig. 1 are given diagrams of two virgin and two cultivated forest-derived soils. The effect of cultivation is of course to mix the upper few inches, but even so it will be readily seen that the distribution is far shallower than that within the prairie soils. Pictures of a typical prairie and forest-derived soil are given in fig. 2.

Even though the plow layer of two soils, one forest-derived and one prairie-derived, may contain about equal amounts of organic matter per acre, the total amount present to a depth of 4 feet is likely to be much greater in the latter. The difference may be considerable. In the poorly-drained prairie soils, such as those of the Webster, Muscatine and Grundy series, the rough limits are from 150-250 tons of organic matter per acre; whereas in the better drained prairie soils such as those of the Clarion, Carrington and Marshall series the amount usually falls between 100 and 150 tons per acre. The range for the forest-derived soils is appreciably lower and generally within the limits of from 50-80 tons per acre.

The shallower distribution of the organic matter within the forest-derived soils also has to be remembered when considering the effects of sheet erosion, for soil erosion is also organic matter erosion. From such forest soil the loss of a few inches of surface soil means serious depletion of the organic matter supply. Whether or not crop yields will fall would then depend on the management practices followed. The same depth of soil lost from a prairie soil, although grave enough, would not remove nearly so great a proportion of the total reserves in the soil, nor would the new surface layer exposed be nearly so low in organic matter content. For example the loss of the top 4 inches from the Weller soil illustrated in fig. 1 would involve the removal of roughly 23 tons of organic matter per acre out of a total of 54



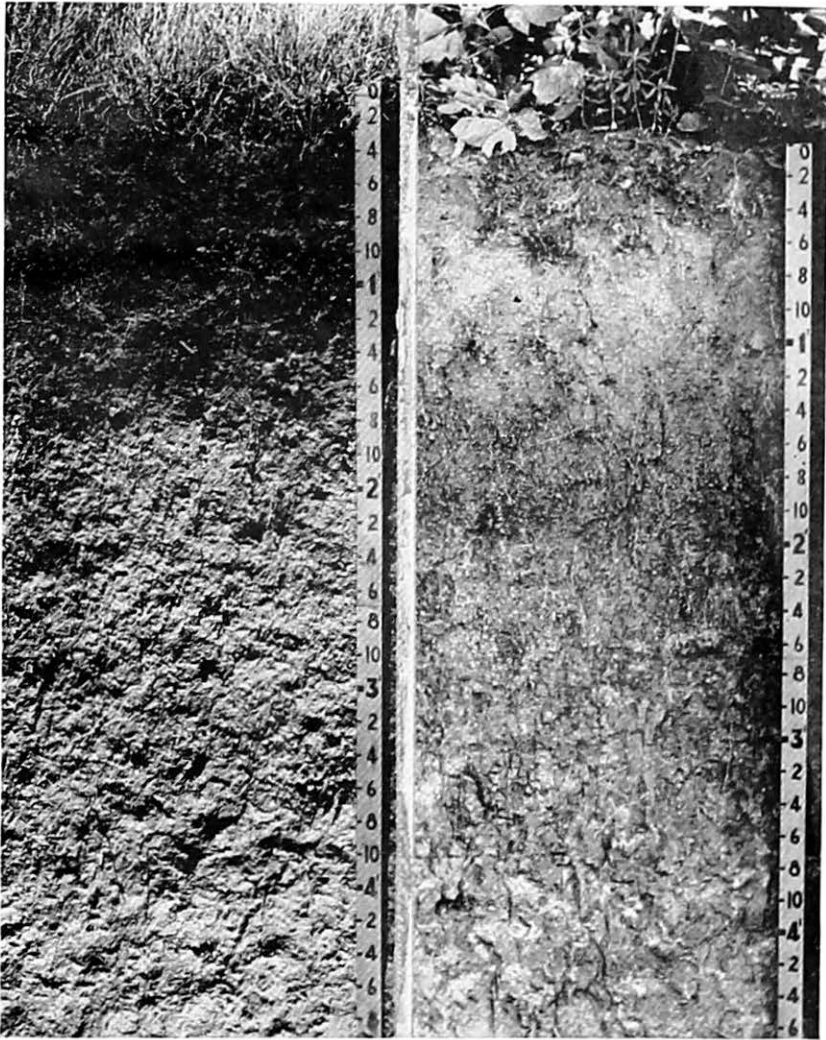


Fig. 2 Photographs of soil profiles. Left, Tama silt loam (prairie-derived); right, Fayette silt loam (forest-derived). A soil profile is a vertical cross section from the surface down to the parent sub-soil.

tons, or 42 percent of the total organic matter supply. The exposed layer would in the next 4 inches have an organic matter content of only about 1 percent. Contrast with this the Tama sample from which the removal of 4 inches of topsoil by erosion would involve the loss of about 24 tons of organic matter, but this would be but 20 percent of the total supply. Moreover the

exposed layer then to be farmed would still contain about 4.5 percent organic matter. The remaining organic matter in the eroded Weller would amount to about 30 tons as compared with about 94 tons in the eroded Tama. Most of the forest-derived soils of Iowa are on parent material of loessial or wind blown origin and in areas of rolling topography, both of which tend to make these soils peculiarly susceptible to erosion and therefore to erosional depletion of their organic matter. Under proper management and with suitable practices to prevent further erosional losses, the yields on partially eroded forest-derived soils do not necessarily fall in proportion to the amount of organic matter lost.

### FUNCTIONS OF SOIL ORGANIC MATTER

Since the organic fraction of soils is a residue of many constituents in varying amounts, its properties are complex, and its roles and functions numerous. There are, however, three main reasons why organic matter in soil affects the growth of the crop.

(1) Organic matter has *nutritional* functions, in that certain important plant nutrients are present therein, and are slowly released therefrom as from a storehouse.

(2) Organic matter has *biological* functions, in that it is the food supply for the vast and varied population of microorganisms that inhabit the soil, the combined activities of which result in the liberation of some of the plant nutrients in an available form.

(3) Organic matter has *physical* functions, in that some of its properties, such as moisture-holding capacity and volume weight, are of such a different order than those of the inorganic constituents that the presence of a few percent of organic matter has an entirely disproportionate leavening effect on the soil as a whole.

### ORGANIC MATTER AS A CARRIER OF PLANT NUTRIENTS

The main plant nutrient present in organic matter is nitrogen, and the nitrogen reserves in the soil are almost completely in the organic form. At any one time there can be found normally only a few pounds of nitrate per acre directly utilizable by the plant, not in fact sufficient for one satisfactory crop. High crop yields therefore depend on the continued liberation of nitrate from

the organic reserves throughout the season. A 75-bushel corn crop requires about 120 pounds of nitrogen. High crop yields are usually more directly related to the nitrogen supply than to that of any other nutrient. The steady decline in average corn yields going south from Iowa to the Gulf is closely correlated with the decrease in level of nitrogen in the soils.

In the plow layer the total nitrogen present equals roughly one-twentieth of the weight of the organic matter, or from 3,000-6,000 lbs. per acre in most Iowa soils. The total amount in the soil as a whole is considerably greater, of course, particularly since the nitrogen content of the organic matter seems to increase somewhat with depth. The availability of that in the lower part of the profile is, however, usually less than that in the plow layer.

Much of the phosphorus in the surface layers of Iowa soils is found in the organic fraction. The amount seems to be roughly one-ninth of the nitrogen present, but the proportion of the total phosphorus that is in the organic form is quite variable.

At lower depths in the soil the proportion of the total phosphorus supply that is in the organic form decreases rapidly.

An appreciable part of the calcium and other available bases such as magnesium and potassium is usually associated with the organic matter. The capacity of organic matter combining with and holding on to these bases far exceeds that of the clay on an equal weight basis. In the surface layers of the prairie soils 40-45 percent of the calcium and other available bases may be retained by the 4 or 5 percent of the organic matter present. As far as is known, the availability of the calcium and potassium

TABLE 1. ORGANIC NITROGEN AND ORGANIC PHOSPHORUS  
IN SOME IOWA SOILS.

Soil	Depth ins.	Organic P	$\frac{\text{Organic P}}{\text{Total P}}$	Organic N
		p. p. m.*	%	%
Carrington silt loam	0-6	246	45.3	0.20
Marshall silt loam	0-6	264	37.8	0.20
Edina silt loam	0-4	316	65.2	0.22
Grundy silt loam	0-6	205	40.2	0.21
Fayette silt loam	0-4	269	47.3	0.24
Weller silt loam	0-4	158	27.2	0.16

\* Parts per million

retained by the organic fraction does not differ appreciably from that held by the remaining inorganic fraction. The loss of base-retaining power that accompanies organic matter depletion has not been sufficiently recognized.

#### **ORGANIC MATTER AS THE FOOD SUPPLY FOR THE SOIL ORGANISMS**

The organic matter of soil can fulfill its nutritional functions with respect to release of nitrate only as it is decomposed. Since the soil organisms are living things they have to have food, and they take in oxygen and give off carbon dioxide just as do animals and man when they breathe. The food for the soil population is the organic matter of the soil. When crop residues are plowed under or a sod broken, the food supply is substantially increased. The size of the microbial population is ordinarily controlled by the food supply available — a soil low in easily digestible food has a small population, whereas a soil rich in food has an enormously large population. Nitrogen in plant residues is in the form of protein, and the soil organisms feed on this also, liberating finally ammonia and nitrate. Before it is liberated much of this nitrogen may be used by the organisms themselves to build their own cells. Small as is each individual there are such vast numbers present that many pounds of nitrogen per acre are present in the living cells of the soil population, and many more in the dead residues of organisms. As the food supply grows short, the size of the microbial population that can be supported diminishes and accordingly excess nitrogen is liberated as ammonia and converted into nitrate that may be used by the plant.

In many respects the activities of the soil organisms can be likened to slow wood fires that can be caused to blaze up brightly by the addition of more fuel in the form of crop residues or other plant materials. As the more available, or inflammable, constituents are consumed, however, so does the blaze die down to a smouldering glow, that can be fanned somewhat by cultivation. These bacterial fires burn only for a part of the year, because the cold winters and consequent low soil temperatures damp them down and keep activity at a minimum for several months each year. The fact that the organic matter in Iowa soils is in cold storage for a part of the year is one of the chief reasons why

their content is so much greater than that of southern soils in which bacterial activities can proceed the year around.

#### ORGANIC MATTER AS AFFECTING THE PHYSICAL PROPERTIES OF SOIL

Soil is predominantly composed of inorganic mineral particles, which vary in size from ultra-fine clay to coarse sand, mixed with a little organic matter. If it is to be productive the various particles must be grouped together into aggregates or crumbs. Proper aggregation provides good environmental conditions for the growth of plants and the activities of microorganisms. A sufficiency of plant nutrients alone does not ensure good crop yields. A soil that has a good structure and is well aggregated is readily worked, and is spoken of as being in "good tilth." It possesses physical characteristics some of which, though easily recognizable in their effects, are rather intangible and difficult to express or measure simply. The soil must be sufficiently porous so that there is adequate aeration for plant roots and the microbial population. It must retain water so that steady growth can be maintained, and yet it must allow water to penetrate and pass through it fast enough so that it does not become unduly wet after periods of rain. It must be friable so that when plowed or worked great clods are not formed, but instead a mellow seed bed can be obtained. It should exhibit some resistance to the beating and washing action of rain on sloping land. The properties involved in conferring these desirable characteristics on a soil overlap but in almost all of them the effect of the presence of organic matter is manifest to a degree that is quite disproportionate to the amount present. Deterioration in the physical characteristics of a soil seems to accompany depletion of organic matter, particularly in the heavier soils. They become more compacted, and their moisture relationships are less satisfactory. They become more difficult to till and more susceptible to erosion.

Soils with desirable physical properties, when cultivated, break up easily into crumbs of various sizes, and yet these crumbs exhibit considerable strength and stability. Recently broken prairie sod has perhaps the finest stable crumb structure of all soils. One of the methods that has been used recently in attempting to measure the physical condition of the soil has been the determination of the proportion of the total weight of the soil that

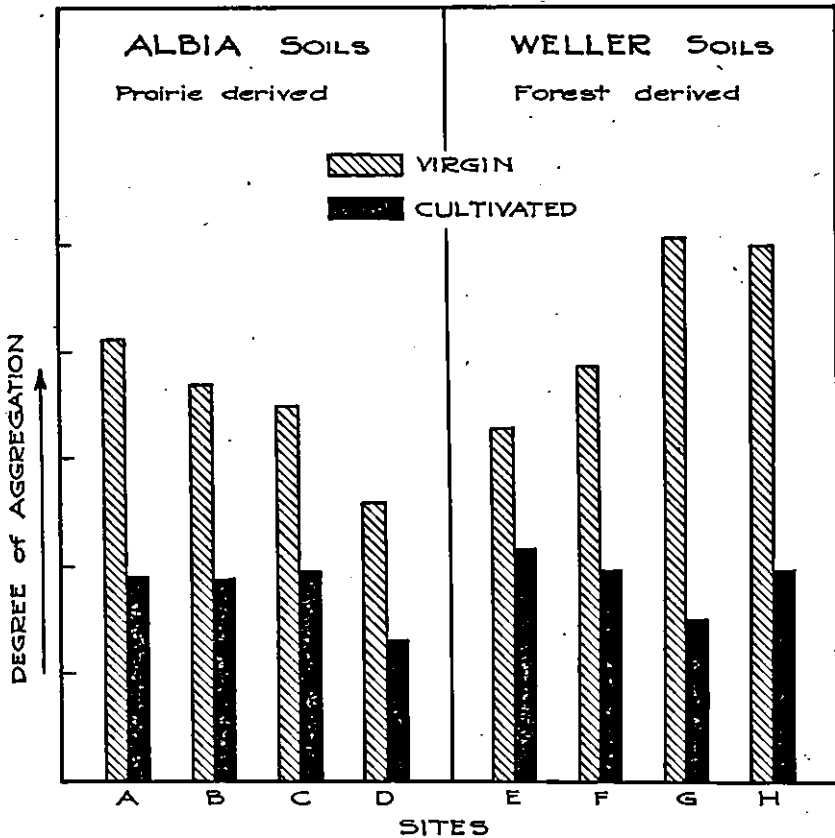


Fig. 3. Comparison of degree of aggregation of virgin and cultivated soils—Albia silt loam (prairie-derived), Weller silt loam (forest-derived).

exists in the form of water-stable crumbs of various sizes. This is accomplished by sieving through a nest of sieves under water. Comparison of the degree of aggregation of a number of surface samples of virgin and cultivated soils taken from sites closely adjacent is given in fig. 3.

The degree of aggregation is not necessarily directly related to the total organic matter present. It seems that there is a form of aggregation produced by the presence of actively decomposing plant residues, perhaps as a result of some product of microbial development. The aggregation of the same samples of the cultivated soils mentioned in fig. 3 was improved by the addition of such varied types of material as alfalfa, cornstalks and sugar. The last, which temporarily produced the greatest effect, resulted

in extremely vigorous microbial growth without itself leaving any insoluble residues.

The physical properties of the organic fraction of soil are not necessarily related to its biological or nutritional properties. There are, for example, certain types of peat that are of little nutritional value even though in many respects they have good physical properties and improve the moisture-holding capacity and aeration of soils if added to them.

### ORGANIC MATTER DEPLETION

As soon as virgin land is broken the utilization of the accumulated organic matter surpluses of centuries begins to occur at a rate far greater than can be balanced by annual additions of crop residues. Biological activity is increased by plowing and cultivation; the bacterial fires burn very brightly. The depletion of organic matter that begins with cropping and cultivation is simply the use of it as food by the soil microorganisms, and cannot be prevented. That it occurs is not a result of poor farming but because the annual balance of organic matter income over expenditure is so much higher under grass than when the land is in cultivation. Most Iowa soils have probably not yet quite reached a stable condition, and indeed the level at which the organic matter becomes stabilized will be controlled in great measure by the present and future choice of crop rotations and management practices. The natural losses of organic matter occurred at a much faster rate during the first two or three decades after breaking of the prairies than is taking place now. Larger amounts proportionately were lost from soils high in organic matter than from those of lower initial organic matter content. Figures obtained by the Missouri Experiment Station suggest that the rates of depletion have been of the order of 25 percent, 10 percent and 7 percent in successive 20-year periods since the virgin sod was broken. The actual amount lost, however, depends on the cropping system practiced. Intertilled crops make for greater depletion than grain crops planted solid. This is borne out by the data from the check plots of the rotation experiment at the Agronomy Farm at Ames (table 2). The figures given are for the 20-year period 1917-37. The area in question had probably been in cultivation for over 40 years previously.

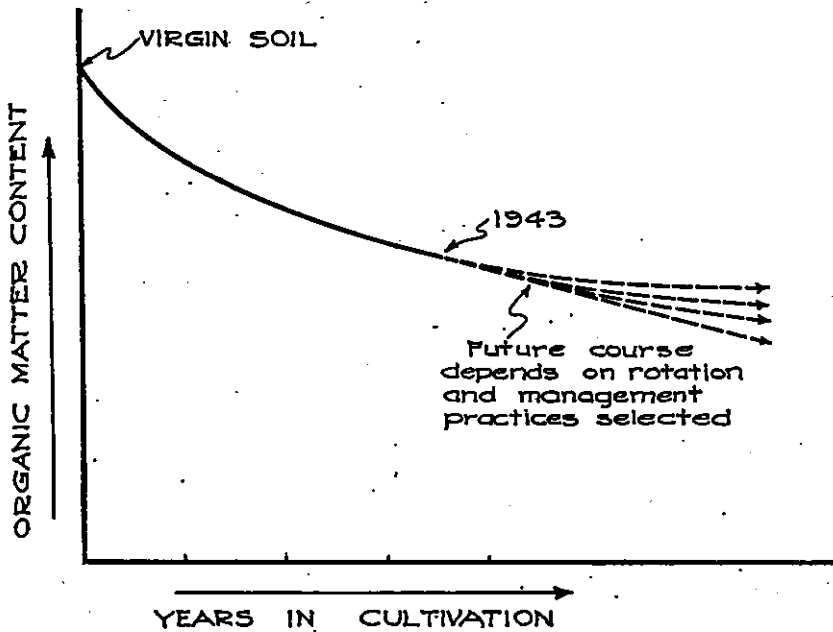


Fig. 4. Trend in organic matter content of soil on land continuously cropped.

Each block of each rotation included different treatments, such as use of manure, incorporation of crop residues, addition of lime or phosphate, and combinations thereof. Although the comparisons are not complete, no treatment or combination brought about any substantial reduction in the losses of organic matter either with continuous corn or in the corn-oats rotation. In the 3-year rotation, however, the losses from plots receiving manure and lime, or crop residues and lime, were small, particularly if phosphate

TABLE 2. DEPLETION OF ORGANIC MATTER IN CHECK PLOTS (OLARION-SERIES) AGRONOMY FARM FOR 20-YEAR PERIOD FROM 1917-1937.

Cropping System	Average loss of organic matter	
	lb. per acre	Percent
Continuous corn	18,100	18.9
2-yr. rotation (Corn — oats)	13,200	16.1
3-yr. rotation (Corn — oats — legume hay)	9,600	11.7
9-yr. rotation (Corn — oats — legume hay — wheat — 5-yr. alfalfa)	8,600	10.2



was also applied. It is no coincidence that on these plots the corn yields have been maintained at a high level.

The organic matter changes and expectations may be indicated diagrammatically as in fig. 4.

### ORGANIC MATTER MANAGEMENT AND REPLACEMENT

The depletion of the reserves of organic matter in the soil affects crop yields in a variety of ways. One of the most important is that the amount of nitrate released is reduced. When the land was first broken out there was much easily available nitrogen. By cultivation the bacterial fires were fanned, by erosion reserves were squandered, so that now a stage has been reached when the amounts released are much smaller. The more resistant parts of the soil organic matter are left, with the result that the bacterial fires are glowing less brightly. It is not the aim of soil management practices to attempt to restore the organic matter content of our soils to their original level; indeed it would be futile to attempt to do that. It is possible, however, to increase substantially the rate at which nitrate and other nutrients become available and at the same time to offset the natural processes of organic matter depletion. To do this, material containing more nitrogen than the ordinary non-leguminous crop residues must be added. Mature crop residues in general contain little protein but plenty of available carbonaceous compounds which are utilized as food by the microorganisms. Carbon dioxide is given off and as a result the ratio of  $\frac{\text{carbon}}{\text{nitrogen}}$  in the residue narrows as decomposition proceeds until in the neighborhood of 12/1. The amount of this residue, which undergoes further change only slowly, will depend in part on the amount of nitrogen in the plant material originally, and in part on the presence of some of the more resistant plant constituents, such as lignin. It would not be possible to increase appreciably the organic matter content of a soil by adding large quantities of an easily available food such as sugar. Sugar would have an effect on the bacterial activity as violent but short-lived as pouring gasoline on dull glowing coals. Young plant materials somewhat resemble sugar in that they are so readily and rapidly used by the soil population that little lasting contribution is made to the general organic



Fig. 5. The application of manure is a valuable means of organic matter replenishment.

matter level though the immediate effects on crop growth may be considerable. To accomplish organic matter replacement the soil should receive a reasonable and steady supply of microbial fuel in the form of plant materials that are not too available. In this way the smouldering bacterial glow of long-cropped soils can be changed to a steadily burning fire that is far more satisfactory than an occasional blaze caused by large and panicky additions. The nitrogen reserves need replenishing at intervals by the incorporation of barnyard manure or the growth of a legume. A consistent program of organic matter replenishment is an essential part of all satisfactory rotational systems.

There are three main means by which the organic matter in the soil may be replenished. These involve the addition of (1) barnyard manure, (2) green manures and (3) mature crop residues. In any good program of organic matter management these are not treated as alternatives, but each is made use of in its proper place, as frequently as possible. Each has its own special qualities, and each supplements the others.

#### **BARNYARD MANURE FOR ORGANIC MATTER RENEWAL**

Farm manure is commonest and perhaps the least appreciated material ordinarily available to offset organic matter depletion

and increase the available nitrogen supply. One ton of average manure contains plant nutrients more than equivalent to 100 lbs. of a 10-5-10 fertilizer (cash value, about \$2.50), though all of the nutrients are not so immediately available as in a fertilizer. About three-fourths of the plant nutrients in crops harvested and fed on the farm may be recovered in the manure and returned to the land if the manure is properly stored and handled. From unprotected, loose piles heavy rains will remove soluble constituents. Much of the nitrogen of fresh manures may be lost as ammonia if fresh manure is spread long before plowing. The ideal is, where possible, to follow the spreader with the plow.

Barnyard manure when added to the soil has a dual effect. First, there is an immediate effect because the easily available nutrients present cause a yield increase in the next succeeding crop. Second, there is a long-time effect because by slow decomposition of the more resistant residue that supplements the organic matter of the soil, yields are maintained at a higher level. Barnyard manure applications have given yield increases on almost all soil types in Iowa, even when included in good rotations that involved also the plowing-under of legumes, as was the case in the experiments summarized in table 3.

Many farmers make a practice of applying manure once in the rotation at a rate of about 2-3 tons per acre per year. When fresh manure is used this cannot be considered a heavy application and beneficial effects, particularly on the later crops in the rotation, would be expected to follow a more generous rate. However, if the supply of manure on a farm is limited, it is probably more desirable to cover the whole farm progressively at the lighter rate than to apply the manure heavily on only a portion of the land. On the Agronomy Farm yield increases have followed applications

TABLE 3. INCREASES IN CROP YIELDS AS A RESULT OF APPLICATIONS OF BARNYARD MANURE\*.

Crops	Crop yield per acre		Increase for manure
	No treatment	Manure	
Corn — 357 crops	50.9 bu.	56.8 bu.	5.9 bu.
Oats — 185 crops	43.2 "	49.7 "	6.5 "
Wheat — 19 crops	21.9 "	25.5 "	3.6 "
Mixed hay — 108 crops	1.2 tons	1.4 tons	0.2 tons
Alfalfa — 35 crops	1.8 "	2.1 "	0.3 "

\* Nine soil types, 70 co-operative fields, Iowa Agr. Exp. Sta. 1918-1938.

TABLE 4. YIELD INCREASES IN 4-YEAR ROTATION FOLLOWING APPLICATIONS OF MANURE AT VARIOUS RATES\*. MANURE ON THE CLOVER SOD, EXCEPT WHERE STATED; LIME WHEN NEEDED.

Manure Applications	Corn (1st yr.)	Corn (2nd yr.)	Oats bu.	Clover tons
8 tons	11.5	9.6	4.5	0.63
8 tons + lime	16.5	8.9	4.8	1.06
12 tons + lime	16.8	11.2	7.1	1.33
16 tons + lime	21.9	13.5	10.9	1.54
20 tons + lime	21.3	16.8	11.4	1.77
2 tons annually	11.5	6.6	2.2	0.78

\* Figures are increases over no treatment for years 1927-38 and include 11 corn crops (1st year), 11 corn crops (2nd year), 11 oat crops and 9 clover crops

up to 20 tons per acre per rotation (table 4), and these are detectable all through the rotation. Most manure spreaders can be adjusted to deliver from 4-12 tons per acre.

Two tons of fresh manure per acre does not add more than 800-1,000 lbs. dry matter, much of which in the form of straw is rather rapidly decomposed on incorporation into the soil. An optimistic estimate of the more resistant residue from such an application in 1 year would be 300-350 lbs. The average annual loss of organic matter from the check plots of a 2-year corn-oats rotation for the last 20-year period has been almost 700 lbs., so it will be readily realized that much heavier manure applications would have to be made to hope wholly to offset depletion at such a rate, though that of itself is not necessarily the goal. Cases are on record, however, in which the soil organic matter level has been maintained unchanged and even increased by heavy applications of barnyard manure, despite intensive cropping. These ordinarily occur, however, only where the original organic matter content was low.

#### GREEN MANURES FOR ORGANIC MATTER RENEWAL

Green manures suited to Iowa are almost invariably legumes or legume-grass mixtures. A well-nodulated legume crop may contain 75-100 lbs. more nitrogen per acre than taken directly from the soil, and the soil reserves may therefore be increased by such an amount if the crop be turned under. The best results will not be achieved, however, if the legume or sod is regarded primarily as a source of hay, unless good care be taken of the manure obtained when the hay is fed. Fortunately, the biennial

legumes generally have deep and extensive root systems that may contain about one-third of the nitrogen present in the whole plant, but even so, in order to incorporate as much material as is reasonably possible, the second top-growth should ordinarily be left and plowed under.

The value of legumes has been measured mainly in the yield of the crop immediately succeeding. Because of the high nitrogen content of legume crops and rapid decomposition, it is probable that this is where they make their main contribution. Certainly most legumes do not exhibit the slower, long-time effect to the extent that follows use of barnyard manure, and this may be due to the fact that most leguminous tissues on decomposition leave only a small resistant residue. Biennial sweet clover lends itself to the greatest flexibility in management, for in the second year as maturity is approached, the material becomes more woody and less nitrogenous so that the rate at which decomposition takes



Fig. 6. Available soil nitrogen is increased and organic matter renewed by turning under green manures.

place is slowed down and the time over which the effects are manifest is consequently lengthened.

Best use is not made of the nitrogen of green manures, such as sweet clover, in the first year, or second growth red clover in the second year if fall plowing is carried out too early. Under such circumstances decomposition takes place with rapidity, and nitrate is so quickly liberated before cold weather sets in that much of it may be lost then and in the spring before the time when the succeeding crop has greatest need for nitrate. For organic matter replacement, incorporation should be practiced either at a stage when the legume is not too rapidly decomposed, or at such a time that liberated nitrate is utilized efficiently by the crop following. In the latter case the effect of the legume on organic matter reserves may be indirect in that by increasing the growth of the succeeding crop, the weight of residues remaining therefrom, subsequently to be plowed under, is increased. Red clover should be plowed late in the fall or in the spring; sweet clover late in the fall of the first year, in the spring of the second year or early in the fall (August) if allowed to remain through the second summer.

#### **CROP RESIDUES FOR ORGANIC MATTER RENEWAL**

The main crop residues in Iowa are cornstalks, straw stubble and soybean straw left when the beans are combined, together with the roots of all crops. The case for the return to the soil of all above-ground residues does not rest solely on the conservation of the plant nutrients which they contain, even though this is considerable. For example, the stover from a 75 bu. corn crop may contain as much as 36 pounds of nitrogen, 4½ pounds of phosphorus and 39 pounds of potassium. Perhaps more important, however, is the fact that crop residues are mature materials which on decomposition leave appreciable amounts of a relatively resistant residue in the soil. One ton of cornstalks will probably be as effective in this respect as 3-4 tons of fresh manure, though no short-time effect would be apparent. Because of the relatively low nitrogen content of cornstalks, straw and soybean stalks and their mature character, the liberation of the nitrogen and other nutrients contained in them is slow, so that yield increases in the next succeeding crop would not be expected. Depressions of yield caused by plowing under straw of low nitrogen content have been reported but are improbable if only the stubble is