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SOIL ORGANIC MATTER AND ION AVAILABILITY FOR PLANTS[1]

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Recent progress in understanding the mobility of cations around the colloidal mineral part of the soil is sufficiently satisfactory to prompt inquiry about ion mobility in relation to the organic matter fraction of the soil. Even though anion behavior, like that of phosphorus, is still a secret, yet the lack of a clear concept of all mineral phases need not deter us from giving some, more or less speculative, attention to ion mobility centered about the organic matter. When this small part of the soil renders such magnitudinous service in plant production, it may well have attention with the hope that an understanding of its behavior will elucidate, in some additional measure, the complex phenomena of plant nutrition.

DIFFERENT PHASES OF ORGANIC MATTER BEHAVIOR AND ION MOBILITY

The scope of organic matter behavior may well be outlined, at the outset, by reminding ourselves that soil organic matter may be both positive and negative in its effects. It may contribute positively in mobilizing ions for better or more rapid delivery to the plants. Contrariwise, it may serve to demobilize, or fix, and remove them from plant access. Effects in these opposite directions may be exercised simply in a physical way by the ion adsorption on the colloidal organic matter. Ions may be thus removed from solution and held so firmly adsorbed as to become a negative factor in plant growth. On the other hand, the ions may be adsorbed at so much higher degrees of saturation as to be delivered more readily for plant service through the simple processes of ionic exchange.

The breakdown of the organic matter through the decay process may serve in a positive chemical way by contributing nutrient cations and anions to the plants, just as any burning process delivers ash. A contrary chemical effect may result, however, when the composition of the decaying compounds fails to serve as a well-balanced bacterial ration and compels the microorganisms to withdraw ions from the soil solution or from the absorption complex and put into immobile form as insoluble microbial complexes many otherwise mobile ions. Because bacteria can operate at lower concentrations than more highly developed plants, this ion demobilization represents a microbial

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competition with plants. These aspects of ion mobility and ion immobility in both physical and chemical ways must be appreciated if the role of organic matter in connection with ion delivery to the growing crop is to be clearly understood.

DECLINING SOIL FERTILITY MEANS DECLINING AMOUNT AND VALUE OF SOIL ORGANIC MATTER

Farm manure has been considered the "foolproof" fertilizer of the past. It will not necessarily be so considered in the future if it is produced on, and returned to, soils excessively tilled and depleted of their store of mobile mineral nutrient ions. Manure, which has been valued, in the main, for its nitrogen content must be valued also for the phosphorus, the potassium, the calcium, the magnesium, and all the other contributions it makes as it gives up its mineral constituents of the past plant generations to create those of the future. The successively diminished store of ions offered by the soil is lowering the value of the manure as it is produced from feeds and roughages grown on such soils. By merely going back to the point whence it came, organic matter can do little to uplift the productivity. Manure is not saturated with active nutrient ions purely because it represents vegetative matter that went through the animal's digestive mill. On soils of declining fertility each cycle of organic matter through decay and plant growth represents vegetation of type and composition still lower in fertility level. Manures produced thereform must reflect the advancing fertility deficiencies as they represent woody organic matter rather than organic matter loaded with nitrogen, minerals, and other nutrients contributed by the soil.

The growth of fungi on manure in the form of commercial mushroom production, according to some preliminary studies,[2] is suggesting that declining soil fertility with its increasing soil acidity, or rather its decreasing exchangeable calcium, is reflecting itself in terms of lowered mushroom-producing capacity from much of the manure being produced at present. Perhaps this is traceable to the lower mineral effectiveness in the straws of the bedding, in the feces, and in the urine of the manure in the mushroom compost. Perhaps it may be located also in the fertility-deficient casing soil as it fails to compensate for these defects in the manure.

Organic matter merely coursing regularly through its cycle of vegetative growth, decay, and reincorporation into a new crop of organic matter as a natural process represents ion mobility, but is not a means of increasing the mass of ionic nutrients in the cycle. On the contrary, it is nature's slow method of holding this mass from slipping downward rapidly. In the humid regions, organic matter is not an elevator of production purely because it is of organic nature. Rather the improved fertility in terms of more calcium, more magnesium, more phosphorus, more potassium, and other similar items is the

[2] Schroeder, R. A. Unpublished report. Department of Horticulture, Agricultural Experiment Station, Columbia, Missouri.

means of providing a greater mass of organic matter. This consists also of improved chemical composition and is set for more rapid destruction through its more effective service in microbial nutrition. Consequently, the higher level of soil fertility rotates faster in these larger masses for better plant production. Organic matter in the soil is the effect and not the cause of the mobile ions that represent the fertility supply of the soil.

ORGANIC MATTER BEHAVIOR FITS INTO THE COLLOIDAL CLAY CONCEPT

Even though the complete separation of the partly decayed organic fraction —the so-called humus—from the mineral part of the soil has been impossible; nevertheless, the properties of organic matter have been worked out well enough to establish the fact that the bulk of the soil organic matter is colloidal in nature and behavior. Its origin from different materials, in different localities, and under different climatic conditions may well inject variations into its carbon-nitrogen ratio, its ash content, and its general chemical composition. Nevertheless, with lignin and other relatively stable compounds making up a large share of the colloid, the composition of this soil fraction is constant enough to warrant generalization of its behavior into some broader principles.

We now know that chemical reaction is possible between the purely organic and the purely mineral colloidal parts of the soil (7). The organic colloid and the soil mineral colloid are similar in behavior and properties. The acid organic matter colloid from peat acts toward hydrogen replacement from its complex by other ions according to the order of their increasing valency—a behavior in close agreement with that of colloidal aluminosilicate, or clay (5). The humus colloid is, however, more highly hydrated. Its union with calcium gives a floccule of about three times the volume of that produced by the union of calcium with the Putnam-clay colloid. Hydrogen and calcium have many similar effects, whether combined with the colloid that is humus or with that which is a mineral clay. The acid organic matter, or hydrogen humus, however, is the more stable in water, the calcium humus being about four times as easily resuspended after drying or flocculation.

HYDROGEN HUMUS MAY DECOMPOSE MINERALS

That the colloidal hydrogen humus may mobilize cations out of the mineral crystal lattice and into its own ionic atmosphere from which these cations may enter the plants more effectively, has recently been established by Graham.[3] Pure, freshly pulverized, and acid-washed anorthite particles of silt size, when mixed with electrodialyzed hydrogen humus, gave up calcium to the organic colloid at rates about three times as great as to the acid, or hydrogen, clay. Successful tests with the anorthite-treated clay for plant nourishment by the calcium so mobilized (6) suggest that the colloidal acid humus may be serving similarly. If this is a fact, then organic matter is not only mobilizing the stock

[3] Graham, E. R. Unpublished report. Department of Soils, Agricultural Experiment Station, Columbia, Missouri.

of ions constituting its own complex, or even not only those caught by adsorption from solution as they were passing by, but it is also apparently quarrying some cations from rock fragments within the soil to mobilize these also.

These fundamental properties of organic matter as a colloid are helpful in understanding ion mobility and possible offerings of nutrients to plants through the many activities of this small fraction of the soil. Ion adsorption and ion exchange as physical or chemical processes by the organic matter fit into the same categories as those by the clay colloid, save that the humus fraction has from two to six times more exchange capacity per unit weight. It is also significant that the ash content of the humus—possibly a reflection of the soil fertility that produced the original humus-forming plants—bears some relation to the exchange capacity. That some variations in the physical and chemical properties of the organic colloid should occur ought not to be seriously disturbing, when the organic matter itself is only an ephemeral compound in the presence of the soil microorganisms using its carbon as an energy source. Such variations are so small that nutrient cation behavior toward organic colloids calls for little revision of the views regarding nutrient cation mobility from or to the colloidal clay fraction which may well serve as the behavior pattern. When anion activities toward both organic and inorganic colloids are equally well cataloged, then plant nutrition will be much better understood.

ION MOBILITY AND ORGANIC MATTER IN SOIL DEVELOPMENT

Organic matter is a factor in moving ions about in the soil profile during the processes of soil development. In the process of podzolization under forest vegetation, the leaf litter provides a hydrogen organic colloid which moves downward through the surface horizon of the soil beneath it. The question may well be raised whether the podzolic surface horizon is depleted of its bases wholly because of acidic action of the organic matter traversing it, or whether the soil was not already highly deficient in the bases, particularly in calcium, before the forest vegetation was established there. Since trees live largely by rotating their mineral capital as they drop their leaves to return the minerals to the soil for repeated use, may not the organic matter be a means of holding minerals against leaching and thus of retarding soil development, rather than an agency in leaching out these nutrients in what is commonly credited as the main role of organic matter in the soil development performance known as podzolization?

Though leaves represent rotating mineral capital, yet they are certainly a poor bacterial ration with reference to nitrogen. Their destruction is not rushed to completion, with carbon dioxide and water as end products. Instead, intermediate complex humus compounds result. When organic matter is rich in protein and also rich in the minerals required in larger quantities by protein-producing vegetation, it decomposes so rapidly and so completely that little humus results. Leaf humus is deficient in the growth-inducing elements; namely, nitrogen, phosphorus, calcium, and others, but still is rich in energy-providing carbon. If it moves down through the soil profile without suffering bacterial destruction, then it seems safe to conclude that it remains unattacked by soil microorganisms, because neither it as a compound, nor the respective soil horizons met enroute, contain the essential nutrients to make microbial use of it possible. As such energy-supplying organic matter goes downward toward clays of higher calcium saturation, it eventually arrives at that degree of offerings of calcium (and probably of other cations) where, supplemented by the soil, it becomes a balanced bacterial ration (4). Under standing water to give anaerobiosis, the gray layer or the glei horizon of podzolic soils develops. There iron is reduced to the ferrous condition as it contributes oxygen for organic matter combustion. The iron becomes soluble and is moved upward or downward as a consequence of the presence of organic matter rather than because of high degree of soil acidity.

In the development of chernozem soils, the organic matter and calcium are both commonly associated through the significance ascribed to the calcium in the preservation of the organic matter. It now seems doubtful whether it is correct to believe that chernozem soils have retained large amounts of organic matter because this was preserved chemically by the calcium, when, in reality, the mobility of the organic matter in combination with calcium is really increased. Calcium is an agency to encourage complete combustion of organic matter (1). The ubiquitous deficiency of calcium points out that it would be more nearly correct to believe that organic matter is accumulating because mineral nutrient deficiences for the microbes keep it from decomposing. Then too, since calcium humate is a much less stable compound in water than is hydrogen humate, such increased mobility and wider distribution of the dark color through the profile of calcium-laden horizons of open structure are additional encouragement for bacterial destruction rather than for preservation.

Under such conditions the idea of preservation because of the presence of calcium is untenable. A more plausible explanation of the high organic matter content of chernozems is that the liberal supply of calcium and other bases induces more nitrogen fixation, both symbiotic and nonsymbiotic, to produce and to hold more carbon and to increase the organic matter content in spite of the increased rate of its destruction by microorganisms in such a favorable medium. Chernozems represent soil development to the maximum of ion mobility, and of ion-organic matter complexes, all at high levels and at high rates of seasonal turnover. In such a concept of soil development with the help of organic matter, may be the key to high soil productivity under our management.

ORGANIC MATTER PRODUCTION AND ION MOBILITY THROUGH PLANT GROWTH

The degree to which a soil has developed, or the extent to which the original rock minerals have moved toward true solution and toward their final resting place in the sea, determines in no small way the ion mobility in any soil. As the organic matter mobilizes or demobilizes various ions, it may be an arresting or a hastening force to this process. It is in this respect that organic matter—itself of plant origin—plays no small role in plant nutrition. Some recent studies offer interesting suggestions regarding organic matter as it modifies the mobility of calcium, nitrogen, and hydrogen. To date, the calcium and the hydrogen have stood out among the cations because of their particular properties and because of their presence in magnitudes measurable by delicate laboratory instruments or by particular plant behaviors. Perhaps other nutrient ions will be brought into the picture when sufficiently accurate methods of following their behavior become available.

MORE ORGANIC MATTER MAY MEAN MORE EXCHANGEABLE CALCIUM AND MORE EXCHANGE CAPACITY

Studies[4] of the successive 1-inch horizons in the Shelby profile at the Soil Conservation Experiment Station, Bethany, Missouri, show that in a bluegrass sod experiencing no soil treatment and no erosion, the exchangeable calcium was related to the organic matter content. The highest organic matter content (5.71 per cent) had associated with it the highest amount of exchangeable calcium (14.60 m.e.), when for the entire seven horizons (0–7 inches) the figures were, as a mean, 3.73 per cent of organic matter and 11.75 m.e. of exchangeable calcium. This is the situation for the organic matter contributed by the crop of bluegrass, which is not commonly considered a calcophile.

The organic matter accumulation from the bluegrass increased not only the exchangeable calcium, but also the exchangeable magnesium. With successive years in bluegrass sod, plot 8 at Bethany, Missouri, with its increasing organic matter content from 1931 to 1937 showed a progressive increase in base saturation from 77 per cent to 91 per cent. Here, then, the process of soil calcification, or an increasing degree of calcium saturation, was going on under the environmental conditions of north Missouri and while the bluegrass crop was being produced but not removed. Leaching was not an impossibility and may have been occurring, but carbonates were not moved to the lower levels. There was a total deficiency of 22 inches in precipitation during the 7-year period, though the annual precipitations were never lower than 21.8 inches in 1937 and the annual mean for the period was 34.44 inches.

Thus this careful plot study points to organic matter production by grass as a means of leaving within the soil an increased mass of a colloidal residue that is organic in nature, that may be highly saturated by calcium, and that will deliver this nutrient much more rapidly in seasonally timed rates when the sod is broken out and the land put into a tilled crop. This suggests that sod crops as soil fertility restorers may have benefits that are not limited to nitrogen: they may be mobilizing the mineral phases of the soil for their own benefits as well. Here were an increased exchange capacity and an increased degree of calcium saturation, because of the increased organic matter provided through the growth of a sod crop and its period of soil fertility rejuvenation.

[4] Whitt, D. N., and Swanson, C. L. Unpublished report. Missouri Soil Conservation Experiment Station, Bethany, Missouri.

CALCIFICATION OF ORGANIC MATTER SEEMINGLY ENCOURAGES AZOFICATION

In this bluegrass sod under study, where the base saturation increased from 77 to 91 per cent, of which 90 per cent was calcium, total nitrogen increased from 0.173 to 0.185 for the years 1931 to 1933 and from 0.190 to 0.205 for 1935 to 1937 respectively. This improvement in the nitrogen content of the soil took place while the hydrogen-ion concentration, supposedly a significant factor for azotobacter, registered pH 6.2 for most of the time, though in the first year, 1931 it stood at 5.6. While this change in pH occurred, the calcium saturation increased 18 per cent. It is interesting to note, in passing, from some other studies (3) with bluegrass and redtop, that complete calcium saturation of the soil made the delivery of nitrogen from the soil to the crop most effective. Thus we are inclined to believe that this nitrogen increase at Bethany under bluegrass sod and the increased calcium saturation are not completely separate performances, even if we are not ready to grant that they are causally connected. Nevertheless, with the increase in the organic matter have come an increase in the mobile supply of nutrient ions and a demobilization of the hydrogen ion, their commonly reciprocal ion on the colloidal exchange complex.

SIGNIFICANCE OF pH MAY BE DWINDLING

Here, as has been previously shown (2), the ions are more efficient with their higher degrees of saturation. Increased mobility of the nutrient ions results not only in increased plant growth above the soil, but also in increased microbial growth and activity within the soil. With more microbial activity, there is a speedier cycle of rotation from soil to crops and back to soil to bring into the cycle other elements not previously involved. That such may have occurred under the bluegrass sod is suggested by the fact that in another plot with a regular crop rotation receiving no treatment and having no soil erosion during these same years, the organic matter content remained constant, when the plow depth was also kept constant to prevent clay incorporation from the subsurface. In those plots showing decreases in organic matter, exchangeable calcium decreased. The amount exchangeable varied with the organic matter while the pH was constant. Here is another indication that pH can scarcely be causally related to crop production if the pH remains constant while the exchangeable calcium and the associated organic matter, both large factors in plant growth, fluctuate so widely.

OTHER POSSIBLE PHASES OF ION MOBILIZATION BY ORGANIC MATTER

If organic matter plays a role in soil development through the mobilization of ions, which may be viewed as a simple chemical process extending over ages of time, and if its role in ion mobilization for plant nutrition in annual cycles suggests that this latter role supports the soil development processes, then, perhaps, other activities of organic matter will gradually add themselves to complete the picture of the organic matter performances in the soil. It may be our misfortune that the understanding and appreciation of the significance of organic matter as a mobilizer of nutrient ions will come too late. By the time we fully appreciate the organic matter heritage in our glacial soils as the source of fertility delivered to our crops at rates commensurate with their seasonal demand for profitable production, then the supply will already be so nearly exhausted as to jeopardize the farming business.

We need to stimulate further thinking about the organic matter as a mobilizer of ions when other observations, the exact significance of which is unverified, are indicating that organic matter is playing such a role. Has it been a mere whim of the fertilizer user of the South to insist that a share of his applied fertilizer nitrogen be in the organic form? Is the struggle to find a proper organic-inorganic ratio in fertilizers (8) for southern crops without physiological foundation? Might not the recent attention to the "acidity" of purely mineral fertilizers suggest a case of calcium deficiency that shows up quickly when not covered by organic matter performances within which apparently the calcium supply is automatically increased with the increasing stock of organic matter? Does our recent attention to the many so-called "growth-substances," "accessories," "biotin," and similar growth-stimulating compounds of known chemical structure, suggest that their shortage is manifesting itself because the diminishing organic matter in the soil brings it into prominence? As the knowledge about the chemical structure of these becomes effective for plant growth improvement, it will set us thinking about the kind and composition of organic matter we put into the soil to mobilize nutrient ions. When carbonaceous vegetation with its wide silica-calcium ratio and low content of other soil-derived nutrients is recognized as a *demobilizer* of ions for plants, while leguminous vegetation with a narrow silica-calcium ratio and high content of elements other than silica from the soil is known as a *mobilizer* of such ions, then organic matter will become a widely used tool for better crop production and for more effective soil and fertility conservation. In the organic matter of the soil is the means of managing the fertility of the soil most wisely for its service to the future.

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