

Insoluble Yet Available

by Dr. William A. Albrecht

Professor Emeritus of Soils, University of Missouri, U.S.

The following article is based on a talk given by the author before a state meeting of fertiliser producers. It is divided into two parts, namely (a) the insoluble yet available cations adsorbed and exchangeable on the clay, and (b) the same situation of behaviours by the inorganic-organic complexes.

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THE creative act by any soil when it grows our crop plants is still much of a mystery and miracle. We do not yet comprehend fully the *modus operandi* of the plant roots connecting with the soil and getting nourishment from that source.

Even though soil comes from the ancient rock, yet plants contain only about five per cent of themselves as the elements of rock origin. The mystery of how the rain-drenched soil can resist being dissolved away and yet pass nourishment through the root to the plant may soon yield to the scientific efforts of clarification and fuller understanding. Such clearer vision of the soil's services in growing crops can do much (a) to elevate the appreciation of the soil: (b) to encourage more judicious management of it, and (c) to bring wider conservation of the only creative power by which all forms of life must be fed.

I. INORGANIC PLANT NUTRIENTS THROUGH SOIL'S ADSORPTION AND EXCHANGE

The soil's behaviours, like those of many other things in nature, do not conform completely to the 'laws' we learn in laboratory chemistry and by which we have been explaining the natural nutrition

of plants. In the laboratory, the solubility of a substance in water, in alcohol, or in certain reagents is commonly the foremost criterion for its description and classification. We are mentally disturbed, then, when we find that some natural substance or commercial product, commonly soluble in the laboratory, behaves as an insoluble one, or vice versa, when put into the soil.

We experience similar confusion when, for example some *insoluble* substances on coming in contact with the mucous membrane of our body, like that of the lungs on inhalation, is *soluble* and harmless there. We are more disturbed when some so-called *soluble* substances are as disturbing (and fatal) to the lungs as the insoluble silicates of rock dusts are in the case of the disease known as 'silicosis'. Land plaster, consisting of the mineral, gypsum, or of the chemical compound, calcium sulphate, is considered soluble in the laboratory. Yet its inhalation brings a breakdown of the lung tissues which on X-ray examination suggests silicosis or even calcification by its accumulations there.

Sulphur—Case in Point

The mental confusion grows still larger when we consider the element sulphur an insoluble one but find that the inhalation of flowers of sulphur for a long time is a case of absorption and one without scar of the lung membranes. According to these two cases, what is classified as a chemically *soluble* substance in the laboratory may be an *insoluble* one by contact with this kind of living tissue, and vice versa.

In a corresponding confusion, the plant root as a living tissue in contact with the soil has not been understood in its absorbing activities because the properties and behaviours of substances in the soil have been assumed to be the same in relation to that living form of nature as they are when tested in relation to chemical reagents, or in solubility tests of them, in the laboratory. In transplanting our knowledge, gained from studies in the laboratory, as only a vision (not tested by plant growth) of what might be the situation or phenomena in the soil, the visionary concepts are not necessarily in accord with the natural facts.

Chemical inspection of fertilisers and regulatory controls of their sales became a practice according to the early beliefs that water solubility of them was an index of their absorption by the plant roots. Yet, after their application, some water-soluble fertilisers are washed out and lost from the soil while others become highly insoluble and

of very limited uptake by plants regardless of that property of solubility in water. But fortunately we are moving toward a fuller comprehension of the facts of nature according as the accumulating research—under its higher refinement through technological aids—is simultaneously refining our concepts and visions of plant nutrition. Fuller understanding is coming about because we see in more detail, and we comprehend more relations of causes and effects between the soil and the plant.

Roots Find Nutrients Still Available in Soils Highly Leached by Rainfall

Just what the plant root does while going through the soil and gathering the many ash or non-combustible elements (also some combustible organic molecules) of nourishment from the supposedly insoluble, pulverised rocks that are weathering to give out their minerals under the forces of the climate, has been another one of those confusions in our thinking. That came about also because it was founded on the criterion of solubilities and insolubilities according to laboratory chemistry. When the nutrient elements considered *insoluble in the laboratory* are *available to*, or taken into, *the plant*, we are content to accept it as mystery. It must then be more of a mystery when the rain falling in excess of evaporation goes down through the soils as drainage water to carry the solubles out and down into wells, into underground streams, and into the sea to be added to the accumulation of salts there. Yet, it is on those washed-out soils that the plant root gets *available* nutrient elements which control the growth processes elaborating carbon dioxide from the air along with water from the soil into sugars, starches and other carbohydrates by means of sunshine as energy source.

It is that water going down through the soil that has been carrying away to the sea—as a beneficial service—both the sodium and the chlorine of which neither dares be in the soil as a salt in more than fractions of a per cent, if food crops are to be grown. It is the rainfall that has been weathering rocks into parts as solution and parts as suspended clay, and by that rock-destruction has been giving us the soil from which not only plants but all living bodies are created. The silicon, or the larger share of most any rock, forms the clays. They do not rush off to the sea. Rather they, as a non-nutrient, hold back while a share of the active elements in solution may move out with the water. But again, the larger share of the solubles, including nutrients, is quickly inactivated by being absorbed on the clay. That process duplicates the manner in which lime or calcium in solution

in 'hard' water is adsorbed on the colloidal compound in the household water softener.

Nature exhibits these effects of adsorbing the soluble elements extensively whenever any kind of substance is so finely divided that it behaves according to its total surface rather than according to its mass or total weight, or when such a finely divided substance stays in suspension to be called a 'colloid'. Clays are classified under that chemical category. It is the clays of our soils, then, by their adsorption on themselves of calcium, magnesium, potassium, iron, aluminium and others, that hold the nutrient elements so that they are not soluble to be carried away in the drainage water but yet will move into the plant root to serve as plant nutrition. Colloidal chemistry, or the surface chemistry of suspensions, came along after the chemistry of solutions was well established, had explained much, and was supposedly well comprehended.

The Mills of God Must Grind Insoluble Rocks as Source of Available Plant Nutrients

We visualise the weathering of rocks to give us our soils by the processes in which the elements of positive electrical charge, initially combined with the silicon and oxygen of negative charge as minerals, are broken apart to become chemically active separates. That condition permits their recombinations into other or secondary minerals and compounds. The silica (silicon and oxygen) combines with water into a large molecular grouping which is not very active, or not significantly ionised, like the smaller positively charged elements are.* The silica, then forms the clay as its possible combinations with iron and aluminium to remain as a gelatinous covering on the weathering mineral crystals. Consequently, from the start of the weathering of a mineral fragment, the potassium, the calcium, the magnesium and the others coming out of it as active separates are enshrouded by the clay envelope on which they may be adsorbed and where they are not really free and active ions to be carried away in solution in the drainage water. Also, they are not soluble in water in the true sense of that terminology. *They are insoluble but yet available.*

** Silicon's behaviours represent slow-speed, inorganic chemistry much as in the case for most all organic substances behaving mainly as large molecules rather than as ions.*

The elements adsorbed on the clay colloid behave as a group or, figuratively speaking, as if lined up in company front within the clay envelope. From there each may move out if some ion (or ions) of corresponding electrical charge approaches from the outside and replaces it with the particular expenditure of energy required for the exchange. This involves what may well be called 'fair trade', or exchanges on the basis of at least nearly equal properties. Those include chemical valence, energies of replacement, and size of ions or molecules concerned.

That is the explanation in about the simplest terms, but not in complete details, of the physico-chemical phenomena of the soil when we call it 'adsorption and exchange of cation'. It represents the prominent soil phenomena so far as the positively charged nutrient elements like calcium, magnesium, potassium and others in less amounts are adsorbed on the inorganic clay colloid to be *insoluble to percolating water but yet available to the plant roots*.

Since the organic matter of the soil, especially the more stable fraction resulting from microbial digestions of it and considered the humus, also has adsorptive and exchanging properties duplicating those of the clay, we can expect the nutrient cations to react with the organic matter fraction of the soil according to the same principles. Fortunately, the humus has a higher adsorption and exchange capacity per unit weight by several times that of the clay, so that by building extra organic matter into the soil there results a higher adsorptive and exchange capacity of it.

This soil phenomenon of adsorption and exchange was initially spoken of as 'base exchange', since calcium, magnesium, potassium and sodium are considered 'basic' in reaction, contrasted to 'acidic', which is the reaction of the cation hydrogen. We use the 'bases' to neutralise the active, sour-tasting hydrogen ion, or to make it inactive and not ionic. But since hydrogen, like these other elements cited as 'bases' is also a cation of positive charge, and will also be adsorbed along with them and exchanged for any of these others on the clay and humus, all in like manner, it is more nearly correct to speak of *cation adsorption and exchange* by these two colloidal fractions of the soil (clay and humus) than to speak of only *base exchange*.

Adsorption and Exchange Permit Quantitative Assessment of Available Cations

In speaking about cation exchange in terms of quantities concerned, the amounts of cations adsorbed are so small, relative to the clay or humus acting as adsorbers of them, that we speak of milli-

grams of cations adsorbed per 100 grams of clay or humus (parts per hundred thousand). But since hydrogen is the common chemical unit of equivalence of all elements, as for example, one gram of hydrogen is the equivalent of 20 grams of calcium, or 12 grams of magnesium, and of 39 grams of potassium, we speak of the *cation exchange capacity (C.E.C.) per 100 grams of clay* in terms of a certain number of *milligrams equivalents (M.E.)* of hydrogen.

Thus the colloidal clay fraction of a soil type like the Putnam silt loam is said to have a cation exchange capacity (C.E.C.) of 65 milligram equivalents (M.E.), (C.E.C.) = 65 M.E.). Accordingly, 100 grams of that colloidal clay (according to accurate measurements) could adsorb a total of 65 milligrams of hydrogen alone; or $65 \times 20 = 1300$ mgms. of only calcium; or $65 \times 12 = 180$ mgms. of magnesium; or $65 \times 39 = 2535$ mgms. of potassium only. By that arrangement in equivalents of the element hydrogen, one can visualise the total exchange capacity satisfied by combinations of extensively varied amounts of each of those three cations cited, to say nothing of including some hydrogen, or of adding also all the positively charged trace elements in their extremely small quantities. By that situation each element can represent a wide range of its quantities according as those are different percentages of the total cation exchange capacity (C.E.C.) including a whole suite of cations.

Adsorption and Exchange Gave Techniques for Measured Variation in Plant's Chemical Composition According to Varied Soil Fertility

By use of the colloidal clay of the Putnam silt loam with controlled quantities of the nutrient cations adsorbed on it as percentages of saturation, that is, in specified ratios to each other, it was discovered that such variation produced different growth effects, and different chemical compositions (carbohydrates vs proteins), of a legume crop like the soybean. Thus, the varied suite of cations adsorbed may represent a balance, or an imbalance, in the nutrition of the plant. As a suggested balance, for example, the adsorbed calcium may well be 75 per cent of the C.E.C., the magnesium, 7.5-10 per cent of it, and the adsorbed potassium, about three per cent, while the remainder of the C.E.C. is taken by hydrogen (to give some acidity) along with a remaining small part taken by the many unmeasured cations of both known and unknown trace elements. Thus we can now *test soils for their available nutrient cations* (not only those soluble in water) and, accordingly, can speak of the soil offering a *plant ration of insoluble but yet available cations held by*

the soil according to which ration or plant's diet the varied growth of the plant responds and a varied final chemical composition results in terms of its nutritional values as feed or food.

Molecular Nature of Clay Mineral Modifies Adsorption-Exchange Activities

Because a given amount of a cation is adsorbed on the clay, it does not follow that an exactly similar amount will always be exchanged readily. In the case of potassium, as an illustration, of a given amount adsorbed on soil colloids only a part may be exchangeable (by laboratory test) while the balance is considered as 'fixed' and not exchangeable or soluble. Just what structural property of the clay molecule brings about this particular behaviour of the potassium is not entirely clear in vision or concept. Other elements, too, are not completely exchangeable. Hence, the forces holding the adsorbed cations and the energies required for exchange are not fully understood. Nevertheless, the colloidal aspects of the clays (made up as they are of different clay minerals) have taken on helpful quantitative meanings by the terms 'adsorption, exchange, cation exchange capacity, percentage saturation of cation exchange capacity', etc.

Those are the behaviours and quantitative assessments of the colloidal properties of the major active fraction of the soil. These contribute clarification of the previous confusion about soluble substances going into the soil to become insoluble against the loss therefrom to the percolating waters. Knowledge of those soil properties has done much to explain how such *insoluble elements* (adsorbed on clay or humus) *are nevertheless available* for exchange to the plant root, or to water, according as either offers to exchange some other cation in the equivalence of the requisite properties. It explains more clearly than ever before how the root can come along with hydrogen, which is the acidic cation enshrouding the root because that plant part respire carbon dioxide to make carbonic acid, and can exchange such from that source for nutrient cations which feed the plant while making the soil more acidic. The uniqueness in that process of nature lies in the fact that the waste product of the root's respiration is the basis of its power to take nutrients off the clay or to make *the insoluble become the available nourishment*.

We Have Not Improved on Nature's Laws by Use of Water-Soluble Fertilisers

In contrast to the confusion in our attempts to manage plant nutrition more efficiently than nature by our use of water-soluble

(salt) fertilisers in extra quantities, nature has long been using a simple practice of mobilising the insoluble elements from the rock minerals into the adsorbed and insoluble condition on the clay and humus. By the same principle, nature moves them from there into the plant, by use of the root's own waste from respiration, namely, carbon dioxide. In the presence of water, that waste has given, carbonic acid—nature's most universal acid—and its active hydrogen to be exchanged to the clay and traded there as an active *non-nutrient cation for the nutrient cations* and their movements into the root as plant nutrition. If we will comprehend and follow nature's practices and principles rather than our own confused thinking, there is still hope that we shall learn of, and have higher appreciation for, nature's successes in crop production for healthy plant survival. Perhaps we can see that nature practices scrupulous conservation, when, in fact, making *available* to plants—more generously than we realise—the essential fertility elements which we believe unavailable because we classify them as insoluble in terms of chemical inspections for regulatory purposes.

II. ORGANIC PLANT NUTRIENTS THROUGH LIVING SOILS

In our attempts to comprehend how the insoluble rock can make soil which, under proper moisture, will nourish plants, we have too long believed that the nutrient inorganic elements from the soil must be water-soluble. That has seemed necessary, at least for the first step of that service, namely the entrance of them as ions into the plant root, or for their movement through the outer wall or membrane of it.

The states' inspections, and their license of commercial fertilisers, use water-solubility and the solubility in citrate solutions, as the criteria of the fertilisers' services. The inspection assesses fees on the tonnages of fertilisers distributed according to those solubility requirements for the nitrogen and potassium units and for those of phosphorus respectively.

Nutrients Are Not Washed Into the Plant by the Transpiration Stream: They Enter Under Their Own Power

In that contention that solubilities of high order are required for entrance into the plant root, we are apt to believe also that such entrance is connected with the large amount of water moving from the soil into the root, passing through the plant, and evaporating to

the atmosphere from the leaf surface. More water is moved through and transpired by the plant according as the evaporation rate from the leaves increases with (a) the rise of the daily temperature, (b) the wind, or air movement over the leaf surface, (c) the lower humidity of the atmosphere, and (d) the larger supply of water in the soil. But because there is a decided flow of water from the soil through the plant for evaporation to the atmosphere, that is not proof that the fertility elements are necessarily moving along that same course because of that current of water as transpiration. Calcium, magnesium, nitrogen, phosphorus, potassium, and all the other essentials are not swept into the plant because they are applied to the soil in water-soluble forms of fertilisers and 'flooded in', as it were.

There are natural facts, some readily demonstrated in the laboratory, which refute such erroneous beliefs that the water-solubility within the soil is a requisite for fertiliser availability and flow with the water into the growing crop. As the first fact, plants will grow and their nutrients will move normally from the soil into the roots without the evaporation of water from the leaves. A potted plant, enclosed in a water-saturated atmosphere with carbon dioxide under a glass bell-jar in the light, will grow normally. This fact tells us that while the transpiration stream is halted because the saturated atmosphere will not take any water of evaporation, the fertility elements are, nevertheless, flowing into the plant from the soil.

In research at the Missouri Station, some soybean plants were grown on soils of such low saturation of the clay by calcium, that the totals of nitrogen, phosphorus and potassium in the total crop of tops and roots were less than those of the planted seed. Such facts tell us that the fertility elements may flow out of the root, or in the reverse direction of the flow of the transpiration stream of water.

That same reverse flow of fertility can be demonstrated under the conditions used for the potted plant within the bell-jar, or when there is no flow of transpiration. Such facts inform us that even in the absence of water movement within the plants, the nutrients will move either into, or out of, the plant, entirely independently of either the static or the flowing condition of transpiration water. Forces, other than the water flowing into the plant root, must move the fertility elements serving in connection with plant nutrition.

Still as another situation, the desert plants have shown according to research reports by Dr. Went, now director of the Missouri Botanical Gardens, that nutrients go into the roots for nourishment of the plants when in the daytime the water is transpired to move from the soil to the atmosphere. Then, also, they go into the roots

when at night-time the atmospheric moisture of condensation moves from the plant back to the soil sufficiently for plant survival through such diurnal reversals in movement of the limited moisture supply.

These facts deny, categorically, any necessity of water-solubility of nutrients for their flow into, or within, the plant for any delivery services of them by the transpiration. They tell us that the fertility, which is feeding—not watering—the crop plants, behaves according to certain laws of physico-chemical relations within the soil and plant, while the water movement behaves according to the meteorological conditions and the climatic situations controlling the conversion of water from the liquid to the gaseous form and vice versa.

Water-solubility of plant nutrients in the soil is not the rule of nature for their services to plants. Rather, they are naturally insoluble there, by which condition they remain there against loss through leaching out of the soil. By virtue of that condition they are still there when the growing root comes along. But that fact does not deny their being available through other mechanisms than simple aqueous solution.

Natural Plant Growth Emphasises the Insolubilities of Both the Organic and the Inorganic Nutrients

When any plant species established itself naturally in its particularly well-suited climatic setting, the crop is at its best (a) in growth, (b) in self protection against pests and diseases, and (c) in reproduction of its kind. But those conditions occur only after many annual crops have grown and died in place to build up a significant supply of its own organic matter on the surface of the soil. As an example, we speak of the 'forest floor' consisting of the accumulated leaves, needles, etc., as a spongy mass of the forest. We speak also of the 'grassy mat' of the prairies. Then, there is the accumulated organic matter within the upper horizon of the soil profile because of which we call it 'the surface soil'. Then with more emphasis on the extra organic matter as the very top of the profile we say 'the prairie sod'. These are the situations when the crops are naturally at their climax, or at their best.

These organic accumulations are some of the means by which nature retains the previously accumulated inorganic combinations until their microbial decompositions set them free as ash elements again. Microbial respiration, or nature's slow process of burning out the carbon to escape as gas, gives the energy by which there is 'the living soil'. The organic, not the inorganic part 'puts life into the soil'. During its decay, some organic matter moves downward in its

colloidal forms within the soil profile. It may precipitate there in combination with iron, manganese, and other elements as insoluble layers.

All this emphasises the insolubilities of both the organic and the inorganic substances in connection with nature's processes for accumulations—not removals—of the organic matter both on, and within, the profile. It is those accumulations of insolubles, to become available later, by which nature grows crops at their best in terms of freedom from pests and diseases, of dense stands, and of big yields. The living soil under the climax crop represents much of the recently contributed, highly carbonaceous substance on which an enormous population of microbial life can feed for its energy which was absorbed by and stored within the previous plant generations as sunshine energy. Consequently a virgin, living soil represents ample energy food for its microbial populations, but a decided shortage of readily available foods for growth, like nitrogen, phosphorus, sulphur, calcium, magnesium, potassium and others. Therefore, if any one of these elements comes out of the decay activities which convert it into available forms, that element will be quickly taken by the microbes as foods for their growth, through its balancing of the excess of those serving only as food of energy source.

Such are the processes by which nature keeps the fertility of the soil insoluble. She conserves and maintains it most scrupulously because it is building a rapidly multiplying microbial population in the soil active in that performance. That conservation is so wisely managed through the biochemical activities of the soil organic matter by which the plant and microbial nutrients are kept insoluble in water but yet available for plant growth.

Nature's management, as just outlined for her accumulating organic matter of the soil, duplicates, in principle, what the straws, and other plant residues and wastes, do as bedding under stabled livestock to conserve the soluble fertility in the animal urine and feces. The bedding is a microbial food representing excess energy. It is what has been called 'go' food. But the urinary salts, especially the nitrogen, are their food for cell growth. These are 'grow' food. When the latter as solubles are added to the bedding, the microbes grow rapidly from this growth food as supplement to the energy food, or carbon, of the bedding. While about one part of carbon is built into the living cells about two parts are burned by them for energy to escape to the atmosphere as respired carbon dioxide gas.

Thus with this reduction in the soil's supply of energy substance through carbon escape, any growth substance like nitrogen, etc., is

carefully conserved within the soil's living cells which consume it the moment any bit of it becomes available as the remains of one generation to be the food for the next one. This process continually conserves the living potential, the growth food or the creative power of the soil. The originally wide ratio of the carbon (carbohydrate) to the nitrogen (proteins) in the straws as plant residues from which the protein-rich parts, like seeds, were harvested, becomes narrower and narrower to approach that of the higher protein concentration of only the living microbial cells. Those must then consume each other when the energy supply in fresh organic matter like the bedding is all consumed. Such are the biochemical results of the heating processes occurring in urine-wetted bedding in barn waste on its way to become what is truly manure in its fertiliser form, and occurring also in any highly woody, organic wastes when composted with some nitrogen and other salts of commercial fertilisers to bring on the process of decay.

But very soon those cycles of re-use and careful retention of the growth foods will have run their course and the surplus energy foods will have been burned out. Then the manure ceases to heat. It will no longer be keeping the soluble growth elements as cellular, excretory wastes combining into insoluble living substances. At that moment, the carbon-nitrogen ratio of the manure (or the soil) has become so narrow that dead microbes are consumed by the surviving others for energy foods as well as for growth foods. After that moment the growth elements made soluble will not be made insoluble so quickly, since there is no more energy food in reserve as fresh organic matter. It is then that those solubles may serve as the plant's nutrition or, like in the unsheltered manure heap, they may be leached away by rainfall. It is after the heating stage is over that manure serves as fertiliser to feed the growing crop, when during the heating process it was serving to feed the microbes, for which plant roots are no competitors within the soil.

The Rise Then Fall of Natural Conservation of Fertility

Give the Successions of Different Climax Crops

Under nature's management of the soil, it is the period of pre-climax crops which represents conservation first of the inorganic fertility and later of both the inorganic and the organic. Man's taking over of the climax or virgin crops and his putting the soil under cultivation prohibits natural conservation. It is replaced by exploitation or by expenditure of the many fertility values which nature had assembled and preserved as insolubles but availables for microbes

and plants because of Her maintenance of much carbonaceous organic matter of a truly living soil. Crop values as nutrition of warm-blooded bodies must decline accordingly as the living soil moves slowly toward its own death.

After a natural crop, like grass on the plains or prairies with its natural animal herds, has reached its climax because not much more inorganic fertility can be added to the annual cycles of fertility turnover because the roots do not reach it, or after annual rainfall has increased to leach more of it away or erosion removes it, then the climax crop is slowly replaced by another which will later reach its climax. But that succeeding crop represents a lower level of physiological processes especially lower than those we see in protein-rich plants to feed warm-blooded bodies. Hence those crops represent less nutritional support for animals and man. In that decline in the succession of crops, the forests, especially the coniferous, can be one of the last of the climax situations of the declining fertility support by the soils.

Contents of Plants are Insoluble and Highly Organic Yet Biochemically Active

Just as the living soil represents little that is water soluble, or salts in solution, likewise there is little that is water-soluble within the plants and within any living tissues growing on the soil, save that some potassium is in solution surrounding the plant cells. Occasionally, some potassium is washed out of the shocks of harvested wheat to be indicated by the encircling better growths of the stubble crop of red clover. It may be similarly washed out of the shocks of fodder-cut corn marked by better fall-seeded wheat around those shocks left for a considerable time during a rainy post-harvest season.

Crop production does not represent chemical processes dependent on the creative fertility elements of soil-origin in water-soluble states. Those biochemical processes of living matter do not depend on compounds with a high degree of ionisation, or of their separation into their component, electrically-active elements for ready conduction of current and speedy recombinations into other compounds. Inside of the single cell and inside of the specific collections of them as particular tissues and living bodies, the very opposite conditions prevail. Proteins, the only compounds which are living, may be broken down into what is called 'amino acids', but they are not acidic in reaction when combined to form the living protein tissue.

While our concepts of inorganic and mineral chemistry emphasise the elements as active ions, those creative atoms are not in that ionic

condition to any degree of significance either in the original rock minerals that go to make soil, or in the life forms of microbes, plants, animals and man that are grown from that soil. Those *elements* need to be viewed *in their compounds*, in their *larger molecules* and as *adsorbed ions* to give the lowest possible ionic activity when held by colloids requiring energies, or work, to exchange them and make them more ionic, or separately active. Living soils are stocked with organic compounds, (a) which control the chemical activities of the essential inorganic elements emphasised for their water-solubilities but are unknown, or forgotten, for their unique combinations into un-ionised and insoluble parts of organic reactions, and (b) which supply nutrient directly in the form of those organic compounds.

Science Learns Facts of Nature, Then Interprets Her Secrets of Long Standing

Scientific studies are uncovering what seems like a natural protection, via the soil organic matter and the living soil's dense microbial population, against excessive salts in the soil. Nature uses the inorganic elements mainly as inclusions within larger organo-complexes. This has demonstrated itself as a means of moving more inorganic fertility of the less soluble nature from the soil into the plant and about within it. This emphasises *the availability of the insoluble*. Now that we have discovered, in the laboratory, the process which we call 'Chelation' whereby an inorganic ion is stably fixed within a larger organic molecule so that both are taken into the plants for their better nutritional service there, we comprehend what has been nature's way by which the insoluble fertility of the soil has become the available to the microbes and the plants during the past ages. But only slowly are we putting science under nature's secrets by which She grows better crops by returning more organic matter back to the soil.

Chelation is the term that interprets what observations in agricultural practice have often suggested. It is a widely recognised fact, for example, that both the soluble and the insoluble phosphates, and particularly the former, are more effective for improving the crop when first mixed with barnyard manure. Also, the simultaneous applications to the soil of ammonium salts and soluble phosphates will mobilise more phosphorus into the plants for better crop growth. Sodium nitrate applied in combination with the latter does not. Calcium nitrate in place of the sodium even reduces the mobilised phosphates, as compared with what occurs when soluble phosphates are applied alone.

The element nitrogen, the common symbol of our only living compounds, i.e. the proteins, is prominent in bringing about the chelation of calcium, magnesium, iron, cobalt and a list of other elements, as examples. It is the nitrogen, in particular, that serves to connect the inorganic elements more stably into the large organic unit of the final complex that results from chelation. It suggests the proteins, and other forms much like them, as the major means of chelation which robs the inorganic elements of their common property and chemical activity which we usually emphasise about them, namely, their solubility and their ionisation, respectively.

This concept of chelation should not stretch our vision beyond its elastic limits when chlorophyll, the green colouring matter in every leaf, is an age-old illustration of nature's use of chelated magnesium. In its chemical composition this photosynthetic agent represents about one part of the inorganic in about forty of total organic for building sugar from water and carbon dioxide under the sunshine's energy. Magnesium is similarly chelated in a long list of other enzymes of both plants and animals.

Hemoglobin in our blood is a case of chelated iron with about one part of it in fifty parts of organic matter. This is the means for taking up oxygen from the air in the lungs to be carried by the blood stream and given up to the tissues while the iron is not ionic.

Then cobalt is also chelated into vitamin B₁₂ in a similarly wide ratio of the inorganic to the organic part of the complex. The importance of this chelation compound was discovered by chickens, taking to the cow's droppings, long before we as chemists had any vision of it. Natural chelation under the dynamics of organic matter and microbes, may be expected to illustrate itself more widely now that much research work is studying it, and to increase our appreciation of this one of nature's secrets, now that the chemistry has given foundation and pattern for our visions of the chemical aspects a bit more fully.

Commercial Chelators Give the Means for Determining the Effectiveness of Naturally Insoluble Yet Available Nutrients in Soil for Plants

The commercially available chelator, ethylene-diamine tetraacetic acid (EDTA) was put into soil of no-iron content along with one half of the plant's roots, while the other half was in similar soil given iron as well as ample phosphates to make both less available according to their solubilities. Yet this commercial chelator was taken by the plant roots from the one half of the soil. It served to mobilise the iron from

the other half into the plant roots and to correct the chlorosis of the plants which occurred under similar soil conditions omitting the applications of this special chelator. More significant, however, was the additional demonstration which added waterleachings from a highly organic soil as a substitute for the manufactured chelator, EDTA, only to find that this natural substitute served in iron mobilisation for the cure of chlorosis just as the EDTA did.

Such facts help us to visualise the services by the soil microbes in their absorption of the 'Salt Shock' when ammonium phosphate is added to the compost heap; when its soluble inorganic nutrient elements are taken into insoluble, much larger organic complexes; and when, thereby, both parts are made more available as nutrition entering the roots of the crop plants. We are gradually visualising that, *within the soil, the organic fertility as chelating forces is dominant over the inorganic in about the same ratio as the combustible organic part of the plants is dominant over the incombustible, the inorganic, part there.*

Phosphorus in Organic Matter is More Efficient Than Its Other Forms in the Soil

That such ratios prevail, relative to the advantages of making the insoluble become the available via the soil organic matter, was recently demonstrated by some research using barley as green manure for feeding radio-active phosphorus into a crop of soybeans, according to the unpublished data from the research studies by Vernon Renner of the Missouri Experiment Station.

Barley plants were grown on sand cultures with a controlled nutrient medium containing radio-active phosphorus. They were harvested, dried, pulverised, sampled for chemical analyses, and then that pulverised organic matter mixed thoroughly into the soil in the ratio of one part of the former (organic matter) to 500 of the latter soil. This represented the common field rate of two tons of this dried green manure per two million pounds of soil per acre per ploughed depth.

The soybeans were harvested after a growth period of sixty days and chemical analyses were made to determine their contents of total phosphorus and of the radio-active phosphorus. This would, via radio-activity, determine the phosphorus contributed to the soybean roots by the green manure applied to the soil. The total phosphorus, minus the radio-active part, would determine the phosphorus coming from the soil, which was a mass 500 times as large as the applied organic matter in the barley as the green manure.

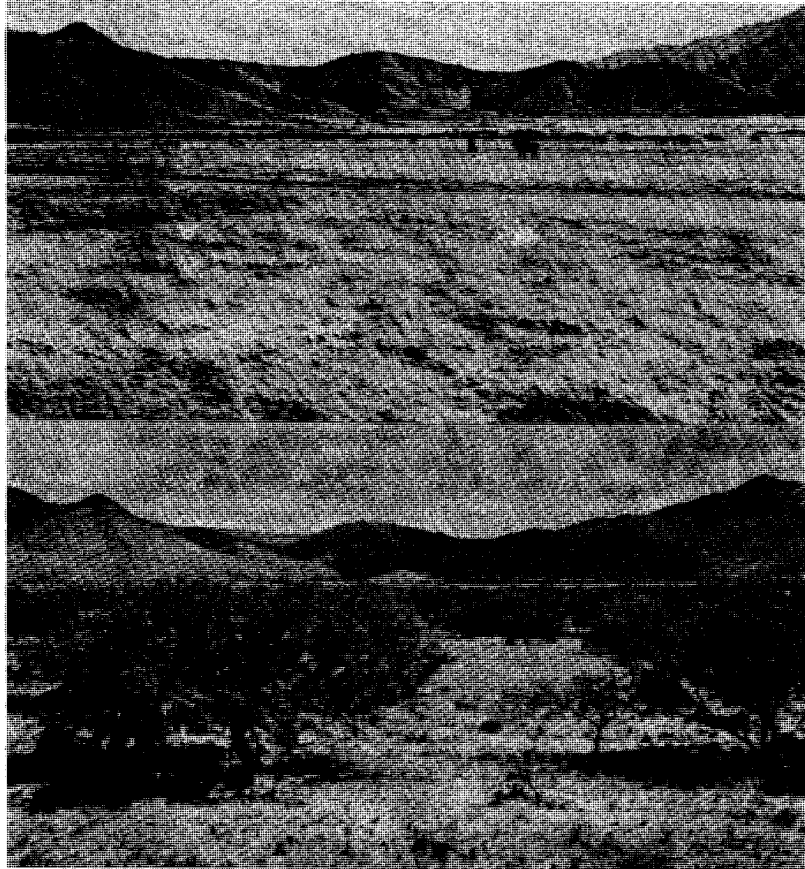
This separation of the phosphorus given by the organic matter of the soil from that given by the larger, originally more inorganic part of the soil showed that one part of the phosphorus taken into the soybeans was radio-active, therefore, taken from the green manure turned under. Five parts of the phosphorus taken into those soybean plants were not radio-active, hence were taken from the original soil.

Thus, it is established very clearly, that when the phosphorus coming from the barley as organic matter which was only one part while the soil was correspondingly five-hundred parts, yet phosphorus from those two sources, respectively went into the plant in the ratio of one to five; the phosphorus from the soil organic matter was just one hundred times as effective in feeding the insoluble but yet available phosphorus to the soybean plants as the soil was when its soil test by an extracting chemical reagent reported the soil 'high' in its available phosphorus.

Knowledge About, and Appreciation of, the Soil as Creation's Starting Point Come Slowly and Late

Some of our pioneer agronomists, as able chemists and scholars, may have had a vision of nature's unique phenomena of the chelation of inorganic fertility of the soil by the organic matter, and microbial processes connected with it, in what they considered 'the living and creative soil' when, as an example, nearly half a century ago Prof. A. W. Blair, of New Jersey, said, 'It is well known for example, that by judicious use of lime and vegetable matter on the soil, reserve of locked-up mineral plant food may be made available.' Others spoke about maintaining the soil fertility and a permanent agriculture by returning organic matter to the soil in combinations with natural rock fertilisers. Those pioneers did not visualise productive permanence in soils treated with water-soluble salts.

Now that we appreciate the rapid decline in the productivity of many soils and our inability to call from the chemical shelves every classified chemical, inorganic element required to hold up crop yields in quantity, much less in nutritional quality, we may realise the weakness in retaining water solubility as the criterion for materials applied to the soil for agricultural crop nourishment. We are slowly seeing the need to nourish also the microbial crop which makes the living soil, and is a favourable help in chelation and thereby in our getting better quality of crops as food and feed. We are learning that, through the organic matter of the soil and its microbial processes, much that is the insoluble yet available fertility is an effective natural creator of excellent crops, and those with a high degree of regularity.



Nature's Climax Crop of Grass (upper photo, 1903), was a short-lived Cattleman's Paradise. Neglected return of the organic matter to the soil brought about Man's Climax Crop of Mesquite (lower photo) by 1943. It was claimed that "The grass was over-run by the Mesquite bush." (Two of them, left, upper photo.)



The Indian Ponders White Man's Conflict With Nature