Let's Live Magazine, January, 1964

HIDDEN IDEAS IN UNOPENED BOOKS
"Mycorrhiza"
II. Misconceptions Persist

by William A. Albrecht, B.A., B.S., M.S., Ph.D.
Prof. Emeritus of Soils, College of Agriculture, University of Missouri, Columbia, Mo.
(Continued from December)

ERRATA

We wish to correct two errors which appeared in the first of Dr. William A. Albrecht's articles on "Mychorriza," in the November, 1963, issue of LET'S LIVE.

In discussing the height of the growing season, which results from microbial processes attuned with rising temperatures, it was erroneously stated that "It is a consequence of the doubling rates of living processes for every 180° F. increase in temperature." The sentence should have read, "for every 18° F. increase in temperature."

In addition, the caption describing the two pictures of the clover crops was reversed. The upper photo showed the field which had received six tons of composted straw fertilizer; the lower photo showed the field to which no composted matter had been added. --Ed.

In last month's chapter we told of the studies made by S. C. Hood of The Hood Laboratory; Tampa. Florida, regarding symbiotic reactions between soil fungi (*mycorrhiza*) and plant roots. Since it is our desire to acquaint the reader with additional previously unknown facts which were reported to the author in a recent manuscript, we now continue with Mr. Hood's comments.

"The fact was finally accepted that organic matter is needed for soil maintenance. The scientists gravely assured the farmers that organic matter was required by the soil to improve its tilth and conserve soil moisture. This was as far as their thinking had gone. Yet the soil's need for organic matter as nutrition of plants was a fact established by the ancient Romans and long since forgotten. It was Vero, a Roman, who said 'Any permanently successful agriculture must be founded on livestock.'

"In the meantime, the market gardeners persisted in their use of barnyard manure as long as it was available from nearby city stables. When the horses disappeared from the cities, they turned to the use of chemical fertilizers with disastrous results to both yield and quality of their produce."

Quality deteriorated

"For 60 years this writer has known a number of old market garden areas in the northeastern states, some of which had been growing vegetables for 100 years. The soil productivity was maintained by the liberal use of horse manure from the nearby city stables. The vegetables were of the highest quality. When manure was no longer available, gardeners turned to chemical fertilizers with the result that in a few years the poor quality of their produce was so prominent that it could not compete with the better quality of what was shipped in from newer soil regions. Some of these old garden lands have later been taken over by the 'suburban sprawl' and the others have been abandoned to weeds for many years.

"In the South, where most of the better lands had been worn out years ago by cotton growing, and their limited amount of virgin organic matter all but exhausted, there was little livestock and that was on the open range. The cotton, corn and tobacco farmers depended entirely on chemical fertilizers. While the cotton lint is a product of photosynthesis, it is produced on a seed rich in proteins. The yield was low and most of the farmers expected nothing more. Corn is mainly a carbohydrate crop, and tobacco has become so changed by cultivation that it is largely a chemical product."

Accepted with reluctance

"In recent years it has been established that small amounts of about a dozen elements other than nitrogen, phosphorus and potassium are needed for complete plant nutrition and, at last, this fact has been reluctantly accepted.

About a year ago a learned professor of one of our large western colleges of agriculture presented an article in one of our most popular magazines in which he held up to ridicule all those who try to maintain their soil productivity by the use of manure, compost and mulches. All that was needed, according to his claims, was chemicals. This was in the enlightened year of 1962. A few months later the same magazine published another article in which the same propaganda was put forth in a different dress. Is there an organized campaign to quiet the already large number of people who realize that there is something wrong with the quality and nutritive value, of our commercially produced food plants?"

Erroneous theory

"Another error, associated with the Liebig Complex, is the claim that all nitrogen-bearing materials in the soil must be changed to nitrate or ammonium salts before their nitrogen can be taken up by the plant. There is also the related claim that only small and simple molecules can pass through the cell walls of roots.

"The acceptance of these errors in basic facts." says Mr. Hood, "blocked all true studies of plant nutrition. All investigations were based on the current erroneous ideas. Many elaborate studies were made of the conditions necessary, and of the pathways followed to convert the plant residues and soil materials into the simple water-soluble components available to plants."

And thus the misconceptions persist.

Let's Live Magazine, February, 1964

HIDDEN IDEAS IN UNOPENED BOOKS
"Mycorrhiza"
III. Facts About Their Magnitude

by William A. Albrecht, B.A., B.S., M.S., Ph.D.
Prof. Emeritus of Soils, College of Agriculture, University of Missouri, Columbia, Mo.

When we make a careful microscopic examination of a portion of the feeding root of a plant." says Mr. S. C. Hood, The Hood Laboratory, Tampa, Florida, "and find connected with it a scattered net of small fungus hyphae, it may, at first thought, appear like an insignificant thing to be made one of importance in the nutrition of the plant. However, when we understand the quantities of the mycelical fiber and surface area of the fungus in the limited soil volume encompassing a single plant, we begin to realize their importance."

Report of studies

"In 1937-38, H. Dittmer[1] reported his quantitative studies of a single winter rye plant, four months old. On this, he found a total root length of 377 miles, of which 80%, or 275 miles, were feeding roots. The root hairs on that single plant numbered 14.5 billion with a fibrous length of 6214 miles. Their surface area was 4704 square feet, or more than a tenth of an acre. The combined length of roots and root hairs amounted to 6990 miles and the combined surface area, to 63,784 square feet, close to 1.5 acres; all this for soil contact and exchange within the root-zone of a single plant.

"Winter rye has an unusually large system of roots and very fine ones. Probably the plant examined was a more robust one. Similar quantitative studies have been made on other plants by other investigators. While other plants do not equal the rye plant, their roots are also of great lengths and extensive areas. In an acre of winter rye, or meadow grass, the total area of roots and root hairs may well exceed 30,000 acres, one-third of which is covered by a net of fungus mycelium with additional area in soil contact. We may well keep the figures in mind as we proceed to the consideration of the relation of the soil fungi to the plant roots."

Root exudates

"In his 1961 summary of the work of some 20 investigators, 'Soil Microorganisms and Higher Plants,' Krasnilikov[2] reports on the qualities and quantities of exudates by plant roots. These researchers found growing roots to exude inorganic elements, sugars, many amino acids, a number of organic ones, vitamins, biotics, antibiotics and many other organic compounds. It is, therefore, to be expected that the root surface is utilized by fungi as a feeding ground.

"Denidenko was cited to have found a single corn plant which, during its vegetative period, exuded 486 milligrams of organic substances when the nutrient solution remained unchanged. When that was changed seven times during the growth period, 2.3 times as much, 1136 milligrams, of organic substances were exuded.

Many compounds

"In 1921 Lyon and Wilson of Cornell Experiment Station[3] found that during the entire vegetation period the roots of plants exude up to the equivalent of 5% of the weight of the total organic matter of the plant. These exudates from growing roots consist of a wide assortment of organic compounds, especially carbohydrates. This fact explains why many investigators found a concentration of microorganisms in the rhizosphere and on the plant roots.

"At the New Jersey Agricultural Experiment Station (1929) Dr. Starkey[4] demonstrated that different plants have different influences on the accumulation of microorganisms in the soil, with the number in the rhizosphere many times greater than in soils at a distance from it. For beet plants, he found 427 million bacteria per gram of soil of the rhizosphere, but only 8.2 million in the control soils. Correspondingly for clover, he found 11.32 billion in the rhizosphere, in contrast to 6.6 million in the control soil, or more than 1700 times as many. For wheat his similar values were 653.4 million and 22.8 million respectively."

Prepared table

"In his own research, Krasilnikov studied 27 crop plants and trees in a wide range of climate and soil conditions. He found, also, the numbers of microbes hundreds and sometimes thousands of times greater in the rhizosphere than in the control soil. He presents the following table showing that the above kind of ratios increase as the roots go deeper into the soils, whether these be the more weathered podzol or the scarcely-weathered chernozen; and that in the same soils the microbial concentration in the rhizosphere of legumes is higher than on non-legumes. The higher rate at greater depths is due to reduction in the numbers within the control rather than to an increase in the rhizosphere. It points out that the organisms follow the roots as incentive to occupy greater depths into the soil."

Kind of Soil	Plant	Depth Examined	Ratio: Numbers in Rhizosphere/Numbers in Control Soil
PODZOL	Rye	0-20	300
		40-60	800
		60-100	1700
	Clover	0-25	630
		40-60	1000
		60-100	2000
CHERNOZEM	Lazern	0-25	50
		40-60	200
		60-100	270
	Wheat	0-25	20
		40-60	150
		60-100	300

(Continued in March)

1. Dittmer, H., "A Quantitative Study of the Roots and Root Hairs of Winter Rye Plant," *Amer. Jour. Bot.,* 24:417, 1937; 25: No. 90, 1938.
2. Previously cited.
3. Lyon, T. L. and Wilson, J,, "Liberation of Organic Matter by Roots of Living Plants," *Cornell Agr. Expt. Sta. Mem.,* 40, 1921.
4. Starkey, R., "Some Influences of the Higher Plants on the Microorganisms of the Soil," *Soil Science,* 27:319, 335, 433, 1929; *Soil Science.* 32:367, 395, 1931.

Let's Live Magazine, March, 1964

HIDDEN IDEAS IN UNOPENED BOOKS

"Mycorrhiza"

III. Facts About Their Magnitude

by William A. Albrecht, B.A., B.S., M.S., Ph.D.
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(Continued from February)

In February's chapter we presented the findings of Mr. S. C. Hood of The Hood Laboratory, Tampa, Florida, concerning the roots of plants. Additional information is furnished herewith by Mr. Hood, who has made an intensive study of "Mycorrhiza."

"The data on the growth of microorganisms deals usually with only actinomycetes, mycobacteria and bacteria," states Mr. Hood. "It is a well established fact that soil conditions favorable for the growth of bacteria also promote the growth of fungi. This fact explains why fungus species consistently inhabit the roots of plants, only they have been little studied and emphasized for their significant connections."

Unorganized data

"When we search out the subject of compounds produced by root-inhabiting fungi, we find extensive literature and great masses of data, but little attempt to organize all these facts about fungus products into usable information. Hundreds of organic compounds have been isolated from media in which various fungi have been grown. Among these are compounds similar to those of plant root exudates, namely, biotics, antibiotics, auxins, enzymes, amino acids and a great number of miscellaneous ones. These were produced by fungi and exuded into the media, into their root contacts and into the soil surrounding the fungi. To this writer it is very significant that the majority of these compounds of fungus production are of the aromatic chemical group, or extensive carbon-ring compounds."

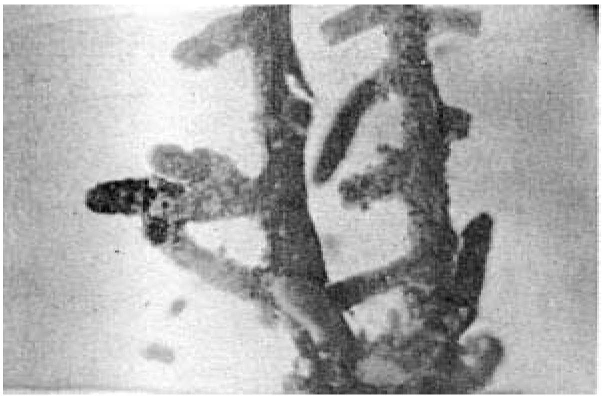
Pathways of production

"In discussing the production of these aromatic compounds at some length Cochrane showed the probable pathway by which Neurospora and Claviceps produce the three amino acids containing the benzene ring in their chemical structure, viz., tryptophane, tyrosine and phenylalanine. He discusses, also in detail, the synthesis of other amino acids by various fungi.

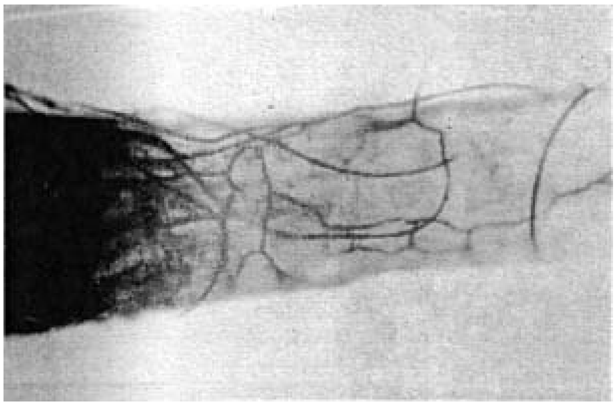
"The old idea associated with the Liebig Complex, namely, that only small and simple molecules can pass through the cell wall and root membrane, has now been entirely disproven; but vestiges of it still remain for many dealing with salt fertilizers.

Much research work on nutrient uptake by roots has been done with tagged, or radioactive dements incorporated into complex organic compounds.

Living Plant Roots in Suggested Symbiosis With Soil Fungi



As nodular excrescences formed by fungi within them. (Fraxinus americana, white ash.)



As outer net enshrouding root of Scuttelaria integrifolia, an herbaceous or shrubby plant of rock gardens.

As outer net of Basidiomycetes and undernet of smaller fungi on root of Galax aphylla.

"By that experimental technique, and others, it has been proven that such complex organic molecules as indole, dicumerol, vitamins, antibiotics and amino acids pass from the soil into the root cells and to other parts of the plant without much change of chemical structure and with change into other molecules equally complex. Much of such work has been summarized by Krasilnikov."

Summary

The whole subject of symbiosis between fungi and plant roots may be summed up so far, in the following statements.

1. Plant roots exude compounds utiized by the fungi growing on them.
2. The fungi, in turn, exude many compounds which are utilized by their host plants.
3. This mutual relation is almost universal in the plant world. We have found it existing in every plant we have examined which was growing on virgin soils. The only exceptions we found were plants of a weed nature growing where natural conditions had been disturbed by man."

Let's Live Magazine, April, 1964

HIDDEN IDEAS IN UNOPENED BOOKS
"Mycorrhiza"
IV. Revelations of Species

by William A. Albrecht, B.A., B.S., M.S., Ph.D.
Prof. Emeritus of Soils, College of Agriculture, University of Missouri, Columbia, Mo.

Microscopic examination of the small feeding roots of any plant growing on a virgin soil," says S. G. Hood, The Hood Laboratories, Tampa, Florida, "will show a network of fungus mycelia over the root surface. The thickness and density of this net will vary with the plant and the soil conditions. On most herbaceous plants it consists of two layers. The outer one is made up of mostly brown or gray septate (sectioned) hyphae spreading over the root surface and sending strands into the surrounding soil. This outer layer is made up of mostly Basidiomycetes. There are often tangles of mycelia in the surrounding soil, containing small rhizomorphs (root-like bodies) which present different forms and colors, according to the species represented.

"Mingled usually with the Basidiomycetes in this outer layer are hyphae of Rhizopus. They are easily identified by the large size and curious U-form of branching. There may be also Mucor, Cunninghamella or other phycomycetes mingled in with others."

Tiny fungi

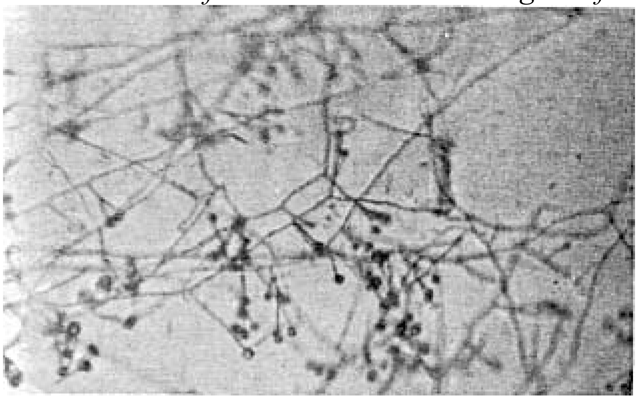
"Then beneath this outer layer of mycelia of mainly Basidiomycetes and Rhizopus, there is an underlayer of very small, glassy hyphae very closely appressed to the root. These fungi are so small and inconspicuous that they are often overlooked. Careful staining is required to make them microscopically visible. They like to follow the groove between epidermal cells where they are especially difficult to demonstrate. This inner, or second, layer consists mostly of the species of Fusarium, Trichoderma and Gliocladium. though others may also occur there. (*These species were illustrated in the March LETS LIVE.*)

"We have isolated 47 genera from the roots of plants.[1] Most of these species are of only occasional occurrence. Many are parasites on the above-ground portions of the plants and probably developed from spores which fell to the ground and germinated there."

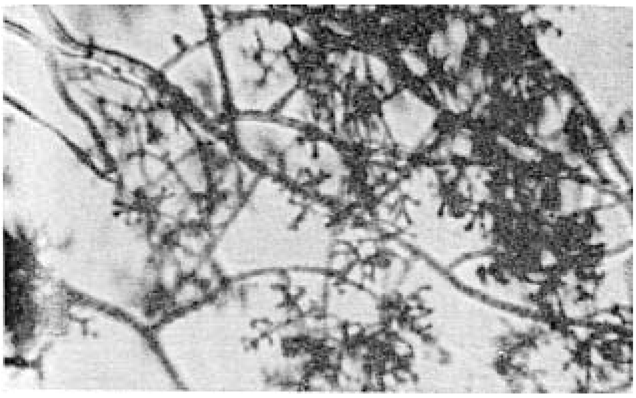
Important in symbiosis

"There are also usually present Penicillium and Aspergillus, the latter being most abundant in later autumn. There are others of the scavenger class. We are of the opinion that Fusarium, Trichoderma, Gliocladium and Basidiomycetes, when the latter is present, are the important fungi in this fungus-plant symbiosis, or mycorrhiza (see illustration).

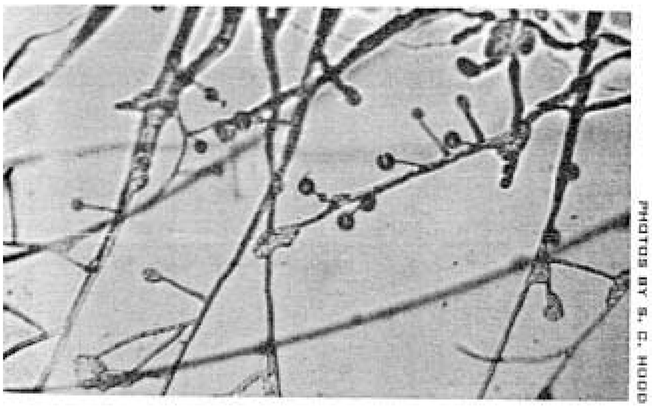
Fungi isolated from plant roots and grown on laboratory media.
(Listed in the order of survival under declining soil fertility)



(A) Glioeladium



(B) Trichoderma viride



(C) Fusarium

"As we go from the richer forest soils, where the fungus flora is very abundant in amount and species, to the soils of less and less organic matter, we find the fungus growth greatly reduced in both amount and kind. The Basidiomycetes are the first to be absent, and then one group after another is missing until, finally, in the exhausted and near-barren soils only an occasional Fusarium remains.

Aid nutrition

"There are some plant species of a weed nature, the first to colonize a bit of. barren waste, that often grow on this type of soil but without fungus associates. The same is also true of many of our cultivated plants, that is, they may grow on very poor soils but without mycorrhiza. On rich soil these same plant species soon pick up their fungus symbiont. Nelson-Jones and Kinder[2] tell us that 'the majority of plants have fungi on their roots. The fungi are useful but not indispensable. In such cases they aid the nutrition of the plant, the plant grows better, and more readily adapts itself to new locations.'"

Widely distributed

"In our studies we found Trichoderma viride, one of the symbiont fungi, present on 54% of all roots collected in North Carolina. On roots of trees of Florida it, or its relative Triehoderma glauca, was found on 60% of them. It was found on roots of 315 herbaceous plants as Florida collections. On experimental corn plots in North Carolina it was found on from 20 to 100% of the roots, varying according to the methods of soil fertilization used.

"Trichoderma viride occurs on plant roots as a very fine under-net of hyphae, one micron in diameter, and very closely appressed to the root surface. It is hyalin or glassy, and difficult to demonstrate. It occurs also as a parasite on many of the Basidiomycetes where it is impossible to be detected unless a conidiophore can be seen. It is also a parasite on many of the Phycomycetes, especially on Rhizopus and the larger Mucors. In culture it does not attack either Fusarium or Gliocladium, but grows intermingled with them in harmony. It was found by Weinding[1] to be parasitic on Rhizoctonia solani. He stated also that it attacks most Basidiomycetes. A fungi-static compound was isolated from Trichoderma viride by Brian[4, 5] and later a second compound, viridin, both of which were found lethal to some fungi and ineffective on others. Weinding[6] isolated gliotoxin from Gliocladium. None of these compounds was tested on plants."

Tests important

"This writer holds to the opinion," says Mr. Hood, "that the genera Fusarium, Trichoderma, and Gliocladium are the major important ones in this fungus-plant roots symbiosis and that the compounds produced by them are used in the economy of the plants. It is important that tests be made on higher plants, using the compounds produced by fungi, either in pure state or by growing the plants with pure cultures of them. This would answer many disputed questions on the role of symbiotic fungi in the economy of higher plants.

"It has been fully demonstrated that this symbiosis is not involved in the process of photosynthesis, since the production of fiber and other carbohydrate materials goes on whether fungi are present or not. It is, therefore, a fair hypothesis that this fungus-plant root symbiosis of mycorrhiza promotes the production of amino acids for the building of the protein molecules.

1. Hood, S.C., "Survey of Root-Inhabiting Fungi on North Carolina and Florida plants," *Bul. Hood Laboratory, No. 7,* 1963.
2. Nelson-Jones, R. and Kinder, M., *Role of Mycorrhiza in Tree Nutrition,* 1949.
3. Weinding, R., "Trichoderma Lignoriura as a Parasite on Other Fungi," *Phytopathology* 22: 837-845, 1932.
4. Brian, P. W., "Production of Gliotoxin by Trichoderma Viride," *Nature* 154: 667, 1944.
5. Brian, P. W., and Curtis, Hemming and McGowan, "The Production of Viridin by Pigment-forming Strains of Trichoderma Viride," *Ann. Appl. Biol.* 33: 190-200, 1946.
6. Previously cited.

HIDDEN IDEAS IN UNOPENED BOOKS
"Mycorrhiza"
V. Parasite or Symbiont
According to Soil as Nutrition

by William A. Albrecht, B.A., B.S., M.S., Ph.D.
Prof. Emeritus of Soils, College of Agriculture, University of Missouri, Columbia, Mo.

We are of the opinion," says S. C. Hood of The Hood Laboratories, Tampa, Florida, "that Fusarium, Trichoderma and Gliocladium are the important genera (in decreasing order) in the symbiosis of fungi with the roots of herbaceous plants, although we recognize that many others are useful in the plant economy.

As of first importance in this Mycorrhizal relation we have placed one of the most serious crop parasites, namely, the Fusarium. This classification of it as both a symbiont and a parasite requires some explanation of the soil conditions responsible for this antithesis.

"During the past eight years we have examined the roots of several thousand native plants. The list contains about 500 species from 122 plant families from a wide range of soils and climate. We have examined the roots of a large number of crop plants grown under the prevailing cultural conditions. About 80% of all roots examined have been cultured on laboratory media in order to determine, as far as possible, the fungus species involved. As the result, some form of Fusarium was found on 6% of North Carolina trees; 25% of North Carolina herbaceous plants; 45% of Florida trees; and 60% of Florida herbaceous plants.

"Our method of sampling by making three cultures from each root specimen represents such a small portion of the entire root system that it may not be considered representative of the true picture. But we found that when from five to 10 cultures were made from a single specimen, the percentage occurrence of Fusarium was usually increased. The occurrence of Fusarium on the roots of the cultivated crop plants ranged from 0 to 100%. It was often the only fungus found. This was usually the case for very sandy soil with very little organic matter.

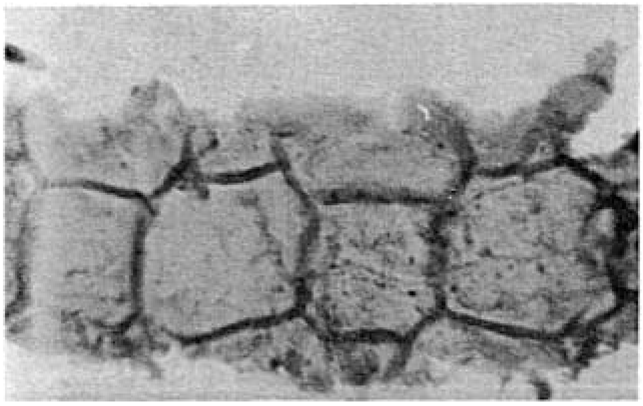
Percentage in 72 plots

"In a series of specimens of corn roots from 12 experimental plots, the occurrence of Fusarium ranged from 13 to 46%. The highest percentage was on a plot which had been inoculated by pouring a water suspension of conidia of Fusarium oxysporum into the soil about the roots when the plants were six inches high. Embedded sections of the roots showed that *Fusarium hyphae had entered the root and formed coils* *inside the cortical cells. There was no damage to the cells or evidence of parasitism. This plot out-grew and out-yielded all other plots in the series.*

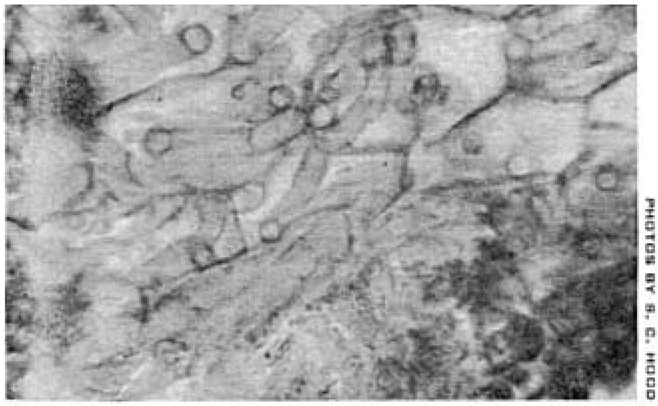
"When in 1885 Frank [1] announced his discovery of mycorrhiza on tree roots and put forth the theory that these fungi formed a beneficial symbiosis, his theory was attacked by Hartig [2] and later by McDougal [3]. They tried to prove that these root-inhabiting fungi were simply controlled parasites, and that the whole relation was parasition. This idea was rejected but this writer holds the opinion that the matter has not been entirely settled, especially with the genus Fusarium.

Various contacts with plant roots by soil fungi suggesting symbiosis.

A. A tangle of fungus net on the root of wiregrass.



B. Fungus hyphae following the groove between epidermal cells on the root of Cerotolia Ericoides.



C. Fungus coils inside cells of root nodules of
Aesculus Octandra (yellow buckeye).

A fine line

"The dividing line between symbiosis and parasitism is very narrow. There is some reciprocal crossing. We have yet to find any evidence of parasitism by these root-inhabiting fungi when the host plant was growing on virgin, undisturbed soil. But we have found cases when the host was growing on cultivated land and on some cultivated crop plants, showing that *plants on cultivated soils are of lower resistance.*

1. Frank, A. B., "Ueber die auf Wurzel symbiose beruhende Ernahrung genrsse," *Ber. d. deut. Bot. Gesell,* 3 :128-145, 1885.
2. Hartig, R, "Die pflanzlichen Wurzel parasiten," *Allgem. Forst. Jaad. Zts.,* 64:118-123, 1886.
3. McDougal, D. T., "Symbiotic Saprophytism," *Ann. Bot.,* 13:1-47, 1889.

(Continued in June)

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HIDDEN IDEAS IN UNOPENED BOOKS

"Mycorrhiza"

V. Parasite or Symbiont
According to Soil as Nutrition

by William A. Albrecht, B.A., B.S., M.S., Ph.D.
Prof. Emeritus of Soils, College of Agriculture, University of Missouri, Columbia, Mo.

(Continued from May)

In last month's installment, S. C. Hood of The Hood Laboratories, Tampa, Florida, stated: "The dividing line between symbiosis and parasitism is very narrow. There is some reciprocal crossing. We have yet to find any evidence of parasitism by these root-inhabiting fungi when the host plant was growing on virgin, undisturbed soil. But we have found cases when the host was growing on cultivated land and on some cultivated crop plants, showing that *plants on cultivated soils are of lower resistance."*

Pertinent report

"The following report is pertinent to this discussion. There was a grower of lilies in Delaware County, Pennsylvania, raising Formosanum lilies from seed, selling the seedling bulbs by mail. His small, back-yard business was producing 15,000 to 20,000 bulbs per year--possible on a small area. He had much trouble with basal rot of the young bulbs, caused by Fusarium lilii, which often took 50% or more of the crop. He consulted the lily experts at Pennsylvania State College and at Beltsville. Maryland. He was told that Fusarium lilii was a very active parasite and there was nothing he could do except get new soil each year.

"This advice showed that these experts had little knowledge of either the distribution of this fungus or of its adaptability. The grower secured new land, even virgin land, on which no lily had ever been grown, nor had lilies been grown in the vicinity. Yet he still had considerable loss; and it was very heavy on a second-year crop."

Needed alkaline medium

"The grower measured the pH of his soil to a depth of six inches, added enough dolomitic limestone to give the soil a pH of 7.0 to that depth, and added pulverized gypsum at the rate of 500 pounds per acre. This was applied in the fall and mixed well into the soil. On the crop the following year. planted in the usual manner, there was but a very small percent of rot. He had realized that this plant, native to alkaline soils of Formosa, had been transplanted to and grown on the acid, podzol soils of the Eastern states until it was of low resistance. He gave the lily a soil suited to its physiological needs and simultaneously a slightly alkaline medium in which

Fusarium, at least this particular acid-soil type, does not thrive. It had been noted that there was no basal rot when this lily was grown on limestone soils."

Versatile group

"The Fusarium oxysparum is very versatile, as are all groups of that genus. They are present almost everywhere as saprophytes in the soil and as inhabitants of plant roots. They have been found in some form in almost every soil where fungus surveys have been made. Five species of Fusarium were found by Hodges [1] in the soils of forest nurseries of the Southern States, while Fusarium oxysparum was present in all 19 states and F. salani in five of them. Six species of Fusarium, with F. oxysparum and F. salani most common, were found in Georgia by Miller. [2] Fusarium of 20% occurrence in Florida chrysanthemum fields was found by Jackson." [3] F. rodeum in the soils of the Nevada test site and Fusarium sp. in the soils of Death Valley were reported by Durrell and Shields. [4] Occurrence of this fungus up to 43% was found in the soils of Iraq by Yousef-Al-Doory et al. [5]

Normally beneficial

"Normally, this genus is a peaceful soprophyte in the soil, and a beneficial symbiont on plant roots. When this fungus encounters a root poorly nourished, a plant of low resistance, it can readily become pathogenic. If this pathogenic relation is allowed to continue, the fungus builds its pathogenic potential and becomes an active parasite. This contention may not be in line with prevailing thought, but it deserves consideration in the light of our observations.

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4. Durrell, L. W., and Shields, Lara, "Fungi Isolated from Soils of Nevada Test Site," *Mycologie* 52:636, 1960.
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Let's Live Magazine, July, 1964

HIDDEN IDEAS IN UNOPENED BOOKS

"Mycorrhiza"

VI. Some Field Observations

by William A. Albrecht, B.A., B.S., M.S., Ph.D.

Prof. Emeritus of Soils, College of Agriculture, University of Missouri, Columbia, Mo.

We can see wildlife about us, and readily appreciate its value. But soil fungi are hidden in the dark underground. "They are so small that they can he seen only with the aid of a microscope of high power," says S. C. Hood, of the Hood Laboratory, Tampa, Florida. This dedicated researcher has furnished us with additional information, as follows:

"There are more kinds of plants underground than grow on the soil's surface, and they are just as important as those we see about us. In fact, it is these tiny underground plants that have made possible the growth of the higher ones. They decompose the dead material. They change it into organic matter to make the more fertile soils on which the higher plants can grow. They make available the reserve mineral elements of the soil. Last, but not least, they enter into a symbiotic relation with the roots of higher plants and supply them with many important compounds."

A close relationship

"It is probable that this symbiotic relation began when the first primitive plant forms left the primordial sea and took to the land. There were primitive forms of fungi and algae, both of which had developed in the water. When cast on dry land, as separates, both were helpless. The fungi could not make carbohydrates. The algae could not secure mineral nutrients from the rocks. But united in a partnership, both could survive. The algae made carbohydrates for both, and the fungi extracted from the rocks the mineral elements needed by both.

"This close relation between these two persists to the present in the lichens, the first builders of soil. As the higher plants developed into their complicated structures, they retained some of this early interrelationship. They are still dependent on their associated fungi for development, especially chemically. Many botanists may not agree with this statement and consider it too highly simplified. We reply that botanists have made the above situation too complicated.

Extremely fine

"These filamentous, underground plants form a cobweb-like growth throughout the soil and over roots. They are so slender that should we twist together 500 of the larger ones, we would have a rope no larger than a human hair. There are some fungus hyphae so small that it would require 3000 strands to make a hair-size rope. This is the reason why the study of them has been neglected and their importance has only recently become recognized. We have made many examinations of crop plants grown under the usual methods. No extensive study of the singular effects of commercial fertilizers was made. However, some of the observations of the effects of such, as well as microscopic studies of plants in the treated fields; are suggestive.

"There is in Western North Carolina a large and beautiful estate on the eastern slope of the valley of the French Broad River. The soil is a typical sandy, clay loam of that region. The estate is operated as a summer camp for 200 girls under care of the requisite staff. For some years the estate managed a garden for supplying the camp kitchen and grew most of the usual necessary vegetables, including asparagus and berries.

Used organic method

"The garden was operated under strictly organic manuring. They managed also a riding stable and large flocks of chickens and turkeys. Consequently, they had abundant manure for direct use and for making compost. Raw rock phosphate and basic slag were supplements. No sprays or insecticides were used, save Bordeaux mixture on the tomatoes for control of bacterial blight. For our studies, we were given free run of the place, with permission to take any specimens. Full advantage was taken of the courtesy.

"We observed that while the whole encircling region was in the climax stage of infestation by the Japanese beetle and Mexican bean beetle, and while the neighboring commercial bean fields were dusted weekly to control insects, only an occasional beetle of either kind could be found in the garden of the estate."

(Continued in August)

Let's Live Magazine, August, 1964

HIDDEN IDEAS IN UNOPENED BOOKS
"Mycorrhiza"
VI. Some Field Observations

by William A. Albrecht, B.A., B.S., M.S., Ph.D.
Prof. Emeritus of Soils, College of Agriculture, University of Missouri, Columbia, Mo.

(Continued from July)

Last month S. C. Hood of The Hood Laboratories, Tampa, Florida, told of a large and beautiful estate on the eastern slope of the valley of the French Broad River in Western North Carolina where studies were made of the soil. The estate is operated as a summer camp for 200 girls. For a number of years the estate managed a garden where most of the necessary vegetables for the kitchen were grown. Only natural composting methods were used to supply fertilizer, and no sprays or insecticides were used. Although the entire encircling region was heavily infested by the Japanese beetle and the Mexican bean beetle and was dusted weekly with insecticide, the garden of the estate was not dusted. Only an occasional beetle was to be found there.

We now continue with Mr. Hood's report:

"We made many examinations of the plants of the garden during three seasons and found every plant well supplied with fungi on the roots. Most common were Fusarium oxysporum, Trichoderma viride and Gliocladium catenulatum."

Unhealthy fungi

"During the third season, the owner took on some other activities and left the garden to the care of one of the men. When the tomatoes were just beginning to set fruit, we made one of our periodic visits. A number of specimens were collected, including some small tomato roots. On laboratory examination, we found that the fungi on them did not appear healthy. Some of the hyphae were shrunken. On later returning to the garden, we saw that the tomato plants showed no signs of wilt from salt shock, but we found the repeated results from this second examination of roots. It was evident that something disturbing had been added to this soil.

"When we contacted the gardener and inquired what he had put on the tomatoes, he replied 'Nothing.' But we located the Indian woman who helped with the hoeing and she said the gardener had put on 'soda.' An unknown amount of nitrate of soda had been put on as a side-dressing. It was not enough to wilt the plants, but enough to nearly kill all of the fungi. A number of cultures of those roots were made on laboratory media. While some of them produced a weak growth of fungi, some of them were sterile."

Test on abandoned garden

"To the rear of our summer laboratory at Pizgah Forest, North Carolina, there is a plot of ground that had formerly been the vegetable garden for the old Patton plantation but had been abandoned. At one side, a strip two rods wide had grown up to a tangle of elderberries, honeysuckle, briers and rank weeds.

"When the property changed hands, the new owner cleared this tangle and planted the plot to corn. A moderate application of chemical fertilizers was made at planting time. This was followed by a side-dressing of nitrate of soda when the corn was given its final cultivation.

"When the corn was in roasting-ear stage, we made some root examinations for fungi. We used roots of Amaranthus retroflixus, Red root, a plant which we found well suited for test purposes. The long, straight taproot extends deep into the soil and a large number of small roots extend horizontally from it. This plant always has on its roots whatever fungi are prevailing and is nicely suited for testing for fungi at various soil depths."

Results

"No fungi were found on these roots of Amaranthus in the upper four inches of soil sampled at several places in the corn rows. But at soil depths from four to six inches, we found on the roots some scattered hyphae which did not appear healthy. At soil depths below six inches, we found the normal amount of healthy fungi on the root samples by usual laboratory examination.

"In the portion of the field cleared of tangle, but planted to corn, we found the same condition as in the other more central parts of the field, save that the fungus was more abundant below the six-inch level. Samples were then taken from the field's edge of cleared and plowed tangle which was left unplanted. Samplings at six to eight feet from the corn row, the area where no fertilizer was applied, showed all the roots covered with fungi at all soil depths. It was plainly evident that fertilizer had prevented the root-inhabiting fungi in the upper four inches of soil. The fertilizer had reached the soil level of four to six inches in quantities sufficient to retard the growth of fungi. Below the soil depth of six inches this one application of fertilizer had not yet become destructive to the fungi found growing normally."

"In the upper reaches of the French Broad River, in Western North Carolina, several thousand acres of beans are grown each season. Some of these are pole beans, some bush beans. The fields are very heavily treated with commercial fertilizers. The plants are dusted weekly for control of diseases and insects. They grow very rapidly, are in perfect health, and yield heavily. Their pods are perfect in appearance and command a high price in the Northern markets. Commercially, the beans are a very successful crop. However, when they are prepared for the table, they are tender but devoid of flavor. They are mainly cellulose and water with none of the rich flavor distinguishing normal snap beans.

"We have made many laboratory examinations of the roots of the bean plants at various stages of growth. They, as legume plants, have no nodules suggesting symbiosis with nitrogen-fixing bacteria. There are also no fungi on the roots. Cultures of the roots on laboratory media show no growth of fungi in most cases. On the same variety of beans grown in local gardens, the plants produce abundant root nodules and have root fungi abundantly. Pods from those plants have the full rich flavor of normal snap beans."

Evidence is accumulating to tell us that, with the rapid depletion of soil organic matter by salt treatments as fertilizer, quantity production may still hold on long after quality as nutrition has been lost.

Let's Live Magazine, September, 1964

HIDDEN IDEAS IN UNOPENED BOOKS
"Mycorrhiza"
VII. Proteins, Amino Acids and Benzene Rings

by William A. Albrecht, B.A., B.S., M.S., Ph.D.
Prof. Emeritus of Soils, College of Agriculture, University of Missouri, Columbia, Mo.

In the course of our studies," says S. C. Hood, Tampa, Florida, "we have found many statements in biochemistry which have a bearing on the subject of mycorrhiza as a fungus-plant root symbiosis. Basic principles in that science hold as true for more than one form of life."

Mr. Hood further observes, "It is a well-established fact that health is most fully assured by a properly balanced diet. What are the chemical compounds in food which promote health and resistance to disease? What are the substances lacking in our present-day foods, because of which lack certain serious ailments become rampant; or poor health conditions result, which should be regarded as a national scandal? We are cognizant of the claims that life expectancy has been lengthened by 20 years, and more. But that is the result of the high mean value of the statistics due to the reduction of infant mortality, hence only an increase at the beginning or youthful end. There is no significant increase of expectancy after the age of 50 years or more."

Cause of poor quality

"Our doctors and health officials have done an excellent job. Our agricultural producers and research workers in the experiment stations have been so concerned with the production of quantity in relation to market economics that sight has been lost of the biotic aspect of food as support of living species in good health. We must look to changes in the soil and modified aspects accordingly, and to soil and crop management for assignment of much of the blame for lowered food quality. We have not learned the simple truth that naturally fertile soils are expendable, before we know fully what originally made them truly creative of healthy species, including man.

"Most individuals in our population over 50 years of age recognize the fact that vegetables offered in the markets are lacking in flavor and quality. The younger folks have probably never known what good produce was like. unless they have had access to that from home gardens. There is no doubt about prevailing deficiency in quality, but just what is that deficiency? This is the question concerning situations that should occupy the concern of our research institutions, if there be such that are not handicapped by financial grants committed to political entanglements."

Significant statement

"Pointing toward deficiencies of proteins and amino acids in the realm of nutrition, there is a significant statement by Polczar and Reid.[1] "Analogues of tryptophan and phenylalanine block coliphage formation; ethionine and methoxinine appear to reduce the rate of influenza virus (strain PRB) in tissue cultures, whereas ethionine inhibits the Lansing strain of poliomyelitis virus growing on embryonic brain tissue. This statement suggests that disease resistance, as least so far as viruses are concerned, lies in the realm of amino acids illustrated by tryptophan and phenylalanine as compounds of benzene ring structures or modifications of such."

"Albrecht[2] emphasized the importance of tryptophane. It is important not only as nutrition to promote the health of animals, but its breakdown in the digestive tract provides compounds active in promoting growth and health of plants also. Sheldon[3] et al. emphasize the importance of tryptophan in animal nutrition, and by culture experiments with forage plants show the effects of the soil's mineral elements on the tryptophan content of these plants.

"We know that tryptophan, tyrosine and phenylalanine are the amino acids containing the benzene ring in their chemical structure. It has been shown that this ring portion is not broken down in the digestive tract of animals. The first of these three amino acids is voided as indole (fecal odor) and may be taken up as such by the plant, where it is changed into the well-known plant hormone, indolacetic acid. This action may be performed also by the microflora of the soil and the acid given to the plant in completed form. This latter is probably what occurs under naturally fertile soil conditions."

1. Polczar, M. J., Jr. and Reid, R.D., *Microbiology,* McGraw-Hill Co., New York,. 1958.
2. Albrecht, W. A., *Soil Fertility and Animal Health,* Fred Hahn Printing Co., Webster City, Iowa, 1958.
3. Sheldon, V. L., Blue, W. G., and Albrecht, W. A., "Biosynthesis of Amino Acids According to Soil Fertility," *I Tryptophan in Forage Crops and Soil,* 3:33-40, 1951.

(Continued in October)

Let's Live Magazine, October, 1964

HIDDEN IDEAS IN UNOPENED BOOKS

"Mycorrhiza"

VII. Proteins, Amino Acids and Benzene Rings

by William A. Albrecht, B.A., B.S., M.S., Ph.D.
Prof. Emeritus of Soils, College of Agriculture, University of Missouri, Columbia, Mo.
(Continued from September)

In last month's chapter, S. C. Hood, of The Hood Laboratories at Tampa, Florida, pointed out the deficiencies of proteins and amino acids in the realm of nutrition resulting from the poor qua1ity of our foods. He remarked that disease resistance, so far as viruses are concerned, lies in the field of amino acids--particularly *tryptophan, tyrosine* and *phenylalanine,* which contain the benzene ring in their chemical structure.

This ring portion is not broken down in the digestive tract of animals. Tryptophan, for example, is voided by the animal as indole, and this, when taken up by the plant, is changed into the well-known plant hormone, indolacetic acid. Under naturally fertile soil conditions, this same action also may be performed by the microflora of the soil and the acid given to the plant in completed form.

Interesting facts

Dr. Hood presents interesting facts concerning the soil microflora in the following remarks:

"According to Cochrane [1] indole and acetic acid are produced by certain fungi, actinomycetes and bacteria. Neurospora crassa produces an enzyme which synthesizes tryptophan from indole. Claviceps carry on the synthesis of tryptophan. And also, gliotoxin produced by Trichoderma viride is believed in its chemical structure to be a reduced indole nucleus.

"It is believed that many of these compounds produced by fungi of the soil are unstable. Wright [2] found that Trichoderma viride produced 40 milligrams of biotoxin per gram of soil after 14 days of incubation in culture. Jeffries [3] tested the stability of some of those compounds and in tabular form showed that their introduction into an orchard soil was stable for but a few days, while in a podzol the stability lasted many days longer.

	PODZOL SOIL	
	Non-sterile	Sterile
Gliotoxin	10 days	16 days
Viridin	8 days	16 days
	ORCHARD SOIL	
	Non-sterile	Sterile
Gliotoxin	2 days	7 days
Viridin	1 day	1 day

Investigators report

"The work of a number of investigators, cited by Krasnilnikov, on the antibiotic substances produced by the micro flora of the soil proves that these complex organic compounds are taken up by plants without change. He reports that actinomycetes, bacteria and fungi, which grow in the soil and in the rhizosphere of the plant roots, saturate this zone, or microfoci, of the soil with the products of their metabolism, including antibiotics. Also, he reports that these microplants enter the higher plants through their roots and exert their action there.

Accordingly, it is evident that the concentration of antibiotics in the soil, when these are formed under natural conditions, will be lower than concentrations used as treatments by artificial introduction. However, under natural conditions, these substances are continually formed and, therefore, one would assume that their entrance into the plant is continuous during the whole vegetative period. In other words, mi-crobial antagonists are factors which naturally increase the resistance, and non-susceptibility of plants to infections.

Role in plant economy

"Since it has been demonstrated that the large, complex, organic molecules of antibiotics and other metabolites of the soil microflora are taken up unchanged by the plant roots, it would be of great interest to know the roles they play in the economy of the plant.

"It has been shown that the majority of the compounds produced by the fungi and other microflora of the soil have one or more benzene rings as basic chemical structure. 'What is the ultimate fate of this ring inside the plant?' is a very logical question. Is it possible that these aromatic rings are used in the synthesis of the three amino acids—tryptophan. tyrosine and phenylalanine--and is it also possible that the lack of tryptophan in our food plants (so well established) is due to the shortage of fungi and soil organic matter needed for them to provide these basic materials? Such inquiry is in advance of any biochemistry establishing it as fact, but in the brashness of ignorance and curiosity, we are presenting the theory."

Early indication

Mr. Hood has given us his extensive observations and critical reports on studies of the symbioses of soil fungi with plants, both legumes and non-legumes. He points out, forcefully, the facts that he finds such symbioses dependent on: (a) the presence of soil organic matter; (b) the absence of fertilizers as salt treatments of the soil; and (c) the absence of executive cultivation accompanied by fertility depletion. Accordingly, the failing symbioses of the fungi and plant roots are an early index of declining values in our crops of field and garden as nutrition of quality.

1. Cochrane, *Physiology of Fungi,* Wiley and Sons, 1958.
2. Wright, J., "Production of Antibiotics in Soil," *Ann. Appl. Biol.,* 43 :288, 1955.
3. Jeffries, E., "The Stability of Antibiotics in Soil," *Jour. Gen. Microbiol,* 7:295, 1952.

Let's Live Magazine, November, 1964

HIDDEN IDEAS IN UNOPENED BOOKS
"Mycorrhiza"
VIII. Early Beliefs Lately Confirmed

by William A. Albrecht, B.A., B.S., M.S., Ph.D.
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The preceding articles on "Mycorrhiza" reported S. C. Hood's studies, microscopic and otherwise, of living plant roots intimately associated with living fungi, with seeming benefit to both on natural soils. Just how those benefits are brought about is not yet elucidated. While it is now granted that bacteria in nodules on roots of legumes are a case of symbiosis (mutual benefits), there is still some hesitation to consider the same true for fungi on the roots of non-legumes.

As early as 1903 Ludwig Jost, [1] a distinguished plant physiologist, was already familiar with fungi as well as bacteria so intimately associated with plant roots for benefits when he told us, "Possibly, however, the fungus aids in the absorption of materials of the ash. and does not supply the needs of the higher plant for nitrogen at all. Fungi make very heavy demands on such materials, and since they collect these very rapidly they are vigorous competitors with flowering and seed-bearing plants."

Function of fungus

"Higher plants are able to grow far better in humus which has been deprived of the fungi naturally present. A mycorrhizal union occurs especially in such plants which live in humus or which, for other reasons, exhibit feeble inflow of minerals. Hence Stahl assumes that these plants make the fungi contribute to their wants in that respect, turning antagonistic neighbors into efficient assistants. . . . The function of the fungus, however, according to Stahl, consists not merely in the *absorption* of nutrient salts from the soil, but also in their *transformation.* He comes to this conclusion from noting that the majority of 'mycotrophic' plants do not contain in their tissues certain waste bodies, such as calcium oxalate, which is associated with the assimilation of nutritive salts." [2]

Even if we cannot outline the physiological modus operandi through which the associations of mycorrhiza are helpful to the latter, or vice versa, the benefits of fungus to plants have recently been demonstrated by experiments and reported for yellow poplar trees by F. Bryan Clark [3] (1963) of the Central States Forest Experiment Station at Red-ford, Indiana.

Growth experiments

"Studies begun in 1959, designed to show effects of various soil factors on tree seedling growth," says Clark, "clearly indicate that endotrophic mycorrhizal fungi are important for the vigorous growth of seedlings of the yellow poplar, or tulip tree (Liriodendron tulipifera L). Uninfected plants were small and chlorotic, but plants infected with the mycorrhizal fungi were large and vigorous.

"In the yellow poplar studies, samples of undisturbed soil were taken in one-gallon tin cans driven into forest soil. The large plugs or cores in the tin containers served as excellent media for growing seedlings with soil structure essentially undisturbed. The sample site is in a mixed hardwood stand in southern Indiana. The soil is classed as a Wellston silt loam and the pH is about 6.0.

"Autoclaving and gassing with methyl bromide were used for sterilization. Both small plugs of natural soil and macerated roots of forest-grown yellow poplar seedlings were used to supply inoculum for sterilized containers. About two to three grams fresh weight of macerated roots were added to each container. Sections of roots used for inoculum were examined and found infected with endotrophic mycorrhiza."

Method of procedure

"Yellow poplar seeds were germinated in trays and planted into the undisturbed soil. The seedlings were grown on a 14-hour day under artificial light for 12 weeks. Distilled water was used for watering.

"Seedlings were recovered (for weighing at the close of test) nearly intact from the containers by soaking and washing. Examinations of the root systems for mycorrhizal fungi were made by Dr. Edward Hocskaylo, plant physiologist, USDA Forest Service, Beltsville, Maryland.

"These were the three treatments of the soil into which the seedlings were planted, viz.. (a) undisturbed forest soil, (b) sterilized forest soil and (c) sterilized forest soil inoculated with yellow poplar roots."

Outstanding differences

"Growth differences among the various treatments were outstanding. The fresh weights of roots and tops averaged 1.6 grams per seedling in sterilized containers. In contrast, seedlings from unsterilized containers and those unsterilized and inoculated with macerated yellow poplar roots averaged 7.7 and 9.0 grains respectively. Microscopic sections of the root systems revealed that the seedlings from sterilized containers were non-mycorrhizal, while seedlings from unsterilized and sterilized-inocu-lated containers were mycorrhizal.

"It is interesting to note that the influence of the fungus was not effective immediately. At 7-weeks there was no height difference between seedlings in sterilized and sterilized-inoculated containers. Evidently the organism or host plant must reach a certain stage of development before the mycorrhizal infection becomes effective."

Scarcity of research

We are not able to find much research on such matters dealing with the organic matter decay within the soil by which fungi as well as plants are nourished. Perhaps when processed organic wastes of urban origin come under higher sales pressures, rather than being catalogued for pollution prevention as they apparently are mainly now, grants for research will help us see that it is the organic matter, and not commercial salts, in the soil by which both fungi and food crops are nourished and that thereby they may be serving symbiotically to help nourish each other in close contact much as nodule bacteria and legumes do.

1. Dr. Ludwig Jost, *Lectures on Plane Physiology* (1903), Translated by R. J. Harvey Gibson (1907), Clarendon Press, Oxford (p. 241).
2. Jahrb. f. wiss. Bot. 34-539, 1900.
3. F. Bryan Clark, "Endotrophic Mycorrhiza Influence Yellow Poplar Seedling Growth," *Science* 140:1220-1221, June 14, 1963.

Let's Live Magazine, December, 1964

HIDDEN IDEAS IN UNOPENED BOOKS

Magnesium . . .

Balance in Soil, Plants and Bodies

by William A. Albrecht, B.A., B.S., M.S., Ph.D.
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Part 1

To a plant physiologist it may seem like a hackneyed statement to say that the balances among the several mineral fertility elements available or exchangeable in the soil will influence the balances of the "ash" elements in the crops grown on it. It is by no means such a hackneyed idea that the soil fertility which determines the composition of crops also determines the nutrient values to animals fed on them.

Helpful reports

Even if the farmer-layman's empiricism has taught him that animal health is a reflection of the fertility of the soil, it may be helpful to see essential chemical elements playing their various roles in nutrition, from the soil up through microbes, plants, animals and man. Such facts are presented in recent scientific reports, apt to remain hidden too long. This knowledge may be helpful even to persons appointed to authoritative positions, when they contend that variations in the productivity of the soil have nothing to do with variable nutritional values of what it grows. [1, 2]

Hidden in reports of late research is increasing information matching the inorganic composition of the soil against the biochemical behaviors of the plants grown thereon. Animal feeders are now using not only the animals' discriminating choices of the same crop on different soil treatments, but also are matching the biochemical values of forages grown on chemically catalogued soils against the animals' physiology as refined as balances of the soil-borne elements in the blood stream. Not only are these latter balances considered as pairs of the nutrient elements, but students of animal feeding are including attempts to catalogue the natural balances of elements in the soil, in the feed and in the healthy animals in triples, quadruples, and more, of those soil-borne.

Imbalances or balances in the forages, attributed to those in the soil, are demonstrated by uncanny discrimination--complete refusal or ready acceptance--on the part of animals used in test assays. The wisdom of their choices has been verified through chemical and biochemical measures.

Similar irregularities

Hidden in the literature are many reports telling us that disastrous irregularities in animal health, due to soil deficiencies, are so similar to those occurring in man that the same name can now be used for the problem in both man and animal.

It is educationally comforting to note that we are adopting a more fundamental approach in considering the role of natural laws in the degeneration of human health. Perhaps we will eventually view our own nutrition from the ground up and study the effects of balances and imbalances as determined by synthesis of dietary compounds by plants supporting both animals and man. Individually we may accept the adages, "To be properly fed is to be healthy," and "We are what we eat."

Of the essential nutrient elements in the soil, magnesium is an excellent one to discuss here in a subsequent series of articles picturing the concept of balanced forces of creation, which start with the soil as foundation. Magnesium is a close associate in natural chemo-dynamics with calcium. The latter is the major inorganic element in the human body.

"Alkaline earths"

The properties of calcium and magnesium classify them as the "alkaline earths." Calcium is usually present in much larger quantities than magnesium. In the human body we have 1.6% calcium and 0.05% magnesium--a ratio of 32:1. But while calcium acts as *parts of construction,* magnesium acts more as *tools in the biochemical performances* in the body.

Calcium and magnesium, naturally precipitated together from sea water, form our limestones. These do not often occur as only magnesium carbonate, but more often as pure calcium carbonate, and then as combinations of the two with increased amounts of magnesium carbonate until they are chemically equivalent in dolomite limestone.

We have been tolerating confusion when we merely say "limestone," or even "lime," without distinguishing as to their application to soil or use in industry. Unwittingly, we have often used magnesium. This mineral is coming into prominence on its own, now that we are applying the other elements separately, but still we are prone to neglect it. Magnesium is more important in a greater number of body processes than is calcium. A series of articles on magnesium seems fitting in a study of the role of soil in nutrition.

1. Andre Voisin, *Grass Tetany,* Crosby Lockwood and Sons, 1963.
2. Warren C. Walker, M.D., Bert L. Vallee, M.D., "Magnesium Deficiency Tetany Syndrome in Man," *Borden's Review of Research,* 22:51-71, No. 4, Oct.-Dec., 1961.

(Continued in January)