here for the first time. Michael Crofoot explores the nature of the living topsoil in "Plant Symbiosis". Stuart B. Hill describes the psychological and social dimensions of wants and needs and how these place certain demands on ecosystems and agriculture. He provides a diagram showing the contrast between a shallow and a deep approach to coping with agricultural pests. The article by Wes Jackson was originally published in **Not Man Apart**, but I have decided to reprint it here since it is one of the best, short articles on the need for, and the prospects of, a sustainable agriculture.

PLANT SYMBIOSIS: A DEEPER ECOLOGY

By Michael Crofoot

Recent discoveries in soil microbiology are developing a body of knowledge which complements and, in fact, closely parallels the emerging dialectic of a deeper ecology. These observations of the interdependent association of plants, soil and microorganisms are so revolutionary and indisputable, they are sending shockwaves through the forestry and agriculture policy making communities, redefining our concepts of how evolution, succession and ecological interconnectedness proceeds. Quite generally, mutualistic symbiosis (two or more organisms living together in benefit to all partners) between plants and certain microorganisms now appears to be the rule rather than the exception on a worldwide scale.

Although many diverse beings play a role in this unfolding drama, the principal actors are fairly well known: the symbiotic nitrogen fixing organisms and the mycorrhizal fungi. Many kinds of organisms take nitrogen out of the air and exchange it with their mother plants for photosynthetically derived products. The best known and most widespread classes are the bacterial rhizobia, symbiotic with the legumes, and the actinomycetal frankia symbiotic with a range of plants from alders to ceanothus to the eleagus clan, which are now termed actinorhizal plants. About 3000 species of legumes are known to form these nitrogen fixing nodules on their roots, while the most current list of nodulated actinorhizal plants now numbers 200 species. Many more species are expected to be reported. Such symbiotic nitrogen fixation can supply most to all of the nitrogen needs of the plant. On a global scale, a great deal more nitrogen (generally the plant world's most limiting element) is supplied to the environment via these symbioses than through the application of industrial fertilizers.

Mycorrhiza literally means fungus root. A symbiotic association is formed between feeder roots of plants and certain fungi; the association acting to much extend the plant roots in their search for nutrients and water, often protecting the roots from disease and pests in the process of infection. There are many kinds of these symbiotic associations ranging from the ectomycorrhizal puffballs and truffles, growing on many trees such as pines, birch and poplars, to the microscopic associations in the endomycorrhizal fungi of most herbaceous plants. It is now agreed that nearly all plants on earth can form mycorrhizal associations, and that in nature almost all plants do.

The scientific literature on these symbioses is voluminous and is exponentially increasing, while researchers devoted to this work number in the thousands. I cannot adequately convey the depth of this work in a short article. However, an outline of some major ecological insights derived from the larger body of literature on these symbioses should illustrate some of the material correspondences in plant ecology to the philosophy of a deeper ecology.

The deeper ecologic tenet of unity in process, or dynamic oneness, runs as a common connective thread through the symbiosis research. Plants are now seen, not as discrete competing entities, but as coevolving manifestations of seed, symbiotic microorganisms, soil, climate and time, The hyphae (or roots) of mycorrhizal fungi symbiotic with different plant species apparently interconnect and form an interpenetrating network through which nutrients and water can flow multidirectionally from tree to herb to shrub. Almost all nitrogen fixing plants are strongly mycorrhizal, suggesting that nitrogen may be directly transferred from, say, a legume to a pine tree by way of shared mycorrhizal hyphae. The sharing of an ectomycorrhizal fungi by an herbaceous spiderwort and a pine tree has been recently reported. Lateral roots of the pine, in a Texan Christmas tree farm appeared to grow directly toward the spiderwort and wrap around the latter's root mass in a "mycorrhizal mucigel." Radioactively marked nitrogen inserted into the spiderwort turned up in the pine some hours later. Similar unreported observations have recently been made in Australia and California.

The physical interpenetration of plant species via myucorrhizal networks appears so common that at the recent North American Conference on Mycorrhiza in Bend, Oregon, a leading scientist remarked that the forest must now be seen as one organism.

The philosophy of biocentric egalitarianism is gaining the upper hand in symbiosis research as well. First, it is important to note that the nitrogen fixing nodule or mycorrhizal root are not plant roots plus microorganisms simply attached. Rather, the nodule and the mycorrhiza are the result of the process of plant and microbe uniting to form an entity unlike either of the partners. In the most recent book on mycorrhizas, a long time leader of the research, J. L. Harley, questions the very concept of the plant as 'host' to the 'trapped' microorganism. He asserts that because nutrients are exchanged in both directions within the symbiotic system--neither plant nor microorganism is host. Rather they are a synergistic unity. In fact, some mycorrhizal fungi can live in a free, nonassociated state, while many trees such as pine and eucalyptus must be infected by mycorrhizal fungi to survive. Half seriously and half in jest, the Director of the USDA's Institute for Mycorrhiza Research and Development once defined the tree as a photosynthetic appendage of mycorrhizal fungi.

Current evolutionary theory holds that the first land plants may have been symbiotic associations between aquatic nitrogen fixing algae and mycorrhizal fungi, quite like our common lichens today. Since then, the so-called higher plants have coevolved in mycorrhizal association with the fungi changing form relatively little. While awaiting further confirmation, this theory indicates that mycorrhizal fungi, these 'lowly of the low', may be primary determinants of evolution. The varying degree of mycorrhizal dependency among plant species is already seen as a major determinant of successional change.

Warrick Fox has stated that "the central intuition of deep ecology...is that we can make no firm ontological divide in the field of existence...there is in reality no boundry between the field and the knower of the field." The forest as organism is a macrocosmic example of that statement. In the microscopic world, fungal spores, bacteria and other organisms, carried by wind and water, are streaming about us and through us. Even as we sit and talk with each other, we are exchanging microorganisms through our shared breath.

Lynn Margulis, in her book Symbiosis in Cell Evolution, shows very strong evidence that cell organelles such as mitochondria and chloroplasts are, in reality, descended from symbiotic microorganisms that were acquired aeons ago in the process of coevolution. Though this cell symbiosis hypothesis was at first derided by the scientific community, recent microscopically observed correlations between the DNA organization of these organelles and certain free living microorganisms begins to confirm it. The nitrogen fixing nodules produced by the symbiosis of legumes and rhizobia have since been suggested as another example of two organisms in the process of becoming genetically one.

A most important facet of the deeper ecology dialectic is a reconceptualization of the human's relationship with mother earth. Humanity is seen not as the crown of creation ordained to have dominion over earth; not to subdue her as captains on "spaceship earth" as we take the helm of evolution firmly in our hands. Rather, the human species is seen as but one of myriad species, all integral to the unfoldment of the planet's destiny; that we are part of a crew, the captain of which is Life herself.

In the research on symbiosis, the grounds for such a reworking of roles and relationship are well established. In the literature there is an undercurrent of inspired awe before this interpenetrating web of Life. In my visits with scores of researchers in the field, I have found a preponderance of couples, women and soft spoken men, who take humility in their symbiotic studies. Such researchers appear to be firmly in the grips of what Spinoza would call loving understanding.

However, with regard to utilizing these discoveries in plant symbiosis, there are two distinct camps which I have termed the 'manipulaters' and the 'nurturers'. The manipulaters, which I believe to be a powerful minority, speak in terms of "exploiting" mycorrhizas and nitrogen fixing organisms for "maximum" productivity from the field. They search for "super strains" of symbiotic microorgainisms, and have a keen interest in biotechnology, such as creating mutant rhizobia which will nodulate and fix nitrogen with corn, or in developing genetic associations between mycorrhizal fungi and free living nitrogen fixing bacteria. Regarding symbiont inoculation of field crops or nursery plants, the manipulaters are working feverishly to produce pure cultures on artificial media, possibly of genetically improved strains, so as to capitalize on a mass producible, commercial product of "superior" effectiveness.

The nurturers, in contrast, seek to work with this new knowledge to encourage "optimum" productivity in the field, implicitly recognizing ecological interconnectedness. They suggest that breeders attempting to develop improved nitrogen fixing alders, for instance, should work toward "optimal symbioses" with plant, frankia and mycorrhiza as an integrated whole. Such nurturing microbiologists are beginning to work with mixed species cultures, selected from native strains. They use the living plant itself as the propagation media, collecting nodules, mushroom fruitbodies and soil from the plant roots for inoculum.

Progress has been slow in genetically engineering nitrogen fixing organisms and mycorrhizal fungi, while the effectiveness of propagating natural symbionts through plant passage is proving itself in many sectors. The outcome of these conflicting camps of symbiosis application remains to be seen, but it will probably be determined by socio/economic factors as much as by ecology.

Finally, the nature and limitations of knowledge itself exhibits close similarities between that of symbiosis research and the deeper ecology perspective. The soil microbial community, and its relation with plant and soil, is seen more as a multidimensional process than mechanistic cause and effect. It is felt that more is to be learned from a study of the whole symbiotic system in soil than from isolated symbionts in the laboratory.

As we ask questions, the answers laboriously acquired present yet deeper questions. On a single actinorhizal plant, research has shown as many as nine organisms symbiotically cocreating, as it were, one single tree.* Inoculating nodulated plants with mycorrhizal fungi increases number of nodules. If the same nodulating plant is artificially kept mycorrhizal only, inoculation with the nodule causing symbiont increases percent mycorrhizal infection. We have a synergy at play here beyond our wildest dreams. The axiom that "the environment is not only more complex than we think, it is more complex than we can ever think" is particularly evident in symbiosis. The more we learn, the more we see what we may never know.

Heidegger says: Let being be. We do not need to rush out and inoculate our native forests. The symbionts are already at work. But in our chemical, monocultural agriculture and tree farms, and in our nurseries with their sterile soils, we are creating conditions positively hostile to these symbiotic relationships. We need to much increase our research into the living soil and develop new technologies, new cultures to nurture it. We are in the position of having to do more to learn to do less.

*The Casuarina genus comprises a group of about 80 species of often actinorhizal shrubs and trees mostly native to Australia. There is great interest in their use in Third World countries to halt the spread of desert and develop sustainable forestry systems. One tree can have nitrogen fixing nodules, several species of ectomycorrhizas, several species of endomycorrhizas, and dense, mat-like proteoid roots caused by an unknown microorganism which increase nutrient absorption. Various Psuedomonas bacteria have been shown to be involved in both the frankia and endomycorrhiza infection process. This gives us nine organisms in all, counting the plant.

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GALE
by Stephen Lewandowski

in midwinter
chicken eggs
freeze in the nest

the wind shrieks
outside while
we crouch
in the chicken house
nailing tar paper
over the windows

tree pruning wind
works all night
testing each branch--
some spring back,
some crash to the ground--
little by little
getting the trees
the world into shape