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Editorial

Wood wide web/underground mycorrhizal hyphal network for plant's communication to each other

Mycorrhizae are a type of fungi that infect the root of plants and are necessary for growth and survival of host plants. The word was first coined by the German biologist Albert Bernard Frank (1885). Existence of mycorrhizal relationship has been recorded in the fossilized plants of Rhynie Chert (400 million years old) deposits. Since the discovery of mycorrhizae, voluminous literature has been accumulated about the types, biology, mechanism of functioning, and the relative benefits of two symbionts. The word mycorrhizae literally mean root inhabiting fungi. These fungi form a symbiotic relationship with the plants, colonizing the roots and sending extremely fine filaments (hyphae) far out into the soil that act as root extensions. In this report attempt has been made to analyze the previous and current concept of benefits of mycorrhizal relationships in the perspective of ecosystem management through sustenance of worldwide woodlands or vegetations.

It is now well known that there are two basic types of mycorrhizae—Arbuscular (AM and AVM) that are called as endomycorrhyzae and ectomycorrhizae. Approximately, 90% of land plants have mycorrhyzae; of these about 80% are carrying arbuscular types of fungi belonging to order Glomales of the phyla Glomeromycota (total phyla of fungi 11), the rest are associated with ectomycorrhizae belonging to Basidiomycota. Mycorrhizae are found in everywhere we find vegetation, from tropical rain forest to Arctic tundra and vast majority of land plants are benefitted by them. When we tread through a forest or a landmass covered with vegetation, in every step we tread over hundreds of kilometers of densely packed mycelia of a large number of species of mycorrhizal fungi. There are an estimated 100 species of AM fungi (Brady and Weil, 2009). AM fungi typically have highly branched tree-like structures that form within the root cells and branch out into the soil to search for plant nutrients. AM fungi supply the vast majority of land plants with inorganic nutrients, mainly phosphorous, but also nitrogen, trace elements, and water. In return, they obtain up to >20% of the photosynthetically fixed CO_2 as carbohydrates (as sugars) from plants. It was calculated that, each year, 5 billion tons of carbon are transferred from plants to fungi and therefore partly get deposited in the soil via the AM symbiosis. AM fungi therefore represent a large sink for atmospheric CO_2 on our planet and play a role in Carbon-sink in the soil (NCBI Review). Mycorrhizae regulate the N_2 cycle of especially the N_2O and reduce emission of this greenhouse gas to air (*less global warming*). Earlier scientists have revealed that nutrients translocation from plant to fungal hyphae and fro to plants are made through septa less mycelial network of the fungus.

In recent time it has been found that hyphal network of one plant is connected and fused with hyphal network of the neighboring plants of same and different species and thereby form a huge network of communication and signal transduction from one plant to the neiboughers. The mycorrhizal mycelial network in a wood connecting same or different plant species of a wood land has strong analogy with our internet system. The Internet is a massive International network of networks, forming a networking infrastructure. It connects millions of computers together globally, forming a network in which any computer can communicate with any other computer as long as they are both connected to the Internet. Many people use the terms Internet and World Wide Web (simply the Web) interchangeably, but in fact the two terms are not synonymous. The Internet and the Web are two separate but related things. The www or simply web is a way of accessing information over the medium of the Internet. It is a kind of information -sharing model that is built on top of the Internet. The Web uses the HTTP protocol, only one of the languages spoken over the Internet, to transmit data.

Famous American mycologist Paul Stamets called this underground hyphal network as "Earth's natural internet" in 2008. He first had the idea in the 1970s when he was studying mycorrhizal fungi using an electron microscope. Stamets noticed similarities between mycelia and ARPANET, the US Department of Defense's early version of the internet. The massive mycorrhizal net work connecting large number plants in a forest or vegetation is now being called as Wood Wide Web.

Plants can communicate in three ways: a) by aerial emission of volatile gases, b) secretion of chemicals through root-leachates and c) through mycelial networks in the soil. Several reports about the first type are known; Allelopathic inhibitions of seedlings of other plants or the same species are considered to be occurring through root

leaching. Concept of communication through mycorrhizal fungal network is of great interest in recent time, especially in the perspective of sustainable forest management.

First concrete evidence of Wood Wide Web has been reported by Simrad et al (1997) in a forest of Paper Birch (Angiosperm) and Douglas fir (Conifer) containing Pacific forest of Vancouver, Canada. The *in situ* experiment used a Paper birch branch enclosed with an air-tight transparent plastic bag and the fed with $C^{14}O_2$. The plastic bag did not allow radioactive contamination of neighboring plants. After about three days radioactive carbon compounds were found in the neighboring Douglas fir plants. The experiment was done again in the winter when the paper birch trees were leafless; reverse translocation radiocarbon from Douglas fir plant to paper birch occurred. Simrad considered that this translation or communication occurred through Wood.w.w. Further research by Simrad and her team showed that the large birch trees transfer carbon nutrients to seedling birch plants that are in the shade of the big tree and not getting enough sun light for their photosynthesis. The large tree was considered as 'Mother tree' that helps the siblings from extinction. Simrad considered that in the Pacific forest of Canada, trees are not competing in the sense struggling of the fittest but seems to be helping each other. (Darwin's theory never stated competition and struggle between the organisms of same species; instead he theorized survival struggle of organisms against environment. 'Struggle and survival of the fittest' phrase was coined by Herbert Spencer to justify colonial politics of Europe).

Ren Sen Zen (2010) of South China University grew a pair tomato plants and allowed them to grow underground fungal network. One plant was inoculated with the early blight pathogen *Alternaria solani* and immediately closed with air-tight plastic bag to prevent the aerial signaling to the other. After about 65 hours, the other plant showed systemic immune response (SAR; systemic acquired response) when challenge inoculated with the pathogen. David Johnson (2013) of University of Aberdeen experimenting with broad been plants reported that the signal of aphid infestation of one plant is transduced to neighboring plants through underground hyphal network of mycorrhizae. In organized woodland the cooperative societal network helps in nutrition distribution and transmission of other defense signals and thereby exhibits the socialistic community pattern (Simrad).

However, there are a few selfish and greedy individuals who are allelopathic and not allow siblings of other plants and not even their own siblings to grow. Classical examples are Black Walnut, 'Bot' (religious Ficus) and Eucalyptus trees. They inhibit the others by secreting toxic chemicals in soil through root exudates. Kathryn Morris (2011) of Xavier University of Cincinnati (Ohio) reported that allelopathic toxin of Marigold and Walnut plants are also sent through mycorrhizal network. Thus it is evident that in the Plant ecosystem, especially in the Woodland ecosystem there are both cooperative and competitive types. The communication, however, is not broadband but slow.

In recent time intensive research is being made on Mycorrhizae especially Arbuscular mycorrhizal fungi (AMF) that are multipurpose organisms with complex ecological ramifications in the soil system. The phytocentric concept of AMF that has prevailed since the naming of these organisms is being replaced by a holistic vision recognizing that AMF are a key element of soil functioning and health rather than a plant root component. Recent advances in knowledge brought about by new techniques for soil microbiology research open the way to AMF management in crop production. Arbuscular mycorrhizal fungi may influence crop development, even in phosphorus-rich soils. However, growing crops in soil with lower fertility would optimize the expression of the multiple beneficial effects of AMF in agro-ecosystem and reduce nutrient seepage to the environment. The consideration of the soil mycorrhizal potential within the framework of soil tests and fertilization recommendations, the development of improved inoculants and signal molecules to manipulate AMF and the development of cultivars with improved symbiotic qualities would insure the production of good crop yields while improving agro ecosystems' sustainability (Hamel and Strullu, 2006).

In India, a great deal of applied mycorrhizal research has been undertaken. Commercial inoculants are used on a large scale, with close to 2500 tons produced in 2006 by four different Indian companies. Used with rice crops, researchers found that mycorrhizal inoculation resulted in yield increases of around 10% with a 25–50% reduction in the amount of fertilizer required – real savings considering India's low phosphorous soils. Voluminous literature is available on 'utility of mycorrhyzae in crop production', but that is a separate story.

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