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Role of Mycorrhizal Fungi in Forestation*

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ABSTRACT

The loss of forest cover results in ecosystem imbalance. As a result of deterioration of the biosphere, soil degradation, over exploitation of forests and population explosion accelerates the rate of deforestation and affects climate. Thus role of forestation in the sustainable development of the ecosystem holds greater promise. In this regard Arbuscular Mycorrhizal fungi as beneficial symbionts of forest plants not only help in the establishment of forest seedlings but also help in their growth, besides increasing soil fertility and stability, tolerance to biotic and abiotic stresses. A brief review on this aspect has been presented.

Keywords: AM fungi, forestation, establishment, plant growth, soil.

ECTOMYCORRHIZA

The ectomycorrhizal roots are characterized by three features namely, i) a mantle which is formed by fungal sheathing or colonization of short feeder roots, ii) the Hartig's net, which is an intercellular hyphal penetration between cortical cells, and iii) colonized feeder roots, showing a morphological differentiation through increased branching and elongation. The root system is heterorhizic with two components, long roots of unlimited growth and short stubby roots of restricted growth. All the root apices grow and may become partially or fully colonized by Mycorrhizal fungus. Root apices when fully colonized grow slowly, branch dichotomously and develop a sheath around them and partially infected root apices continue to grow actively (**Fig. 1A, 2B**).

The dichotomously branched root system along with dense mycelial connections occupy a large volume of soil and acts as a physiologically active organ of absorption. The mycorrhizal association helps in increased uptake of nutrients, water and confers tolerance to root pathogens, drought, edaphic and environmental factors. Ectomycorrhizal fungi provide host plants (macrosymbiont) with growth hormones including auxins, gibberellins, cytokinins and growth regulating "B" vitamins. Mycorrhizal fungi protect the delicate root system from attack by pathogenic soil borne fungi through, a) use of surplus carbohydrates, b) provides physical barrier, c) secretion of antibiotics e.g. diatretyne nitrite, and d) favouring beneficial rhizosphere microflora around the roots. Mycorrhizal fungi contributes to soil organic matter and nutrient cycling in forest ecosystem. Ectomycorrhizal fungi can be grown in pure cultures and therefore has a potential practical utility in regeneration and reclamation of barren lands.

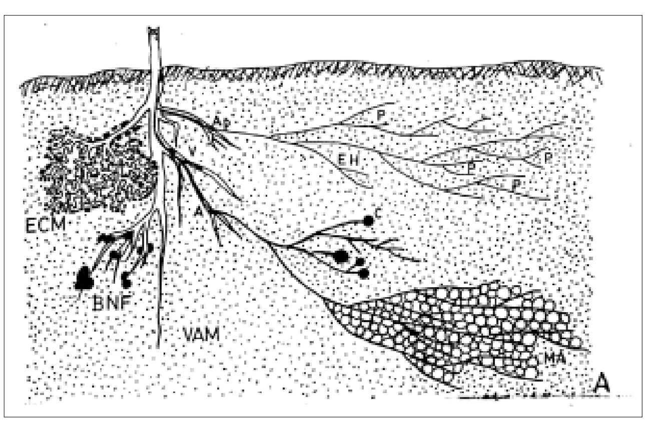

Fig. 1: A. Diagram of three major symbiotic associations with plant roots in the rhizosphere. Ectomycorrhiza (ECM); Nitrogen fixation (BNF) and Arbuscular Mycorrhizal (VAM), P - Phosphate ion; MA - Macro aggregate.

ARBUSCULAR MYCORRHIZAL FUNGI (AM)

Arbuscular Mycorrhizal fungi are characterized by three main features within the plant roots i.e. i) an internal hyphal system connected to external hyphal network through the initial entry points, ii) intracellular arbuscules, which are dichotomously branched, tree like structures enclosed by host plasmalemma and are apparent sites of nutrient exchange between the fungus and the plant, and iii) the vesicles, which are terminal and/or intercalary, thin-walled expanded structures and are not delimited by a septum and contain large quantities of lipids (**Fig. 2C**).

Arbuscular mycorrhizal fungi are obligate symbionts and can only multiply and spread in association with a host plant root. The major obstacle in exploiting the potential use of Arbuscular Mycorrhizal fungi in inoculation studies and forestation programmes are , a) the large scale production of high quality inoculum, b) standardization of inoculum dosage which is infective enough to produce desired growth response, and c) selection of AM symbiont or host fungal combination under given environmental conditions or for particular environmental conditions. The basic requirements for the production of high quality inoculum are small, bulk, high infectivity, highly effective, good shelf life and free from harmful pathogens. The ability of AM fungi to penetrate and spread in roots of the target crop under production condition is the measure of infectivity (Abbott and Robson, 1981a).

The ability of AM fungi to enhance growth or induce stress tolerance are measure of its effectiveness. Effectiveness of a mycorrhizal fungal species may depend upon extramatrical hyphal development, spore multiplication, propagule survival and root colonization. Inoculum effectivity interacts with concentration and position of the inoculum (Abbott and

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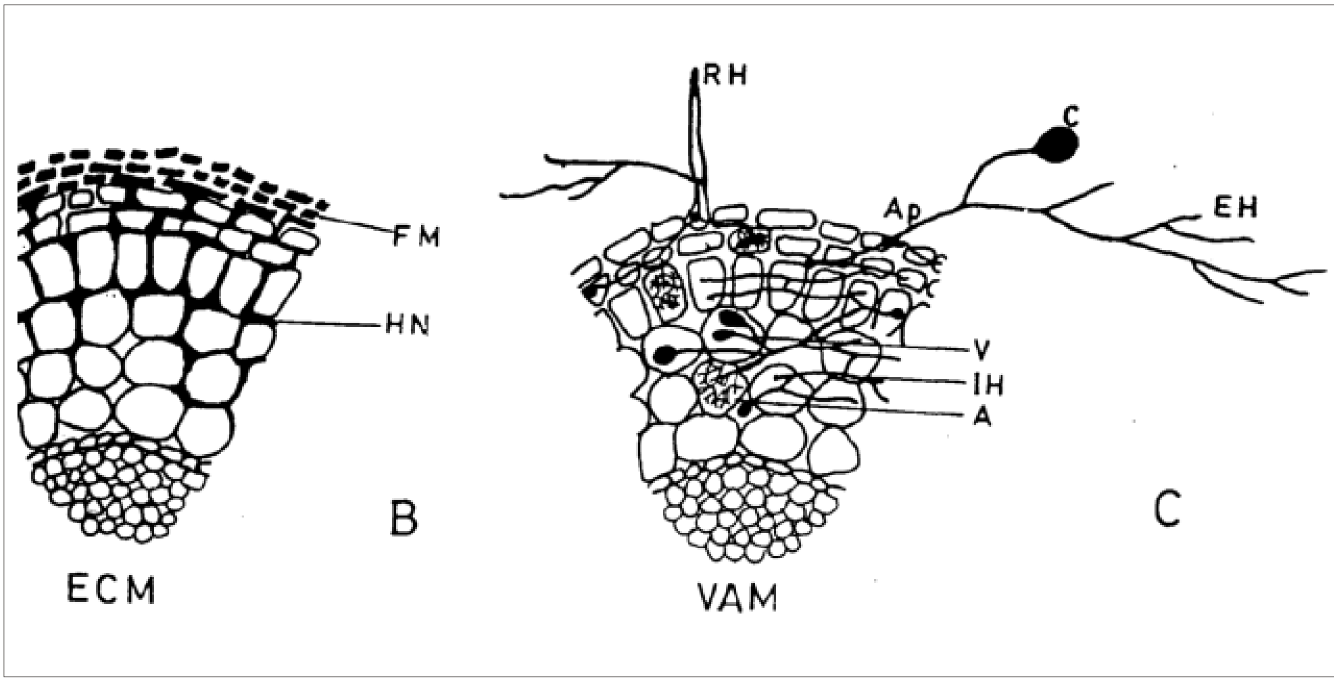

Fig. 2 **B**. & **C**. Transverse section of a root with a schematic representation of Ectomycorrhiza (B), (FM - Fungal Mantle; HN - Hartig's Net) and arbuscular mycorrhiza (C). RH-Root hair; Ap-Appressorium; V- Vesicle; EH-External hyphae; IH - Internal hyphae; C-Chlamydospore.

Robson, 1981b) as well as its infectivity (Wilson and Trinick, 1983).

The selection, establishment, multiplication and management of superior AM fungal species is a pre-requisite for the success of reforestation efforts. The AM fungi persists in soil as spores, colonized root or hyphal network and can be a source of effective inoculum. The Arbuscular mycorrhizal fungi can be established and maintained on interim cover crops such as grasses in pot cultures for routine experimentation. In pot culture AM fungi colonizes the living host plant roots and its extramatrical hyphae proliferate in the surrounding soil producing auxiliary and resting spores. Thus, the pot cultures provide soil based mixed inoculum consisting of spores, infected roots and hyphae. The pot cultures are complex system comprising of colonized host plant roots, AM fungal spores, soil microfiora and edaphic factors. The root inoculum is far easier to obtain in large quantities than spores and it is possible to harvest a large amount of inoculum in short time. The soil inoculum is considered to be more rapidly infective than spore inoculum, possibly because of a greater number of infective propagules i.e. AM spores, external hyphae, AM colonized root fragments consisting of vesicles, arbuscules and intraradical hyphae. The plant roots provide a suitable ecological niche and the associated beneficial soil microflora favours the germination of AM spores.

The root based hyphal network in soil rather than the resting spores is the primary inoculum for seedlings that become established on natural grassland. When used as inoculum, fragments of roots containing intraradical vesicles have induced more rapid colonization and a greater growth response in the host plant than the spores of same species (Abbott and Robson, 1981b; Powell, 1976; Warner and Mosse, 1980).

Mycorrhizal infection typically occurs just behind the root apex, presumably because the rate of root growth carries the apex beyond the infective AM fungal spore before the penetration takes place. The AM root colonization depends upon the host plant-fungal interactions, soil-inoculum potential, edaphic and environmental conditions.

For field sown crops the inoculum must be introduced at the time of seed sowing. The technique used is the addition of a potential soil inoculum to the furrow below the seed at the time of planting (Hayman, 1982). For successful inoculation, the introduced Arbuscular Mycorrhizal fungi would need to form substantial colonization in competition with naturally occurring indigenous AM populations and also increase plant growth.

Screening for efficient mycorrhizal fungi in promoting tree growth on adverse sites is an important step in using these fungi for forestation. The basic requirement is site specific evaluation of efficient mycorrhizal fungal species based on species diversity of the existing indigenous AM population. AM fungi individually or as mixed population have a capacity to adopt to different environments. The choice of mixed inocula ensures wider adaptation to different environmental conditions and greater consistency in benefits to the host plant the Arbuscular mycorrhizal fungi differ in their rate of promoting plant growth and their performance depends on interaction between fungus, the soil where it is growing, as well as the environmental factors. The most common method to evaluate AM species effectiveness is to test plant growth response in adverse conditions such as nutrient deficient soils. The selected host-endophyte combination is introduced in natural field conditions to improve plant growth and survival.

The selected Arbuscular Mycorrhizal symbiont should be able to enhance nutrient uptake by host plant, adaptation to soil environment and persistence in soil maintaining abilities effectivity as well as infectivity. The introduced symbiont should be able to colonize new plant roots quickly, maintain superiority over the existing indigenous populations of AM fungi and the extramatrical hyphae should proliferate extensively in soil facilitating easier absorption in nutritionally poor zone.

For plant growth to respond to inoculation with AM fungi, there must be either an absence or low inoculum potential of indigenous AM fungi and species which are less effective than the inoculant fungi in ability to stimulate nutrient uptake by plants (Abbott and Robson, 1981a and b). The external hyphae of AM fungi proliferates extensively in the soil and provide a larger absorptive and physiologically active area for nutrient and water absorption. The passage of nutrients from soil to the growing plant involves three steps, 1) mobilization of nutrients from soil to the surface of the growing plant root, 2) movement from surface to the interior of root i.e. nutrient uptake, and 3) transport of the absorbed nutrients to the shoot i.e., translocation.

The Arbuscular mycorrhizal fungi increase plant growth in the nutritionally poor soils, as in tropics and the access to poorly soluble form of phosphate is of interest. Phosphate is an essential element for plant nutrition and can be assimilated as soluble phosphate. However, in the soil a large part of the phosphorus is poorly soluble and has low mobility in the soil. Arbuscular Mycorrhizal fungi bridges the depletion zone and have a high affinity for soluble phosphate or have a high phosphorus solublizing and mobilizing potential. Mycorrhizal plants are known to use the same source of inorganic phosphate in soil as do plant roots but have greater access by growth of fungal hyphae supplementing the plant roots. This also appears to be the way in which mycorrhiza responses to poorly soluble phosphate such as rock phosphate. The AM fungi have surface phosphatases that enable them to obtain soil phosphate more rapidly than non-mycorrhizal roots. AM inoculations have beneficial effects on plant growth in low fertility soil as compared to high fertility soils. The high soil nutrient supply, particularly phosphorus suppresses mycorrhizal formation. Thus, the soil fertility is one of the important environmental parameter regulating mycorrhizae response. Mycorrhizae are significantly affected by edaphic factors such as soil pH, moisture, organic matter and temperature. AM fungi do not readily adapt to soils with a pH different from their soil of origin and that pH change restricts AM establishment. However, AM fungi adapt to edaphic conditions characterized in part by soil pH and pH is important in limiting the distribution of some AM fungi.

The arid and semi-arid regions are associated with alkaline and sandy soils with high pH and low soil moisture. The vegetation is typically xerophytic, sparse and found to be highly Arbuscular Mycorrhizal dependent. The nutrient deficient soils with low population densities of indigenous AM fungi limit the productivity of vegetation. Arbuscular mycorrhizal fungi improve water, nutritional and eco-physiological processes of the host plants and confer tolerance to such harsh conditions of water stress and nutrient deficiency. The AM colonization of seedling root systems helps in greater nutrient and water uptake and ensures better growth and survival in the fields.

The Arbuscular mycorrhizal technology is an integral component of seedling production and regeneration efforts. However, the use of AM mycorrhizae as potential tool for tree seedling production is still at nascent stages but the advances in mycorrhizal research have highlighted the scope of their use in sustainable land development and forest cover. The major constraint in drawing benefits for field application is the large scale production of AM inocula. Under such set of limitations, the possible area of successful utilization of AM mycorrhizae is nursery raised tree seedlings which requires much lower quantity of inoculum to make plants mycorrhizal. The pre-inoculation of seedlings in the nursery with selected AM symbionts results in healthy juvenile seedling growth with well developed mycorrhizal root system and provides the best opportunity for the introduction of superior, beneficial AM fungal strains at new forestation site. AM fungi confer tolerance to various biotic and abiotic stressants and reduce seedling loss and enhance primary establishment, growth and survival on outplanting in the field. Seedling quality and field performance are largely governed by processes occurring in the rhizosphere of seedlings. The mycorrhizal symbiosis improves nutrient acquisition and utilization efficiency, water relations and root absorption efficiency which are vital for survival and growth in adverse edaphic and environmental conditions.

The arid, semi-arid and wasteland soils are generally deficient in mineral nutrients, particularly phosphorus and have saline-alkaline problematic soils. Seedlings planted on such lands show poor juvenile growth and high mortality. Inoculation of the seedlings with Arbuscular Mycorrhiza in the nursery is important for forestation and rehabilitation of degraded land areas.

The conditions for utilizing AM fungi in the field (Fitter, 1985) are, i) the levels of reliance of Plants on AM fungi for nutrition and stress resistance, ii) the seasonality of association establishment, iii) host plant endophyte compatibility, and iv) nutritional or other edaphic characteristics of the host soil.

The Arbuscular Mycorrhizal symbiosis is beneficial for plant growth and survival in many ways:

Increased nutrient uptake from soil by increasing the absorptive surface area of the root system. The extramatrical AM hyphae proliferate in bulk soil and make available poorly mobile elements such as phosphorus, zinc and copper. The Vesicular-arbuscular (VA) mycorrhizal plants are well nourished as compared to non-mycorrhizal plants in nutrient deficient soils. The AM fungi confer drought tolerance to plants by increasing the water absorption capacity of the root system or by altering the host physiology. The external hyphal network contributes to the process of creating a stable soil aggregate structure, improving soil structure for better aeration and water percolation. The Arbuscular Mycorrhizal fungi increase the beneficial microbial populations in the mycorrhizosphere with increased enzymatic activities. The tripartite relationship between host, AM fungus and *Rhizobium* results in higher nitrogen fixation and increased availability of phosphorus improving plant growth response. Mycorrhiza plays an important role in changing the ecology of a given site and is used to reclaim degraded lands. VA mycorrhiza reduces the incidence and/or severity of root diseases and provides resistance to root borne diseases as well as resistance against harmful pathogenic organisms including nematodes. Mycorrhizal associations promote mineral cycling and are key components of efficient closed nutrient cycle of natural ecosystems. The VA mycorrhiza increases plant tolerance to various biotic and abiotic stressants including alkalinity, salinity, toxicities associated with mining operations, heavy metals and mineral imbalances. Mycorrhiza confers resistance to high soil temperatures, improves soil fertility and phytobiomass production per unit area of land. Arbuscular Mycorrhizae have a potential use as biofertilizers and replace the fertilizer requirements of trees in areas of marginal fertility and reduce the need for current high levels of fertilizers. Arbuscular mycorrhizaI symbiosis confers tolerance to survive transplantation shock and increases the primary establishment, growth and survival of seedlings on outplanting. Arbuscular mycorrhizal technology is an efficient, low input biotechnology forestation tool for marginal, degraded, arid and semi-arid lands.

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