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RESEARCH ARTICLE

ROLE OF ECTOMYCORRHIZA IN FOREST ECOSYSTEMS: A REVIEW.

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Abstract

The fungal symbionts forming ectomycorrhizas benefit forest trees in a number of ways. The ectomycorrhizal fungi form as an important component of forest ecosystem. It contributes to a number of key ecosystem functions such as carbon cycling, nutrient mobilization from soil organic matter to soil minerals and also linking trees through their common mycorrhizal networks. The mycorrhizal association is mostly applied to nursery seedlings and has been successfully used in reforestation programs through mycorrhizal inoculation techniques. In this review it discusses the possibility of working in forest settings. The approach should help in developing a research based on the functional ecology of ectomycorrhiza and its implications on managing the effects of climate change on forests.

Introduction:-

The symbiotic root and fungus association also called as mycorrhiza was defined by a German Botanist, Albert Bernard Frank (1885), a Greek word, 'mycos'=fungus: 'rhiza'=root. About 95% of world's species of vascular plants are known to be mycorrhizal (Trappe, 1977). The partner in the association are members of the fungus kingdom (Zygomycetes, Ascomycetes and Basidiomycetes) and most vascular plant (Kendrick,1985). According to Taylor (2005) 7-1000 fungal and 8000 plant species are capable of forming ectomycorrhizas. Ectomycorrhizal fungi (ECM) form an important component of the forest ecosystems, mainly because of their capabilities in nutrient mobilization and soil aggregation (Smith and Read 1997). Ectomycorrhizal fungi can contribute effectively upto 25% or more of the root biomass of forest, thus, contributing as a major structural component of the forest ecosystem (Monoharachary *et al*., 2005). Majority of the ectomycorrhiza colonize plant are woody perennial such as *Eucalyptus, Dipterocarpus, Quercus*. Many forest trees cannot grow without ectomycorrhizae and certain trees such as pine, have an obligate requirement for ectomycorrhiza (Berry, 1982). The benefits of ectomycorrhizal colonization are likely to arise particularly under stress condition, in analogue to mycorrhizal benefit in mineral nutritional (Read and Boyd, 1986).

Importance of Ectomycorrhiza as:-

Ectomycorrhiza in forest Production:-

Ectomycorrhiza plays an important role in reforestation programme. The subject has been ably reviewed by several workers and most important ones are by Trappe (1977). Grossnickle (1985) reviewed the importance of ectomycorrhizae in the growth of trees during the reforestation of mine lands with the requirements for the occurrence of the mycorrhizae, their enhancement of tree growth, the effect of temperature, nutrients, soil moisture and soil pH on their effectiveness and their use in the establishment of trees during revegetation of mine site. Vogt *et*

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al. (1991) suggested that increase research is needed into the relationship between plant carbon fixation and allocation and nutrient acquisition by mycorrhizae in many forest ecosystem and for their plant physiological stages and that these comparisons need to be considered not only on how symbiotic association modify the plant uptake of nutrients but the interaction between the mycorrhiza and decomposer microbes and fauna. Mycorrhiza are fungi are likely to be most beneficial in revegetated ecosystem, where the proportions of plant capable of forming Ectomycorrhiza is high and nutrient deficiencies are an important limitation for plant growth (Jasper, 1992). Gagola *et al*. (1992) developed mycorrhizal technology with appropriate ectomycorrhiza for reforestation of the polluted area with *Picea abies* seedlings. Ectomycorrhizal are known to play important role in afforestation programme and also to establishment of exotics. They also help the plants to withstand transplantation shock, to increase tolerance to high soil temperature, soil acidity, alluminium and heavy metal toxicity (Ramarao, 2002).

Reclamation of degraded lands:-
Ectomycorrhizal fungi play a significant role in tree growth. It was observed that for successful application of mycorrhizal research in forestry, it is essential to carefully choose ectomycorrhizal association that are adapted to reforestation sites (Perry *et al*. 1987). Marx *et al*., (1988) discussed an ectomycorrhizae as biological tools in reclamation and revegetation of wastelands. Ectomycorrhiza is known to benefit in nutrient absorption of inorganic nutrients specially phosphate ions production and supply of growth regulators, decreasing soil toxicity, increasing resistance to root pathogens and extreme soil temperature as repoted by Heinrich *et al.*, 1989.Chalermpongse and Boonyuen (1990) suggested that inoculation with *Pisolithus tinctorius* and manure fertilization promoted vigour, durability and survival of seedlings when tested to reforest the old tin-mined areas.

Ectomycorrhiza can modify the roots and this change is correlated with the production of cytokinin and other growth hormones which increase physiological process of roots (Anderson and Rygiewiez, 1991). To understand the role of mycorrhizas in the establishment of native trees and shrubs as part of the process of rehabilation of degraded sites, Muligan *et al*. (1992) recorded the mycorrhizal status of trees in disturbed landscapes. Roots of 37 native species (including 18 *Eucalyptus* and 14 *Acacia*) from 15-open cut coal mines have been examined. They reported that 11% of the plants possessed EMs alone, 35% had VAM alone and 51% had both. The acidity typical of most substrates of ectomycorrhizal plants, and in particular of the man made substrate such as mine spoils which they colonize, is conducive to the solubilization of potentially toxic ions (Smith and Read, 1997). The impact of this atmospheric change upon mycorrhizal function and the response to the perturbation are subjects of great importances (Smith and Read, 1997) which are beginning to receive retention. The species of ectomycorrhizal fungi used on various trees species in experimentally inoculation programmes have shown a great promise for adopting large scale inoculation technique in artificial rehabilition of degraded land which is reliable, less time consuming technique and less time consuming technique and less expensive inoculums production technique (Ajungla *et al*., 2012). The use of mycorrhizal has been considered a valuable tool in the restoration of disturbed and degraded lands as the mycorrhizal fungi plays a crucial role in plant growth and survival through plant nutrient uptake, water relations, ecosystem establishment, plant diversity and productivity of plants (Al-Karaki, 2013).

Nutrient supply:-
The Ectomycorrhiza are essential for host plant nutrient uptake and play important role in nutrient cycling and host productivity in forest (Cromack, 1979; Read, 1992). An estimated 50-70% of the net annual productivity may be translocated to root and associated mycorrhiza (Norton,1990;Vogt, 1982). The nutrient uptake capacity of a fungus was correlated with the amount of mycelium colonizing the soil. There exist a correlation between the capability of the fungal mycorrhizae with the roots of the seedling and is stimulating the uptake of nutrients (Ajungla *et al*., 2012).

Nitrogen uptake by Ectomycorrhiza:-
The importance of nitrogen to forest productivity is well established and has stimulated interest in understanding mechanism of nutrient uptake form forest soil. Influence of nitrogen on growth of ectomycorrhizal fungi has been extensively studied (Bowen, 1973). Gunther *et al*. (1998) found that association with plants increased the capacity for the ectomycorrhizal *Suillus granulates* and *Paxillus involutus* to produce hydrolytic and oxidative extracellular enzymes. Additionally, *P. involutus* produce extracellular peroxidases only when grown with symbiosis with *Pinus sylvestris* seedlings (Gunther *et al*., 1998). Some Ectomycorrhiza produces oxidatives enzymes that can catalyze the decomposition of more recalcitrant compounds such as aromatic N (Mehrag and Cairney, 2000). Intact ectomycorrhizal plants have been observed to rapidly colonize and mobilize nitrogen from patches of litter and soil organic matter in microcosms (Abuzinadah and Read, 1989).

It is well known that plant litter entering the soil has a high C:N ratio and which is rich in lignins and tannins (Ramrao, 2002). Only a few mycorrhiza can mobilize this nutrient from primary source (Ramarao, 2002). If carbon supply of a host plant are abundant, then stoichiometric requirements may induce N-limitation in mycorrhizal fungi (Sterner and Elser, 2002). Nitrogen uptake kinetic in arbuscular and ectomycorrhizal fungi and plant roots often increase with a supply of C-rich hexoses (Pearson and Jakobsen, 1993; Javelle *et al*., 1999; Foyer *et al*., 2003). Generally plants increase investment in mycorrhizal fungi when below ground resources such as N and P are scarce, as when light or carbondioxide are prevalent (Smith and Read, 1997; Whitbeck, 2001; Treseder, 2004). The major inorganic nutrient of forest soil are ammonium and nitrate which typically comprises less than 0.01% of total nitrogen in forest soils of different stand ages (Aquilera *et al*., 1993) and ammonium is assumed to be major form in inorganic nitrogen is taken up by mycorrhizal and non mycorrhizal plant (Singh and Lakhanpal, 2005). Plants that associated with mycorrhizal fungi are predicted to have greater access to N compared to non mycorrhizal plants (Schimel and Bennett, 2004). Ectomycorrhizal fungi (87%) are able to produce proteases or can grow on protein as pure N source (Talbot and Treseder, 2010). The mixed mycobionts inoculated seedlings exhibited maximum uptake of NPK compared to that of individual inoculated (Ajungla *et al*., 2010).

Phosphate uptake by Ectomycorrhiza:-

Phosphorus is generally considered to be most important plant growth limiting factor which can be supplied by mycorrhizal association, because of the many abiotic and biotic factors which can restrict its mobility in soil (Wood *et al*., 1984). Effect of nutrients and mycorrhiza on growth and dry matter in *Pinus contorta* seedling has been discussed by Roussaeu and Van (1986). The result showed that nitrogen and phosphorus significantly affect total dry weight and shoot/ root ratio. Marschner (1994) observed a positive correlation between phosphatase activity and the length of fungal hyphae associated with ectomycorrhizal mantles. Jayachandran *et al*., (1989) showed that mycorrhizal plants are able to mineralize organic P source that were not available to non mycorrhizal plant. Mycorrhizal association provides greater exploration of phosphorus absorbing area, resulting increased flow of phosphorus into the plant. Harley (1989, 1991) suggested that the production of phosphatases by ectomycorrhizal fungi play an important role in the hydrolysis of organic and inorganic phosphate, comprising of upto 80% of the total soil phosphate also important in solubilization of organic phytates, which constitute a large of total phosphate in humic soil. Acid phosphatases were considered to be involved in the phosphate nutrition plants and the key enzymes in the utilization of complex phosphate esters by ericoid and ectomycorrhizas system (Ramarao, 2002).

Ectomycorrhiza and Carbon cycling:-

Green plants provide almost all of the carbon compounds of their mycorrhizal system through their phosynthetic activity. It was proved by Melin and Nilsson (1957) that the movement of carbohydrate was from the host to ectomycorrhizalfungi. Mycorrhizal fungi depend on their host plant for carbon and mycorrhizas are strong sinks for host carbon (Paul and Kaucey, 1981). Extra carbondioxide from elevated atmospheric carbondioxide can also enter the rhizosphere via root turn over and exudation (Norby *et al*., 1987). In many teresterial ecosystem mycorrhiza may be single largest consumer of net primary production of carbon (Allen, 1991). Elevated carbondioxide from atmosphere or adequate water tended to result in increased mycorrhizal infection only in high soil nitrogen, possible as a interaction of soil nitrogen and water (Green *et al*., 1992) or carbondioxide (Griffin, Thomas and Strain., 1993). Mycorrhiza can stimulate a host plant to allocate more carbon below ground and can represents a significant carbon cost to host, with estimate ranging from 4-17% of fixed carbon (Meyer, 1974; Paul and Kaucey, 1981; Rygiewicz and Anderson, 1994). The relative increase of biomass was greater below ground at elevated carbondioxide and high nitrogen (Prior *et al*., 1997). The increase in below ground biomass was reflected in greater fine root length and number of ectomycorrhiza per seedlings at elevated carbondioxide and adequate water. Alteration in plant carbon balance enhanced by host mycorrhiza symbiont interaction suggest potential beneficial effects of elevated atmospheric carbon dioxide (Runion *et al*., 1997).

Medicinal importance:-

Ever since Fleming's discovery of penicillin from *Penicillium chrysogenum* fungi have been fundamental to the development of modern antibiotics and other pharmaceuticals. Secondary metabolites of many macrofungi, including shiitake *Lentinus, Lactarius piperatus, Cantharellus cibarius, Ganoderma lucidum* and *Usnea* spp.have been shown to have antitumour or antibiotics properties (Nisbet and Fox, 1991). Fungal metabolites are used in the agrochemical, fine chemical and pharmaceuticals industries and in industrial service ranging from oil recovery to effluent treatment to bioplastics and biocontrol (Nisbet and fox, 1991). Presently, over 11,500 fungal species are maintained in intentional culture collections, primarily for industrial uses (Nisbet and Fox, 1991). Pharmaceuticals companies are actively screening ectomycorrhizal fungi from the Pacific Northwestern United States for useful metabolites (FEMAT, 1994).

Antibiotic Production:-

Hyppel (1968) found that over 1/3 of 85 species and strain of mycorrhizal fungi tested inhibited *Fomes* to a significant extent Marx and his associates (1972, 1973, 1975) made a detailed examination of the potential of mycorrhizal fungi to inhibit pathogens. De la Cruz (1989) reported the improvement in growth of *Pinus* and *Eucalyptus* due to ectomycorrhiza formed by *Scleroderma* sp. and *Pisolithus tinctorius*. He and his co-workers developed a clay tablet inoculum containindbasidiospores of both the fungus, they observed EMs when tablet inoculum was added to potted seedlings of *Pinus carribeae, Eucalyptus camaldulensis* and *Eucalyptus delgupta* after 3 months, in the Philippines. Marx (1991) reported that *Pisolithus tinctorius* obtained from Georgia, USA was used to mass inoculation in pine seedlings in nurseries in Venezuela. Maximum ectomycorrhiza developed was achieved suggesting an improvement in seedlings survival and growth on Venezuerlan reforestation sites. Darusman *et al*., (1995) demonatrated that *Scleroderma columnare* produced the highest antibacterial antibiotic.

Production of Hormones:-

Mac Dougal and Dufrenoy (1944) demonstrated that excess auxin was present in the fungal mantles in mycorrhizas of *Pinus radiata* and also in the stem mycorrhiza of an orchid (*Corralorhiza maculatum*). Subba Rao and Slankis (1959) found several indole compounds in EM of *Pinus sylvestris* and *P. strobus*. Moser (1959) reported that the auxin production by ectomycorrhizal fungi are greatly influenced by the nitrogen source and its concentration. Melin's (1963) discovery of M factor in the root exudates of *Pinussylvestris* was significant as it stimulate the mycelia growth of symbiotic fungi in pure culture. Skoog and Schimtz, (1972) observed that EM fungi produce auxins and cytokinins are known to mobilize nutrient and control their translocation in higher plants also enhanced chloroplast development. Several growth hormones and growth regulators were synthesize and liberated by EM fungus *Boletus edulis* var. *pinicolus* (Gogala, 1967, 1971). Miller (1967,1971) demonstrated that EM fungi (*Rhizopogon roseolus*, *Suillus cothurnatus*)released cytokinin in culture solution. Slankis (1973) stated: "the hormone- induced changes in the physiology and metabolism of the higher symbiont must also play a significant role in its stimulation. The exact nature and extent of the fungus hormonal effect on the host plant is not yet known and needs to be further studied". Ng *et al*. (1982) confirmed that *R. luteolus* and a few strain of *Suillus luteus* produced cytokinin in cultures.

Bioindicators:-

Ectomycorrhizas are also known as potential bioindicators due to their huge number of species, specialization and important ecological functions. Ectomycorrhizal fungal species has its own set of physiological characteristics (Trappe, 1977). Ectomycorrhizal colonization is essential for reforestation success on harsh sites (Amaranthus and Perry, 1987, 1989). Some may be particularly effective at extracting phosphorus or nitrogen from mineral soil, others more effective at releasing bound nutrients from organic matter. Some may thrive in coarse woody debris, others in humus or other substrate components. Even individual small trees may have ectomycorrhizal association (Amaranthus and Perry, 1987).

Drought tolerance:-

It has been shown that the external mycelium of ectomycorrhizal fungi transport water to the root of host plant (Duddridge*et al*., 1981) and it has been shown that the water taken up by the external mycelium can be sufficient to make a differences between the survival and death of a tree seedling (Boyd *et al*., 1986). Read and Boyd (1986) suggested that the benefits of colonization are likely to rise particularly under stresses condition, in analogue to mycorrhizal benefits in minerals nutrition. They suggested that mycorrhizas could be benefit through their capacity to provide the minimum requirements for survival of the host plant during droughts. According to Lakhanpal and Kumar (1986) the higher rate decrease of moisture percentage was more in non mycorrhiza seedlings, than mycorrhizal seedlings. Boyd (1987) suggested that the improved contact between the hyphae and soil particles increased the potential for mycorrhizal water uptake. Mycorrhiza can also induce a higher root/ shoot ratio in seedlings, which then leads to sustained water uptake and transpiration during drought even in the absence of nutrition effects (Davis *et al*., 1996). Larger root system in mycorrhizas have a higher conductance, which then leads to sustained water uptake and transpiration during drought even in the absence of nutritional effect (Davis *et al*., 1996). In some fungal species, the external mycelium consists of individual hyphae and the contact with soil or litter is made largely by the mantle (Agerer, 2001). Ortega *et al*., (2004) found a better performance of *Pinus radiata* inoculated with *Rhizopogon roseolus* and *Scleroderma citridum* particularly in a dry site. In this the roots and hyphal extension was likely mechanism for imporved performance. As the soil dries and water is retained only in small pores where fungal hyphae can grow, but roots cannot the water uptake function of hyphae becomes more significant for survival (Allen, 2007).). Beniwal *et a*l., (2010) showed that mycorrhizal seedlings kept their photosynthesis up during drough, while it was reduced to nil in non mycorrhizal seedling. Under stress environmental conditions, plants with mycorrhizal associations can adapt far better than the non-mycorrhizal plants (Sharma *et al*., 2010).

Ectomycorrhiza have shown to be important in plant water uptake but these studies are mostly limited to small seedlings (Lehto *et al*., 2011). Adequate mineral nutrition leads to sustained photosynthesis and improved whole plant performance. Nutrition uptake during dry spells, survival and recovery of nutrient uptake after soil thawing may turn out to be among the most important feature of Ectomycorrhiza during in regard to water (Lehto *et al*., 2011). Phosphorus content and potassium content in ectomycorrhizal infected *Pinus patula* seedlings indicated enhanced ability to absorb P and K in mycorrhizal seedling compared to non mycorrrhizal seedlings. Low availability phosphorus content in the rhizoshere soil favored more mycorrhizal association in pine seedlings (Imliyanger (2012).

Ectomycorrhiza in plant protection:-

Ectomycorrhiza are known to be responsible for resistance to diseases against plant. Zak (1964) postulated that mycorrhizal fungi may protect absorbing roots of trees by utilizing root carbohydrate and other chemicals thereby reducing the attractiveness of the root to pathogens, providing a mechanical barrier to the pathogen in the form of fungal mantle, secreting antibiotics which inhibit or kill pathogen, and lastly by attracting a protective rhizosphere population of other microorganisms. The resistance of naturally occurring ectotrophic mycorrhizae of short leaf and pine to infection by *Phytophthora cinnamon* was demonstrated by Marx and Davey (1969). Studies conducted by Chakravorty and Unestam (1985) showed that *Laccaria laccata*, *Pisolithus tinctorius* and mixture of naturally occurring mycorrhiza were highly protective to *Pinus sylvestris* seedlings against *Fusarium moniliforme* and *Rhizoctonia solani*. *Amanita muscaria*, *Laccaria laccata*, *L. ftaterna* and *Suillus brevipes* were tested for their antagonistic activity (Nataranjan and Govindaswamy, 1990). *S.breviceps* caused maximum inhibition of *Fusarium solani* and *Cylindrocladium pravum*, *Laccaria laccta* inhibited *Armillaria mellea*, *C. parvum*, *F.oxysporum* and *Amanita muscaria* showed its antagonistic activity against *Rhizoctonia solani* (Singh and Lakhanpal, 2005). In ectomycorrhiza the fungal mantle composed of tightly interwoven hyphae and covering the root tip and cortex completely act as a mechanical barrier against pathogen infection. Many plant cells are known to synthesize inhibitory chemicals in response to pathogenic attack. Mycorrhizal fungi may afford protection also by stimulating host root cells to elaborate inhibitor that may maintained the symbiotic state and that also serve to inhibit infection by pathogens (Singh and Lakhanpal, 2005).

Conclusion:-

Generally the importance of the occurrence of mycorrhizal relationship is ignored as they occur underground and are invisible but it is seen how mycorrhizal association plays a crucial and essential role in forest ecosystems. More than 90% of the land plants are associated with mycorrhizal fungi, with mostly tree species such as *Pseudotsuga*, *Picea*, *Pinus*, *Abies*, *Salix*, *Querccus*, *Betula* and *Fagus* are ectomycorrhizal. A major benefit of ectomycorrhizal association is that the mycorrhizal mycelial networks which is the most dynamic and diverse component of the symbiosis function as the primary organs for adsorption of nutrient in many host plant and most of the woody plants in the forest ecosystems depends on ectomycorrhizal fungi for their growth and survival.

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