



ROLE OF AM FUNGI IN RECLAMATION OF SALT AFFECTED SOILS: A REVIEW

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ABSTRACT

The AM fungi are group of fungi known to form symbiotic association with mostly all kind of plants. These fungi help the plants in improving nutritional quality and water supply. They are also known to help plants by producing growth promoting substances, provide protection against pathogens and maintain soil quality. Many of these AM fungi are known to provide nutrients and water in extreme condition. This property of AM fungi is nowadays used for reclamation of problematic soils such as alkaline, acidic, alkali-saline, calcareous, usar, wastelands of mines etc. this review throw light on the different experiments performed using different AM fungi alone or in combination with other microorganisms to improve the soil quality. It also covers some important aspects by which AM fungi helps the plants in establishing itself in the salt affected soils.

Keywords: AM Fungi, Salt Affected Soils, Intensive Agriculture

INTRODUCTION

Salt affected are serious problem nowadays and it is increasing day by day. India is also affected by this sever problem [1]. Out of 1.5 billion hectares of agricultural land in world, about 77 million hectares (5%) is affected by high salt content [2]. In India approximately

7 mha land is salt affected out of which, 2.5 mha occurs in Indo-Gangetic plains covering the states of Uttar Pradesh, Haryana, Punjab, Delhi and parts of Bihar. In Uttar Pradesh alone about 1.29 mha is salt affected and commonly known as 'usar' or 'reh' in local

language [3]. This condition is due to intensive agriculture and unmanaged practices such as excessive irrigation, tillage and high dose of inorganic fertilizers [4-6]. The high salt content in soil does not support the plant in establishment and growth and development [1, 7]. High salt content reduces the osmotic potential of soil [8] and increases toxicity of Na^+ and Cl^- , which result with interference of many physiological, metabolic and molecular processes [9, 10].

AM Fungi in Salt Affected Soils

AM fungi are known to occur in salt affected soils naturally [11-13]. The distribution of AM fungi varies from low [3, 14, 15] to high [16, 17]. The most dominant AM fungi in salt affected soil were found to be *Glomus* sp. [3, 16]. The reason for occurrence of high AM fungi spore in salt affected soil is given that the high salt concentration increases environmental stress, which in turns stimulates sporulation [16, 18]. The AM fungi are also reported from the salt-marsh areas of the world [11, 15, 19, 20]. AM fungi are also reported to make association with halophytes, which love to grow in salt water [21-23].

AM Fungi in Plant Growth Improvement

VAM fungi improve the plant growth performance [24] by enhancing the nutrient and water uptake capacity, altering the hormone level and improving the various

physiological processes, such as photosynthesis, nitrogen fixation etc. Especially in the stressed conditions, it helps in the establishment and survival of the host. Mycorrhizal fungi serve as the highly efficient extension of the host root system. VAM fungi increase the effective absorbing surface of the host root by as much as ten times [25]. Mycorrhizal fungi also produce enzymes, auxins, cytokinins, vitamins and other substances that increase rootlet size and longevity [26]. A number of workers have reported significant reduction in mortality and increase in root/shoot biomass and yield in the mycorrhizal plants [27, 31].

VAM fungi in symbiotic association with plants affect the hormone level increase the level of cytokinin [32] and alter level of gibberellins and abscisic acid [33]. They also affect the growth regulating substances, which are useful not only in root development and many basic processes of plant growth but also in mobilization of nutrients and their translocation [26, 34]. The possible mechanism for the production of growth regulators by VAM symbiont or its host plant has not been investigated in detail. However, the production is possibly related to the physiochemical changes in the host plant brought about by symbiont [35].

AM Fungi in Reclamation of Salt Affected Soils

Role of AM fungi in establishment of plant community in problematic soils i.e. alkaline, acidic alkali-saline, calcareous, usar, wastelands of brick-mines and other degraded sites has been recognized by many workers [36, 37]. Mycorrhizal association has been shown to play important role in the establishment of green cover over desert, semi-desert as well as sandy and silica sites developed due to mining activities [38-41].

Advantage of AM fungi in reclamation of saline soils has been attributed to better transport of phosphorus than sodium ions to host plants [42, 43]. Behl, 1990, [44] investigated the role of endomycorrhizae in fuelwood plantation nurseries for alkaline soil sites and found that AM fungi improved the growth of hardwood tree on degraded alkaline soils. Sengupta and Chaudhuri [45] studied the effect of dual inoculation of *Rhizobium* and mycorrhizal fungi (*Glomus fasciculatum*) on the growth response of *Sesbania grandiflora* in coastal saline and sand dune soils collected from Sundarbans of W. Bengal. Both single and dual inoculations gave better result. Uniyal and Thapar and Uniyal, 1995, [46] studied the effectiveness of AM fungi and rhizobia in promoting growth and biomass of *Prosopis juliflora* seedlings in

a pot experiment using nutrient deficient sodic soil. Best results were obtained with dual inoculation treatments. Kumar and Mangal [47] studied the response of potato to AM inoculation (*Glomus mosseae*) under different salinity levels (0.75, 4, 6, 8 and 10 d Sm⁻¹) with and without phosphorus nutrition. Significant improvement in tuber yield was observed for all treatment combinations. Madan et al. [48] studied the effect of AM fungi on *Ailanthus excelsa*, *Pongamia glabra* and *Cassia siamea* in highly alkaline saline soils. The results showed that mycorrhizal inoculation provided 100% survival in all the three types of plants. Sidhu and Behl [49] investigated the efficiency of VA mycorrhizae, *Glomus fasciculatum*, *G. macrocarpum* and *G. mosseae*, on the growth of *Prosopis juliflora* in salt-affected soils at four different pH levels 7.8, 8.5, 9.5 and 10.5. AM fungi increased plant growth in all the four treatments as compared to the non-mycorrhizal plants. Janardhanan and Khaliq [50] studied the influence of AM fungi, *G. mosseae*, *G. fasciculatum* and *G. aggregatum*, on growth and productivity of chamomile in alkaline Usar soil. Saralabai and Vivekanandan [51], on the basis of experimental results, revealed that AM fungi have the potential to survive extremities of stress like high pH and EC values of the soil.

Vijaya *et al.* [52] studied the sodic soil tolerance of teak (*Tectona grandis*) seedlings produced after gibberellic acid seed treatment. Giri *et al.* [53] studied the growth response and dependency of *Sesbania aegyptiaca* on *Glomus macrocarpum* in salt stressed soil. Chandra *et al.* [54] studied the soils of five different wastelands and four petrocrops. The results clearly showed the potential of AM fungi in improving the quality and establishment of petrocrops. Giri and Mukerji [55] studied the effect of AM fungus *Glomus macrocarpum* on the growth and dependency of *Sesbania grandiflora* in saline soil. Inoculation with *Glomus macrocarpum* gives better result.

Improved tolerance to various stresses in mycorrhizal plants, particularly to salt stress, is commonly attributed to the nutritional as well as non-nutritional effects of the AM fungi. It has also been attributed to the increased tolerance of the plants to fluctuations in temperature and pH [56-57].

Nutritional Effects of AM Fungi

The AM fungi are known to have positive effect on the nutrient supply to the plants. AM fungi becomes more important in the sense, they supply some of nutrients which have very less mobility like phosphorus [58, 59]. The mycorrhizal dependency of plant

increases with increasing salt concentration [55].

Phosphorus: In soil, P might be present in large amounts, but the preferred form for assimilation, orthophosphate (Pi), is usually much depleted owing to adsorption to soil particles or conversion into organic complexes, ranging from 1-10 μ M [60]. However, uptake of P by plants seems to be by far much faster than rates of P release and diffusion in the soil, with the consequence that P-depleted areas formed around the root. Salinity in soil also interferes with mineral absorption. It minimizes the uptake of minerals especially phosphorus because it forms inorganic complexes with Ca²⁺, Mg²⁺ and Zn²⁺ and precipitates, and make it insoluble [60, 61]. Among many less sophisticated ways to overcome this problem, such as release of phosphatase, organic acids or changes in root morphology, most terrestrial plants have chosen to use the 'Pi catering service' provided by vesicular arbuscular mycorrhizal fungi [62]. AM fungi are known to provide phosphorus at very low concentration of it [59, 63, 64]. Earlier reports suggested that increased uptake of phosphorus by mycorrhizal plants is due to the production of organic acids by AM resulting in better availability of available phosphorus [64, 65]. Proton ATPase system located on plasma

membrane of AM fungi has also been associated with increased uptake of phosphorus [66, 67]. Phosphate absorbed by extramatrical hyphae is accumulated in vacuoles in the form of polyphosphate granules [68]. It is transported to arbuscules by cytoplasmic streaming [35].

Most plants have two Pi uptake pathways [69, 70] direct uptake, at the plant-soil interface, and the mycorrhizal or symbiotic uptake, at the plant-fungal interface. The direct pathway involves two types of Pi transporters: (i) a low-affinity transporter that is constitutively expressed; and (ii) a high-affinity transporter inducible under Pi-deficient conditions. Molecular experiments demonstrated that plants are able to suppress/reduce the direct high-affinity uptake pathway when colonized by AM fungi [71, 72]. In some cases, the plant is able to rely completely on the fungal delivery of Pi. It involves the active participation of fungal P transporters able to load Pi from the soil into their cytoplasm, the further translocation of phosphorus towards the plant, the release of Pi into the plant-fungal interface and the Pi uptake by the plant cells. Several of the molecular components of this complex Pi symbiotic uptake pathway have been elucidated in the last decade, including a fungal Pi transporter operating at the soil interface at low Pi concentrations [73,

74] and several plant Pi transporters induced in cortical cells colonized by AM fungi and thus responsible for the transfer of Pi from apoplast to plant cytoplasm [75-77].

Nitrogen: Apart from benefiting plants by aiding phosphorus uptake from the soil, AM fungi also take up and transfer significant amounts of nitrogen to their host plants [59, 78, 79]. The availability of nitrogen frequently limits plant growth, and depending on soil conditions nitrogen transfer by mycorrhizal fungi can represent a significant route of uptake by plants [80, 81]. AM fungi have been strongly implicated in the transfer of nitrogen from one plant to another [81]. It can increase the utilization of different forms of nitrogen by plants and have been shown to take up nitrogen directly and transfer it to host roots [82, 83]. In saline condition nitrogen absorption and metabolism is greatly affected. Salinity interferes with NO_3^- uptake and reduction in protein synthesis [84].

AM fungi have been known to possess nitrate reductase, glutamine synthetase and glutamate dehydrogenase, which are important enzymes of primary nitrogen assimilation and catabolism in plants [85, 86]. Their ability to accumulate ammonium in alkaline soil and derive nitrogen from sources that are less available to non-mycorrhizal plants have been reported [87]. It has also been suggested that

AM fungi acquire nitrogen from organic substances by enhancing decomposition [83]. Recent investigations based on stable isotope labeling experiments have shown that inorganic nitrogen taken up by AM fungi outside the roots is incorporated into amino acids, translocated from extraradical to intramatrical mycelium as arginine, [88, 89].

Other Nutrients: AM fungi have been reported to play a key role in improvement of uptake of nutrients viz; zinc, calcium, magnesium and iron [59, 90] copper and manganese [59, 91]. Calcium ions (Ca^{2+}) are very important component of plant cell wall and play a vital role in many metabolic processes. AM fungi are known to enhance the Ca^{2+} uptake in normal as well as stress condition [59, 92, 93]. Higher concentration of Ca^{2+} ions nullify the toxic effect of the Na^+ and Cl^- ions in saline soils [94]. AM fungi play a key role in improvement of uptake of nutrients other than phosphorus by altering acquisition mode of the absorbing system [95, 96]. They have been shown to be involved in the uptake of Cu, Zn and other trace elements having low mobility in soil. They have also been shown to increase iron and sulphate uptake [59, 97].

The AM fungi are known to maintain $\text{K}^+ : \text{Na}^+$ ratio. In saline soil Na^+ absorption is preferred over K^+ due to this K^+ deficiency

occurs in plants. K^+ plays important role in many metabolic processes such as stomatal opening and protein synthesis [98, 99]. AM fungi enhance K^+ absorption under saline condition [99-101] thus increasing $\text{K}^+ : \text{Na}^+$ ratio in roots and shoots of plant [99]. This ratio $\text{K}^+ : \text{Na}^+$ is basically maintained by K^+ and Na^+ transporters in membrane [102]. Higher $\text{K}^+ : \text{Na}^+$ ratio protects metabolic processes, which involve K^+ ion from disruption. Some of them are vital for plant growth. Increased uptake of sulphate has been attributed to an improved phosphate nutrition mediated by AM fungi [96]. Uptake of Br, Cl and others has been shown to be directly influenced by AM fungi [59, 103]. There are contrasting reports about Cl^- absorption by AM fungi. Some authors are of view that AM fungi reduces Cl^- uptake [101]. This property of AM fungi can be beneficial for plants growing in the saline soil. The other are of view that AM fungi enhances Cl^- absorption [59, 103, 104].

Non-Nutritional Effects of AM Fungi

Several eco-physiological studies investigating the role of AM symbiosis in protection against abiotic stresses have demonstrated that the symbiosis often results in altered rates of water movement into, through and out of host plants, with consequent effects on tissue hydration,

hormone production and plant physiology [105-109]. Other mechanism may include osmotic adjustment, which assists in the maintenance of leaf turgor, and effects on physiological processes such as photosynthesis, transpiration, conductance and water use efficiency [110, 111].

Due to excessive salt concentration, soil water potential becomes more negative due to which physiological drought condition develops [112]. Plants must decrease their water potential to maintain a favorable gradient for water flow from soil into roots. Osmotic adjustment helps in decreasing the plant osmotic potential by active accumulation of organic ions or solutes [113]. The solutes that participate in osmotic adjustment are inorganic ions (mainly K^+ and Cl^-) or uncharged organic compounds like proline, glycine, betaine as well as carbohydrates like sucrose, pinitol or mannitol [114]. One of the best known responses of plants to stress is the accumulation of soluble, low molecular mass, non-protein amino acid proline [115-117]. Many researchers have found that AM fungi help in maintaining osmotic potential in plants thus AM plants have more water content than non AM plants [8, 118]. This is due to longer and altered root system [119]

and lower water saturation deficit and higher turgor potential [118, 120].

To date, studies carried out on osmoregulation in AM symbiosis are scarce, although an increase in proline accumulation has been observed in mycorrhizal plants subjected to various stresses [121-123]. Proline accumulation increases with mycorrhization with AM fungi [100, 124]. The concentration of proline was found to be more in roots than shoots [100, 124] which help in maintaining more negative osmotic potential than external environment. It is also reported that AM plant accumulates more betaines than non-AM plants. The betaine accumulation may increase up to two folds in AM plants. It has also been shown that mycorrhizal colonization and drought stress interact in modifying free amino acids and sugar pools in roots [107]. Ruiz-Lozano *et al.*, [110] studied the effect of three different species of *Glomus*, *G. mosseae*, *G. fasciculatum* and *G. deserticola*, on *Lactuca sativa* plants under different salt concentrations and reported that proline accumulation was considerably lower for P amended non-mycorrhizal and mycorrhizal plants except for *G. mosseae* colonized plants. Transpiration, CO_2 exchange rate, stomatal conductance and water use efficiency were higher in mycorrhizal plants. Phosphorus content of P

fertilized non-mycorrhizal plants was similar to or higher than those of *G. mosseae* and *G. fasciculatum* colonized plants. Hence, it was suggested that the effect of *G. mosseae* and *G. fasciculatum* on salt tolerance of lettuce could not be attributed to the difference in the P content. The mechanism by which these two AM fungi alleviated salt stress appeared to be based on physiological processes rather than on nutrient uptake.

Many of the degenerative reactions associated with abiotic stresses and oxidative stress caused by salinity and/or alkalinity are mediated by reduced oxygen species such as superoxide radicals or hydrogen peroxide [125]. Prevention of oxidative stress and the elimination of reactive oxygen species are the most effective approaches used by plants to gain tolerance [126]. Several reports suggest that mycorrhizal protection against oxidative stress may be one of the most important mechanisms by which AM symbiosis increases the tolerance of host plants [127-129]. AM fungi are known to enhance the activity of several antioxidant enzymes such as superoxide dismutase, catalase, ascorbate peroxidase, glutathione reductase etc.

Palma *et al.*, [127] showed that the AM fungus *Glomus mosseae* possesses CuZn-SOD activity and that mycorrhizal clover roots exhibit two additional superoxide

dismutase isoforms as compared to non-mycorrhizal roots, a mycCuZn-SOD and a Mn-SOD. Ruiz-Lozano *et al.*, [128] also reported that mycorrhizal lettuce plants subjected to drought stress have increased superoxide dismutase activity compared to non-mycorrhizal controls. Later molecular analysis confirmed this response at the transcriptional level [108]. Ghorbanli *et al.*, [130] studied the effect of salt acclimated mycorrhizal fungus *Glomus etunicatum* on the antioxidative enzymes in soybean plants grown under salt stress and different concentrations of NaCl. Activities of superoxide dismutase, peroxidase and catalase increased in the shoots of both mycorrhizal and non-mycorrhizal plants grown under NaCl salinity. Mycorrhizal plants had greater superoxide dismutase, peroxidase and ascorbate peroxidase activity under salinity. Under salt stress, soybean plants inoculated with salt pre-treated mycorrhizal fungi showed increased superoxide dismutase and peroxidase activity in shoots.

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