2. REVIEW OF LITERATURE

2.1. PLANT-MICROBE INTERACTIONS

Plants are exposed to diverse species of microbes that are present in soil. Plants are the prime source of nutrients for microbes and provide nutrients indirectly from root exudates and dead plant matter. In some cases, nutrients are provided directly to microbes that form close associations with plants. Plant-microbe interactions lead to many beneficial and harmful sequences. Plant roots carry large number of microbes on their surface. The interfacial volume between the plant root and the bulk of the soil is called the rhizosphere. During recent years, studies on beneficial aspects of plant root-microbe interactions, metabolites mediating microbial-plant communication and plant strategies to manage nutrient fluxes and nutrient acquisition have gained great importance (Nakas and Hagedorn, 1990).

One of the most extensive applications of plant root-microbe relationship has been in the area of mycorrhizal symbiosis. Less exploited but studied with increasing intensity are the arbuscular mycorrhizal symbiosis (Mosse and Hayman, 1971; Buwalda et al., 1983; Raju et al., 1990; Gill and Singh, 1999; Mukherjee et al., 2000; Vijaya, 2000; Vijayakumar et al., 2000; Clark and Zeto, 2002, Tripathi et al., 2005; Iman et al., 2008; Ramakrishnan and Lenin 2010 and Xie et al., 2014). The present review encompasses the pertinent observations related to these associations.
2.2. OCCURRENCE OF AM FUNGI

2.2.1. Geographical distribution

AM is cosmopolitan in occurrence. Their distribution is well documented from different geographical regions of the world like polar (Stubblefield et al., 1987), temperate (Berch and Fortin, 1984), tropic (Redhead, 1968) and sub-tropic (Sharma et al., 1986). Tropical AM fungi are more diverse than temperate (Sieverding, 1990). AM fungi has been reported in salt marsh soils (Sengupta and Chaudhuri, 1990) and in alkaline and saline waste lands in northern parts of India (Janardhanan et al., 1994) and metal contaminated area (Wilkinson and Dickinson, 1995; Tanushree Chatterjee, 1999) and effluent polluted soils (Selvaraj and Bhaskaran, 1996; Ramakrishnan et al., 2001). It is estimated that about 90 per cent of vascular plants normally establish relationship with AM fungi. AM associations have been observed in 1000 genera of plants representing 200 families. There are about 3,00,000 hosts for AM in the world flora (Kendrick and Berch, 1985).

2.2.2. Plant habit and habitat

Occurrence of AM has been reported in all flora of land plants from bryophytes to angiosperms (Harley and Smith, 1983); in plants of different habitats viz., hydrophytes (Bagyaraj et al., 1979), halophytes (Sengupta and Chaudhuri, 1990) and xerophytes (Bethlenfalvay et al., 1984) in different growth forms viz., herbs
(Kehri *et al.*, 1987), shrubs (Manoharachary *et al.*, 1987) and trees (Kandasamy *et al.*, 1987; Ganesan *et al.*, 1991; Vijaya and Srivasuki, 1997). AM occurrence was also reported in food grains and other crops (Thompson, 1990; Manoharachary and Prakash, 1991) and medicinal plants (Srivastava and Monica Basu, 1995; Srinivasan and Lakshmanaperumalsamy, 1997).

### 2.2.3. Plant communities

AM has been reported in many plant communities such as health lands (Sward *et al.*, 1978), rangelands (Trappe, 1981), steppes and prairies (Anderson *et al.*, 1984), deserts (Bethlenfalvay *et al.*, 1984), grasslands (Allen *et al.*, 1995) and forests (Renker *et al.*, 2005).

Potty *et al.* (1982) reported that AM fungi was associated with different tuber crops *viz.*, cassava, sweet potato, yams, coleus, ginger and arrow root. The dominant mycorrhizal flora observed in cassava, sweet potato, coleus belonged to the genus *Glomus* and *Gigaspora*. *Gigaspora* were present only in cassava and sweet potato. *Acaulospora* and *Sclerocystis* were present in coleus and yams.

Harbanskaurkehri *et al.* (1987) reported that AM infection in the plants of non-cultivated lands of Allahabad was from 23-42 per cent, the lowest being in *Amaranthus spinosus* and highest in *Datura metel*. They also reported that the infection ranged from 80-100 per cent in
the plants from cultivated fields. It was noticed that the infection was 80 per cent in *Lycopersicum esculentum* and 100 per cent in *Allium cepa*.

Manoharachary *et al.* (1987) surveyed the weeds around Hyderabad city for AM association. They reported that 60 per cent of plants showed AM association and found the association of *Glomus* sp. with *Waltheria indica*, *Abutilon indicum*, *Ageratum conyzoides*, *Tephrosia purpurea* and *Sida cordifolia*.

Sulochana and Manoharachary (1989) first reported the association of AM in castor and safflower from Asia. Sesame, soybean, groundnut, sunflower and safflower, coconut and castor were having mycorrhizal association (Manoharachary and Prakash, 1991).

Potty (1991) reported the occurrence of AM fungus in the scales, epidermis and sloughed off tissues, around corms and cormels of Taro (*Colocassia esculenta*). Mycorrhizal fungal propagules were found in between the layers of the outer skin of *Dioscorea* (Potty *et al.*, 1993).

Ganesan and Mahadevan (1994) observed AM propagules, hyphae, arbuscules and vesicles on the surface of the cassava tuber peel. They also found that mycorrhizal inoculation reduced the HCN level of cassava tuber.
Type of soil is one of the important factors which influences the arbuscular mycorrhizal association and distribution (Sivasaravanan and Sundaram, 1995).

Arbuscular mycorrhizal fungi, *Glomus fasciculatum*, *Gl. aggregatum* and *Gl. mosseae* were found associated with mangrove tree species of Pichavaram (Lingan *et al.*, 1999). The natural colonization of arbuscular mycorrhizal fungi in the roots of *Ipomoea batatas* L. ranged from 15.4 per cent to 32.0 per cent in the coastal soils of Tamilnadu (Tholkappian *et al.*, 2000). The natural colonization of AM fungi were disturbed in increased levels of chemical fertilizer and heavy metals (Ramakrishnan *et al.*, 2001). Bidartondo *et al.* (2002) analyzed non-photosynthetic plant species *viz.*, *Arachnitis uniflora*, five voyria species and one voyriella species for mycorrhizal colonization and reported that non-photosynthetic plants associate with AM fungi and can display the characteristic specificity of epiparasites.

### 2.3. Classiﬁcation of AM Fungi

The classification involves arrangement of organisms into taxonomic group of different rankings according to particular characters of common development and evolutionary relationship.

The name mycorrhiza was suggested by A.B. Frank in 1885. He distinguished extensively outside the root (ectomycorrhiza) and the other which developed within the root cell (endomycorrhizae).
As early as 1896, Janes observed the vesicles. Dangeard (1900) observed arbuscles of a fungus inside roots of poplar. Galluad (1904) named and studied the development stages of arbuscles. Arbuscular mycorrhizal fungi were placed under Mucorales of zygomycetes on the basis of their reproduction (Bucholtz, 1912). Thaxter’s classic monograph on endomycorrhizal fungi emphasizes types with large sporocarps and described species forming zygospores, chlamydospores and sporangiospores (Thaxter, 1992). Peyronel in 1923 was the first to recognize that the vesicular-arbuscular mycorrhizal fungi were members of the Endogonales.

Gerdemann and Nicolson (1963) developed procedures for collecting spores from soil by a method called wet sieving and decanting method and described new species found by their techniques. From India for the first time AM fungi were reported by Rikhy and Mukerji (1974).

The family Endogonaceae was monographed by Gerdemann and Trappe in 1974 with segregation of the genus Endogone into seven genera. Benjamin (1979) was the first to raise the family Endogonaceae to order Endogonales in the class Zygomycotina.

The binomial keys of Hall and Fish (1979) and Nicolson and Schenck (1979) are helpful for the classification. Trappe (1982) proposed synoptic key for the identification of genera of Endogonaceae.
which included number of characters such as shape of spore, the form and number of hyphae attached to the enclosing cells and the presence or absence of sporocarps.

At molecular and biochemical level, ELISA (Enzyme Linked Immuno Sorbant Assay) technique is used to investigate the relation in Endogonaceae. Aldwell et al. (1985) used ELISA technique and found a close relationship between Glomus and Sclerocytis.

Sen and Hepper (1986) characterized six different Glomus sp. by selective enzyme staining following polyacrylamide gel electrophoresis. The most recent classification was given by Berch (1986). He states that the family Endogonaceae contains seven genera. These are Acaulospora, Endogone, Glomus, Gigaspora, Entrophospora, Sclerocytis and Modicella. All Gigaspora species form AM, while Glomus, Sclerocystis, Acaulospora and Entrophospora species form VAM. Morton (1988) studied the evolutionary relationship among vesicular arbuscular mycorrhizal fungi in the Endogonaceae with the help of morphological characters. Three important genera of the Endogonaceae family are Glomus, Gigaspora and Acaulospora.

Sanders et al. (1992) suggested that affinities between antigen of Acaulospora laevis and Gigaspora margarita might be taxonomically informative. Selective enrichment of amplified DNA
(SEAD) technique have been used to investigate the taxonomic composition of mycorrhizal fungi (Clapp et al., 1994). Unlike Gigaspora and Scutellospora, species of Glomus, Sclerocystis, Acaulospora and Entrophospora were known to form intraradical vesicles, beside arbuscles. The vesicles have now been termed as chlamydospores, because of the following similarities; i) they were formed terminally, intracalarily or laterally on an undifferentiated non-gametangial hyphae and ii) they were initially thin walled, but later developed smooth to ornamental thick layers (Mehrotra, 1993; Mehrotra and Baijal, 1994; Wu et al., 1995).

Morton and Redecker (2001) studied the two families, Archaeosporaceae and Paraglomaceae with one genus, Archaeospora and Paraglomus respectively, were added to the sub-order Glomineae due to similar morphological and phylogenetical characters between Glomaceae and Acaulosporaceae. However, to clearly differentiate the former two genera from the latter, analysis of their DNA sequences (SSU rRNA) and fatty acid profiles had to be analyzed to determine their phylogenetic relationship with the two families.

Arbuscular mycorrhizas were formerly classified in the phylum Zygomycota under the family Endogonaceae due to their resemblance with Endogone species. But this was later re-evaluated when it was found that AM fungi produced asexual spores rather than
sexual spores like other *Endogone* species. The relationship between AM fungi and other fungi as detected by molecular analysis elevated the group to the phylum Glomeromycota (Koide and Mosse, 2004). This new phylum is divided into four orders, eight families and ten genera (Walker and Schubler, 2004).

Thus, the AMF were placed in their own fungal phylum, the Glomeromycota as weakly supported sister group of Ascomycota and Basidiomycota (the Dikarya). This sister group relationship was also indicated by a six gene phylogeny (James *et al.*, 2006). Recently several taxonomic changes within the Glomeromycota, mainly in the Diversisporales, took place, *e.g.* the erection of two new (phylogenetically unsupported) genera *Entrophospora* and *Kuklospora* (Sieverding and Oehl, 2006).

The phylogenetic affiliation of *Entrophospora* still remains unclear as no reliable sequence data are available. Oehl *et al.* (2008) published a revision of *Gigasporaceae* and split it into three new families and five new genera.

The latter study was based on sequences of the mitochondrial genome from *Rhizophagus irregularis* (formerly named *Glomus intraradices*, Stockinger *et al.*, 2009), showing the Mortierellales – formerly grouped within the Zygomycota – as sister group of regarding the four main lineages in the Glomeromycota it was known that the Paraglomerales
and Archaeosporales are basal lineages within the phylum, whereas the branching order was not yet resolved, and separate from the phylogenetically younger orders Diversisporales and Glomerales.

Recently Morton and Msiska (2010) reported the leaving only Racocetra as a new genus within the Gigasporaceae. A major revision of the Glomerales was recently published by Schubler and Waker (2010). This was so far impossible as the phylogenetic.

2.4. STUDIES ON THE SCREENING AND SELECTION OF EFFICIENT AM FUNGI

The selection of efficient AM fungi should begin with an initial screening of isolates to determine whether they form association with the particular host (Molina and Trappe, 1982).

Mycorrhizal isolates are to be screened in undisturbed soil collected from the field because, disturbance may decrease the colonization capacity of indigenous mycorrhizal populations (Jasper et al., 1991). When the indigenous AM fungi have low or high root colonization capacity, but are ineffective, inoculating with effective mycorrhizal fungi may increase the plant growth (Dodd et al., 1990; Sieverding, 1991).

Best results have been observed by inoculating conifers with AM fungi in Europe (Le Tacon et al., 1991).
Most natural field soils and non-sterile soils contain indigenous mycorrhizal fungi. The introduced mycorrhizal fungi will depend on the “effectiveness” on these indigenous fungi, “their ability to benefit plant growth” (Abbott and Gazey, 1992). The minimize the incompatibility between fungus and the host or between fungus and soil, the inoculant fungi should be selected from the soil in which the inoculated seedlings are to be planted (Sieverding, 1991; Abbott and Gazey, 1992).

2.5. AM FUNGI INOCULATION

The initial selection of inoculant fungi must be conducted under controlled conditions and the characteristics of effective AM fungi can be evaluated in the field, paying particular attention to their ability to infect and persist in soil (Abbott and Robson, 1982).

The four major characteristics of arbuscular mycorrhizal fungi are considered important to their potential as inoculant fungi viz., infect rapidly, extensively form hyphae in soil which is well distributed for enhancing phosphorus uptake, absorb phosphorus from the soil solution and form large number of propagules (Abbott and Robson, 1984).

Dearth of AM inoculum has limited the broad use of AM fungi. This scarcity is due to the inability to culture AM fungi aseptically, which makes use of a host plant essential for multiplication.
of the endophyte. Presently, two types of inoculum are feasible-AM colonized roots and AM infected soil carrying chlamydospores (Miller et al., 1986). It has been found that an inoculum of root segments caused more rapid growth stimulation than spores (Hall, 1976).

The choice of inoculum placement is very important. The inoculum containing 300 to 400 spores per gram is put in a planting hole made by a hoe and the cassava stake is placed vertically on top (Sieverding and Toro, 1986).

Inoculum has been banded just below the seed for inoculation of most of the transplanted field crops (Khan, 1972; Schenck and Tucker, 1974; Menge et al., 1980). Jackson et al. (1972) found that layering the inoculum 5 cm under the seed was superior than placing inoculum around the seed or banding the inoculum along side of the seed.

The importance of sufficient inoculum volume as a factor for an inoculation response with cassava was studied (Howeler et al., 1987). About 10 g of root inoculum was mixed with 100 g sand to increase the spatial distribution of inoculum levels. The cassava yield response was proportional to the amount of inoculum level applied.

Cassava is proved to be a better alternate host for multiplication of AM (Potty, 1985). The tuber skin (normal waste material) which has the infective organs of AM fungi can be used as inoculum
source for introduction in the nursery. For seed propagated crops the lignite slurry (1 part of water with spores of AM: 2 parts of lignite) treatment is found to be useful (Potty, 1990).

The soil inoculum also had the disadvantage transport and bulky and heavy, hence caused problems with transport and commercial distribution (Sieverding, 1991). Therefore it is recommended to produce soil medium at the site conform where it is required. On farm production of soil inoculums for AM fungi has been described by Sreenivasa and Bagyarai (1989) and Sieverding (1991).

Maximum inoculum production is achieved from a vigorously growing plant with high rate of colonization. Hence the substrate used should support good plant growth. Disease on host crop should be controlled uncontaminated spores or other sources of AM fungi inoculum, clean material of a suitable host, dilute fertilizer solution were other requirement of soilless media used for AM fungi production (Jarstfer and Sylvia, 1993).

Mycorrhizal inoculation treatments stimulated significantly the production of shoot biomass to a higher extent than the addition of the amendment alone to soil or higher combined treatment (Caravaca et al., 2004). Gianinazzi and Vosatka (2004) studied the difficulties in the massive production of mycorrhizal inoculation the incorporation of AM technology to crop production systems is more feasible for those requiring a nursery stage.
As many reports have proved that AM fungi inoculation is effective to increase crop yield under sterilized soil (Nidchaporn, 2005). The efficiency of these AM fungi should be tested in the field where native AM fungi coexist. When the native AM fungi are effective enough, soil and fertilizer management would be more effective technology than AM fungi inoculum.

Yagoob Habibzadeh (2015) reported that mycorrhizal fungi produce hyphae absorb nutrient from soil enhancement growth of plants under very low phosphorus conditions.

Cely et al. 2016 revealed that the plant growth, nutrient absorption and yield. The results showed that AMF inoculation increased around 20 % of root colonization in both soybean and cotton; nutrients analyses in vegetal tissues showed increase of P and nitrogen content in inoculated plants, these results reflect in a higher yield.

2.6. STUDIES ON THE EFFECT OF AM ON THE GROWTH AND YIELD OF CROPS

There have been number of reports of increased growth and yield of different crops in pot and field trial by inoculation with efficient arbuscular mycorrhizal fungi. Related literatures are reviewed hereunder.

The inoculation of AM fungi, *Glomus mosseae* significantly increased the yield in groundnut (Daft and El-Giahmi, 1976). The inoculation of AM fungi *Glomus mosseae* increased the grain yield upto 290 per cent in barley (Saif and Khan, 1977). The shoot and root weight increased in finger millet by inoculation of AM fungi *Glomus fasciculatum* in an unsterile soil which is low in available phosphorus (Bagyaraj and Manjunath, 1980). The inoculation of *Gl. fasciculatum* increased the growth of onion (Hirrel and Gerdemann, 1980).
In low fertility soils, colonization of soyabean roots by most of the isolates of *Glomus* significantly increased the plant dry weight and yield (Carling and Brown, 1980). Inoculation of *Gl. mosseae* with lettuce, onion and clover increased the yield in low soil phosphate (Owusu-Bennoah and Wild, 1980). The root and shoot dry weight obtained by mycorrhizal cotton plants supplemented with 75 per cent of \(P_2O_5\) requirement were on par with non-mycorrhizal plants receiving full dose of \(P_2O_5\) (Bagyaraj, 1980). Inoculation of onion cultivars with different isolates of AM fungi significantly increased the growth of onion (Powell *et al.*, 1982).

In pearlmillet inoculation of *Glomus* and *Gigaspora* isolates enhanced the plant growth (Krishna and Dart, 1984). Mycorrhizal inoculated maize and soyabean plants enhanced the plant growth (Thangaraju *et al.*, 1986).

Inoculation of *Glomus fasciculatum* significantly increased the grain yield of wheat (Singh and Subba Rao, 1988). *Glomus* and *Gigaspora* isolates significantly enhanced the root and shoot dry weights of barley plants (Champawat *et al.*, 1987). The inoculation of AM fungi *Gl. fasciculatum* increased the yield upto 7.5 per cent over control in tomato (Mohandas, 1987). Mycorrhizal inoculation significantly increased cassava yield on an average of 20-25 per cent in acid soils
having low P level both under greenhouse and field conditions (Howeler et al., 1987). AM fungi inoculation to Capsicum annum enhanced the plant growth of the plants (Suvercha and Mukerji, 1988).

Furlan and Michele Bernier-Cardou (1989) reported that dry biomass of onion plants inoculated with Gigaspora calospora was found to be 41 per cent higher than that of non AM plants. Cassava plants inoculated with Glomus fasciculatum showed increased tuber yield and plant top weight (Sivaprasad et al., 1989). Increased growth and yield were observed due to arbuscular mycorrhizal inoculation of various levels of phosphorus in Arachis hypogaea (Bell et al., 1989; Rao et al., 1990).


AM inoculated plants exhibited maximum tuber size and maximum number of tubers per plant in cassava, elephant foot yam and taro (Ganesan and Mahadevan, 1994). Tomato plants inoculated with AM fungi increased the fruit yield (Arangarasan, 1994).
Height and leaf number of *Amaranthus viridis* and *Trigonella* sp. at 40 days after sowing were significantly greater when inoculated with *Glomus fasciculatum* than the uninoculated control (Sree Ramulu *et al.*, 1996).

Arbuscular mycorrhizal fungus inoculation significantly increased the root and shoot weight, root volume and the chemical constituents when maize was grown in sterilized low phosphate soil compared with unsterilized high phosphate soil (Sitaramaiah *et al.*, 1997). The percentage of arbuscular mycorrhizal infection and growth were increased in bamboo seedlings (Ravikumar *et al.*, 1997), in *Terminalia arjuna* L. (Prasad and Prasad., 1997) and in trifoliate orange (Yamashita *et al.*, 1998).

Arbuscular mycorrhizal association has been correlated with improvement in growth, biomass accumulation and nutrient absorption by plants, grown on nutrient deficient soil (Read, 1998).

The plants grown in unsterilized soil in association with phosphorus had significantly increased plant growth, dry matter production, yield attributes, nutrient uptake, root colonization and spore density than the non-mycorrhizal plants, however these parameters were comparatively less than the mycorrhizal plants grown in sterilized soil (Hazarika *et al.*, 1999).
In both P application and AM inoculation of P deficient soil, increased the grain yield, weight and grain lipid content under normal as well as under soil moisture stress (Gill and Singh, 1999).

In wheat and chickpea crops, AM inoculation increased the root biomass (Mukherjee et al., 2000). AM inoculated plants exhibited high flower yield in African marigold (Rajadurai and Beaulah. 2000). Mycorrhizal inoculated wheat cultivars growth and yield upto 42 per cent more than uninoculated wheat (Zhu et al., 2001).

Karaki (2002) studied the field response of garlic inoculated with arbuscular mycorrhizal fungi and reported that there was a significant increase in yield and mean bulb weight than uninoculated plants regardless of P level. Bhattachariya and Bagyaraj (2002) reported that growth and nutritional status was enhanced by AM fungi inhabiting the roots of coffee seedlings.

Kumutha et al. (2003) studied the interaction effect of AM fungi and the plant growth promoting rhizobacteria Pseudomonas on mulberry. There was a significant increase in leaf dry matter, and leaf area in inoculated treatments, however inoculation effect is more pronounced in dual inoculated treatments, than individual inoculated ones.

In both nitrogen and sulphur application with AM inoculated spring onion exhibited high yield and pungency (Guo *et al.*, 2006b). Growth improvements of *Lotus glaber* plants by *Glomus intraradices* were more visible than non-AM plants under salt stress (Analia *et al.*, 2007). AM fungi inoculated sunflower can improve the plant growth and root disease resistance than control plants (Jalaluddin *et al.*, 2008).

AM fungi inoculation significantly increased the number of sympoidal branches, number of bolls, boll weight and quality of cotton compared than uninoculated plants (Ramakrishnan and Thamizhiniyan, 2009).

The plant height and sympoidal branches obtained by mycorrhizal cotton plants supplemented with 50 per cent of NPK requirement were on par with non-mycorrhizal plants receiving full dose of NPK (Sridevi and Ramakrishnan, 2010a). Sangeeta Paul *et al.* (2011) reported that growth and yield of cotton plants uninoculated with AM fungi and *Azotobacter* was found to be 48 per cent higher than that of uninoculated plants.
Conversa et al. (2012) find that field conditions, tomato plants inoculated with Glomus intraradices were found to produce larger inflorescences, higher number of flowers and higher fruits.

Cekic et al. (2012) reported that AM fungi positively affected the growth of pepper plants, improved shoot and root dry weight and leaf area compared with non-mycorrhizal plants. The positive impact of AMF inoculation was also reported by study of Hassan and Abakeer (2013) on Vicia faba.

The work of Sultana and Miao (2014) revealed that AMF stimulates the growth of the legume, Trofolium incarnatum. AM fungi proved to increase significantly the number of leaves, root and shoot length, total biomass fresh and dry weight and mycorrhizal dependency and mycorrhizal inoculation effect on Piper longum (Seema and Rajkumar, 2015).

2.7. AM AND BIOCHEMICAL ACTIVITIES

The interface between the arbuscular membrane and the plant cell has very high enzymatic activity (Jeanmaire et al., 1988). Most extra activities (synthesis, metabolic processes) occur at the interface between the fungus and the plant cell (Gianinazzi, 1991) and specific proteins (endomycorrhizins) are produced during cellular interactions in AM (Wyss et al., 1990).
It is generally accepted that any interaction between cells involves the exchange of chemical signals (Halverson and Stacey, 1986). Since the different signals (chemicals) involved have to be synthesized, the relevant metabolic processes should be stimulated after establishing contact between host and fungus.

Higher content of amino acids (arginine, phenylalanine, serine) and isoflavonoid, reduced sugars and enzymes are found in mycorrhizal plants (Graham, 1983).

Thamizhiniyan et al. (2009) mentioned that higher contents biochemical, protein, starch and amino acids contents were observed. In AM fungi + Azospirillum applied plants when compared with control plants.

Lenin et al. (2010) observed that effects of Arbuscular mycorrhizal fungi (Am) on the morphological and biochemical changes of four different vegetables viz., Tomato (Lycopersicum essulentum L.), Brinjal (Solanum melogena L.), Chilli (Capsicum annum L.) and Bhendi (Abelmoschus schuss moench) grown under nursery conditions. The maximum increase in the plants morphological parameters and biochemical parameters like chlorophyll, protein and content of nitrogen, phosphorus, and potassium were observed in AM fungi treated seedlings when compared to non-mycorrhizal seedlings (control).
2.7.1. Studies on the effect of AM on chlorophyll content and photosynthetic rate

Mycorrhizal plants translocate higher amount of photosynthates from shoot to root than non-mycorrhizal plants without altering the leaf area and the AM fungi derive their carbon requirement from the host plants (Harold, 1980).

Arbuscular mycorrhizae have shown the increased stomatal conductance and photosynthesis after water stress of rough lemon (Levy and Krikun, 1980). Photosynthetic rates, under saturating light conditions increased 68 per cent with infection by the fungus *Glomus fasciculatum* in *Bouteloua gracilis* as a consequence of a 33 per cent reduction in stomatal resistance and 67 per cent reduction in mesophyll cell resistance to CO$_2$ uptake (Allen *et al.*, 1981).

Krishna *et al.* (1981) observed that bundle sheath chloroplasts were larger and more numerous, and that the veins and mesophyll cells of mycorrhizal finger millet were larger than those of non-mycorrhizal plants.

Mycorrhizal infection by *Glomus fasciculatum* increased chlorophyll and phosphate concentrations by 28 per cent and 70 per cent respectively in rangeland grass *Bouteloua gracilis* (Allen *et al.*, 1981).

AM fungus, the microsymbiont of the system, solely depends upon the host photosynthate to meet its carbon requirement. Hence, the effectiveness of the symbiosis is very much linked with the photosynthetic efficiency of the host plant (Sivaprasad and Rai, 1984).
Photosynthetic uptake of sweet potato inoculated with *Gigaspora gilmorai* was higher from third week onwards and it was 33.3 per cent increase over control (Potty, 1988).

Inoculation of black gram in an unsterile soil with *Glomus epigaeum* increased the chlorophyll content and N, P and K content (Umadevi and Sitaramaiah, 1990).

Total chlorophyll, chlorophyll-a and chlorophyll-b were maximum in AM inoculated cassava plants both under pot and field conditions (Ganesan and Mahadevan, 1994).

The Photosynthetic pigments of total chlorophyll, chlorophyll ‘a’ and chlorophyll ‘b’, were maximum in AM inoculated cassava plants both under pot and field conditions (Ganesan and Mahadevan, 1994).

Therefore, carotenoids can directly deactivate, and can also quench the excited triple state of chlorophyll (Foyer and Harbinson, 1994). Moreover, it has been mentioned that the higher chlorophyll content in AM than in non-AM plants has sometimes been associated with a higher rate of photosynthesis, or with the increase in nitrogen and magnesium contents (major components of chlorophyll molecules) of mycorrhizal plants (Mathur and Vyas, 1995).
Abdel et al. (2002) reported that VAM had significantly higher chlorophyll content at both the stages of crop growth. The increase in total chlorophyll concentration of drought plants in response to mycorrhizal effects was positively correlated with respective levels of mycorrhizal infection in broad bean plants.

The chlorophyll is the essential component for photosynthesis and it increases with mycorrhizal colonization (Colla et al., 2008). Thus AM symbiosis enhanced the chlorophyll content of Solanum leaves which was in agreement with the results of other studies (Elahi et al., 2010).

Azize et al. (2011) reported that the mycorrhiza helps solanum plants to perform better in low and high phosphate level by enhancing antioxidant enzyme activity, acid and alkaline phosphatase activity and total chlorophyll content.

2.7.2. Studies on the effect of AM on carotenoids

Moon and Itri (1984) showed that some types of cancer have been linked with the lack of certain oxygenated carotenoids (Caroten and Xanthophylls) in the diet. Which are thus considering being anticancer compounds.

Gross and Ohad (1987) find that during the ripening of fruits, there is an increase in the xanthophylls pigments. Mature fruits contain esterifies xanthophylls (Goodwin, 1987). The ester fixation process progressively during maturation.
2.7.3. Studies on the effect of AM on Anthocyanin

Anthocyanin occurrence may have been as a result of phytoalexin accumulation. However, there was no study reported or noted that any VAM fungi such as *G. intraradices* have caused anthocyanin occurrence in pepper. But, it was reported that some fungal pathogens had enhanced anthocyanin production in callus cultures of *Daucus carota* (Rajendran *et al.*, 1994), and in addition to stress conditions had induced anthocyanin accumulation (Atanassova *et al.*, 2001).

Higher anthocyanin concentration following AM colonization might depend on the activation of a defence response in the plant. Indeed, pathogens and insects increase the concentration of anthocyanins and antioxidants in strawberry fruits as defense mechanisms in fruits (Hargreaves *et al.*, 2008).

Mycorrhizal symbiosis enhanced the concentrations of anthocyanins in the inner leaves of the three cultivars of lettuce and also in the outer leaves. Anthocyanins are the most important group of water-soluble pigments in plants, and they are regarded as important components in human nutrition due to their antioxidant capacities.

In addition, they have exhibited ant carcinogenic effects in several cell culture systems including cancer cells of the colon, endothelial, liver, and leukemic You and Wang *et al.* (2011). Because
outer leaves of head lettuce are usually stripped off during harvest, the relevant increases of anthocyanins in the internal leaves of mycorrhizal lettuce plants can be especially interesting for the human diet.

2.7.4. Studies on the effect of AM on ascorbic acid

Kayanas Surmeli (1994) and showed that tomato, ascorbic acid concentration increased until the red stage, and then in the later stages of ripening, the content decreased. The total ascorbic acid content Jalapenobell, long green, red chilli during ripening gradually decreased (Howard et al., 1994).

The concentrations of total ascorbate (vitamin C) in nonmycorrhizal plants were very similar to those measured by Konstantopoulos et al. (2010) in greenhouse lettuce (cv. Parris Island) at harvest. Although the total content of ascorbate in plants increased after the inoculation of the three cultivars of lettuce with AMF, on a wet basis the concentrations of ascorbate were very similar between non mycorrhizal and mycorrhizal plants as a consequence of the dilution effect due to the greater size of lettuce associated with AMF.

The only exception was the enhancement of the concentration of total ascorbate in the inner leaves of CT after inoculation with *G. fasciculatum*. Recently, Geneva et al. (2010) found that favorable effect of mycorrhizal infection with *G. intraradices* for increasing the ascorbate content in leaves of *Solanum officinalis*. 
Although the total content of ascorbate in plants increased after the inoculation of the three cultivars of lettuce with AMF, on a wet basis the concentrations of ascorbate were very similar between non mycorrhizal and mycorrhizal plants as a consequence of the dilution effect due to the greater size of lettuce associated with AMF.

### 2.7.5. Studies on the effect of AM on protein

Protein content was much higher in mycorrhizal than in non-mycorrhizal root extracts, in agreement with Dumas et al. (1989) for tobacco and onion. A 2.6-fold higher protein content was found in mycorrhizal than in non-mycorrhizal red clover roots. Other reports have not shown such a large difference in both types of roots as have been described so far, and further deep studies on this aspect are needed. Perhaps this difference is a consequence of factors such as higher metabolic activity in AM-colonized root cells and the presence of internal and external fungal mycelium. It is difficult to speculate further because our actual knowledge of AM fungal proteins is very limited, and we don't know if the new proteins are of fungal or plant origin. Five polypeptides with 16, 17, 18, 22 and 30 KDA were found only in AM roots, and were considered to be endomycorrhizae (Pacovsky, 1989).

Wyss et al. (1990) have also found some polypeptides in both the low and high molecular weight ranges, which were immuno precipitated with an antiserum against soluble membrane. Some polypeptides, at both low and high molecular weight, were more
abundant in P2, P6 and P8 or were exclusive to P4, PS and P7 mycorrhizal roots. Others were less abundant (P1 and P3) in mycorrhizal than in nonmycorrhizal roots.

After mycorrhizal infection, changes in polypeptide accumulation fall into three categories: decreasing, increasing and synthesis of new proteins (Martin and Hilbert, 1991). We do not know the role of the polypeptides in the symbiosis. But after IEF analysis and staining for activity of SOD, a SOD isozyme appeared only in mycorrhizal root extracts.

Sharma and Kothari (1992) indicated that increase in protein content of AM colonized plants increases the synthesis of chlorophyll and growth rate. In drought conditions the protein concentrations of AM plants has been found to be higher than non-mycorrhizal plants (Subramanian and Charest, 1998).

2.8. AM ENZYMES

2.8.1. Phosphatase

The activity of some mycorrhizal fungi in culture to utilize some phytates (Theodorou, 1968) and presence of an active p-nitrophenyl phosphatase in Fagus sylvatica mycorrhizas (Woolhouse, 1969) has already been demonstrated. The capacity of AM plants to utilize complex inorganic phosphate was first demonstrated by Daft and Nicolson (1969).
The presence of AM specific alkaline phosphatase activity in *Allium cepa* and *Plantanus occidentalis* plants inoculated with *Glomus mosseae* has been reported by Gianinazzi-Pearson and Gianinazzi (1976). Qualitative changes of root soluble phosphatase activity were observed during AM infection.

Mac Donald and Lewis (1978) cytochemically demonstrated the presence of acid phosphatase in *Glomus mosseae*. Acid phosphatase was found in lysing and growing AM fungal structures.

Gianinazzi-Pearson and Gianinazzi (1978) demonstrated the presence of soluble phosphatase specific to AM fungal infection in enzyme extracts from onion roots inoculated with *Glomus mosseae*. Maximum activity occurred when the infection was still in an early stage (100% arbuscular). Gianinazzi-Pearson and Gianinazzi (1983) found the increased alkaline phosphatase activity in *Glomus mosseae* and *Glomus* species inoculated soybean (*Glycine max*) roots of non-phosphate fertilized plants than in 50 days old phosphate fertilized plants.

Smith and Gianinazzi-Pearson (1987) found higher alkaline phosphatase activity of *Glomus mosseae* than the infected roots of *Allium cepa*. Dodd *et al.* (1987) compared the effect of individual inoculation of *Gl. geosporum*, *Gl. monosporum* and *Gl. mosseae* on acid phosphatase activity in roots of *Brassica napus*, *Triticum aestivum* and
Allium cepa. They found higher acid phosphatase activity in plants infected with Gl. geosporum and Gl. mosseae than in Gl. monosporum inoculated plants. Anita et al. (1988) found high acid phosphatase activity in Gl. fasciculatum inoculated roots of Trigonella species Tisserant et al. (1993) showed by histochemical tests the presence of alkaline phosphatase in Glomus species infected roots of Allium porrum and Platanus acerifolia.

2.8.2. Nitrate reductase

The greater part of the nitrogen incorporated in to plants is taken up as nitrate from the soil. It has not been demonstrated as yet whether the mycorrhizal fungi themselves reduce nitrate to nitrite and ammonia, and synthesize an amino acid, which is then transferred to the host by active transport. Proteins and or amino acids could be made available for the plant with each degradation of an arbuscule within the root. An alternative is that nitrate could be directly transferred to the plants, which then reduce it and supply the symbiotic fungus. The key enzyme for nitrate assimilation is nitrate reductase. Sequence comparison and or DNA-DNA hybridizations indicated that the PCR amplificates did indeed come from the organisms from which DNA had been isolated. A DNA hybridization experiment with the digoxigenine labelled PCR-segment and DNA isolated from about
0-5 million *Glomus* spores confirmed that this mycorrhizal fungus possesses a nitrate reductase gene (Kaldorf *et al.*, 1994). The data indicated that the parasitic fungi tested might possess the enzyme.

Nitrate reductase activity of AM inoculated plants was distinctly higher than control plants (Selvaraj and Subramanian, 1995).

### 2.9. STUDIES ON AM IN RELATION TO NITROGEN

In contrast, Baylis as early as 1967 reported that the mycorrhizal infection frequently resulted in lower concentration of nitrogen in host plants.

Controversial reports are available regarding the correlation among association of AM fungi and nitrogen uptake by the host plants. Ross and Harper (1970) recorded high concentration of nitrogen in foliages of mycorrhizal soybean plants than that of non-mycorrhizal plants. Possingham and Groot-Obbnik (1971) in grape vine; Ross (1971) and Smith and Bowen (1979) in legumes and Menge *et al.* (1980) in avacado recorded an increased nitrogen uptake following AM association.

Chamers and Smith (1980) reported that both NH$_4^+$ and NO$_3^-$ depressed root colonization by arbuscular mycorrhizal fungi, but they did not consider the phosphorus status of the plant. They suggested that the suppressive effect of NH$_4^+$ was due to a drop in rhizosphere pH. It appears that high concentration of nitrogen fertilizers can reduce the AM infection (Johnson *et al.*, 1980).
Furlan and Michele Bernier-Cardou (1989) reported in onion that nitrogen fertilization stimulates root colonization by the AM fungus by 9 per cent.

Vaast and Zasoski (1992) studied the effect of AM fungi and nitrogen sources on rhizosphere soil characteristics and nutrient acquisition of coffee seedlings. Rhizosphere pH from mycorrhizal seedlings was significantly higher in all N treatments. Enhanced growth and N uptake of mycorrhizal seedlings treated with NO$_3$-N and NH$_4$ NO$_3$-N were associated with increase in rhizosphere pH.

Transport of N by arbuscular mycorrhizal hyphae has been demonstrated using $^{15}$N as a tracer. Hamel and Smith (1992) reported on the effect of mycorrhizal inoculation on $^{15}$N transfer from soybean to corn and on plant growth in intercropping systems as compared to monocultures. Soybean to mycorrhizal-mediated N transfer did occur, resulting in high $^{15}$N enrichment of corn plants.

Johansen et al. (1993) reported that the subterranean clover grown alone or in symbiosis with Glomus intraradices shows that leaflets of non-mycorrhizal controls contained only traces of $^{32}$P but considerable amounts of $^{15}$N, and mycorrhizal plants increased the concentration of $^{15}$N labelled in leaflets.
Heijne et al. (1994) studied the effect of atmospheric ammonia and ammonium sulphate on AM colonization in three heathland species. AM colonization increased in all the tree species when treated with gaseous ammonia but was not affected by exposure to an ammonium sulphate. Mycorrhizal plants had higher total amounts of N and P than nonmycorrhizal plants.

Johansen et al. (1994) confirmed the ability of arbuscular mycorrhizal hyphae to transport N towards host plant roots over distances of several cm. External hyphae transported less nitrogen when associated with plants of high N status than when plants were N deficient indicating that the fungus was able to regulate the hyphal uptake of soil mineral nitrogen.

In wheat, inoculation with Glomus species increased the N uptake by 98.3 per cent over the uninoculated plants (Mikhaeel et al., 1997). The increased nitrogen uptake was recorded in soybean inoculated with AM fungi and Brady rhizobium (Heggo et al., 1998).

The nitrogen metabolism and nitrogen uptake by the AM fungi in crop plants studied by many workers (Toussaint et al., 2004; Cruz et al., 2004).
Tu et al. (2006) found that low-level mineral N inputs may significantly enhance nutrient cycling and plant resource capture in terrestrial ecosystem via stimulation of root growth and mycorrhizal function. Mycorrhizal fungi can also improve absorption of N from NH$_4^+$ -N mineral fertilizers, transporting it to the host plant.

Basela and Mahadeen (2008) find that promotion effect of inorganic fertilizers on chlorophyll contents might be attributed to the fact that nitrogen is a constituent of chlorophyll molecule. Moreover, nitrogen is the main constituent of all amino acids in proteins and lipids that act as structural compounds of the chloroplast. It had been observed that nitrogen fertilizer is an essential component of any system in which the aim is to maintain good yield (Law and Egharevba, 2009). The productivity of pepper is highly responsive to N fertilizer.

Nitrogen is the mineral element that plants require in a great amount. It serves as an important part of many plant cell components, including amino acids and nucleic acids. N deficiency in a plant tissue rapidly inhibits plant growth, and induces chlorosis in leaves. Salinity adversely influences N acquisition and utilization by affecting different stages of N metabolism, such as NO$_3^-$ uptake and reduction and protein synthesis (Evelin et al. 2009).
Application of AM fungi can result in a more efficient assimilation of N in the host plants, due to the following: (a) nitrate assimilation in the extra radical mycelia through the activity of nitrate reductase located in the arbucular containing cells leading to the formation of arginine, which catabolizes and produces other substances of ammonia; (b) increased production of enzymes controlling the primary nitrogen fixation in the extra-radical mycelia, whereas enzymes controlling arginine catabolism are upregulated in the intra-radical mycelia; (c) decreasing the toxic effects of Na ions by deducing its uptake and this may indirectly help in maintaining the chlorophyll content of the plant (Kapoor et al., 2013).

2.10. STUDIES ON AM IN RELATION TO PHOSPHORUS

For many plants mycorrhizal associations are one way guaranteeing adequate phosphorus absorption from the soil reserves. However, phosphorus is usually considered to be the major problem when AM infection is poor in marginal lands.

Arbuscular mycorrhizae are widespread in natural soil and their infection in plants is the primary cause in improving phosphate uptake leading to improved growth in phosphorus deficient soils (Sanders and Tinker, 1973).
Mycorrhizas markedly increased the growth and phosphorus content of tops at intermediate rates of phosphorus in subterranean clover (Pairunan et al, 1980).

Increasing phosphorus supply decreased the percentage of root length converted to mycorrhizas in subterranean clover (Same et al, 1983). Babu et al. (1988) calculated the economics of AM inoculation in chilli. They concluded that 50 to 75 per cent of P can be dispensed with by inoculating with mycorrhizal fungi and hence can save fertilizers.

Furlan and Michele Bernier-Cardou (1989) reported in onion that P fertilization increased tissue P content of AM plants by 114 per cent when no K⁺ is added compared to 78 per cent when plants are fertilized with K⁺. Rajapakse et al. (1989) reported that root colonization percentage in cowpea plants inoculated with Glomus fasciculatum was negatively correlated with P content of growth medium and shoot P concentration.

Sorghum plants inoculated with Glomus fasciculatum is a low P (3.6 mg kg⁻¹) soil recorded decreased root colonization and shoot growth enhancements with increased soil P applications (Raju et al, 1990). Champawat (1990) reported that the dry matter of shoot and root of groundnut inoculated with Glomus fasciculatum alone were higher
than those of shoot and root of inoculated plants in association with P fertilizer. P fertilization with AM fungi reduced the intensity of mycorrhizal infection as well as the number of extramatrical chlamydospores in the soil.

In contrast, Koide and Mingguang Li (1990) conducted experiments in sunflower and indicated that infection is regulated by the status of the root which results from local availability of soil nutrients and not by shoot N and P status. They suggested that when infection cannot function to benefit the host plant (such as by increasing phosphate uptake under phosphate-limiting conditions), the host plant will limit the extent of infection.

Blal et al. (1990) reported that AM inoculation increased fertilizer utilization coefficient of micropropagated oil palm plants 2.7 to 5.6 fold. Potty (1990) reported that mycorrhizal cassava plants showed higher phosphorus uptake at low P levels.

Phosphorus content in shoot and root were significantly more in AM inoculated chickpea than uninoculated plants, and it was highest in *Glomus fasciculatum* followed by *Glomus constrictum* and *Gigaspora calospora* (Champawat, 1992). Pearson and Jakobsen (1993) reported that the roots colonized by AM fungus in cucumber plants had higher rates of root-P uptake compared with control roots,
suggesting that the root-P uptake compared with control roots, suggesting that the root-P uptake systems has been stimulated by the presence of the fungus.

The phosphorus tissue concentration was higher in plants infected with AM, but tended to be lower in the presence of ammonia or ammonium sulphate (Heijne et al., 1994). AM fungi can transport significant amounts of P released from organic matter to their host plants (Joner and Jakobsen, 1994).

The uptake of phosphorus in cassava cultivar Rose local increased with arbuscular mycorrhizal inoculation in four different soil types of coastal Tamilnadu (Sivasaravanan and Sundaram, 1995). The phosphorus uptake of mycorrhizal clover plants decreased as the bulk density of the soil increased from 1.0 to 1.6 mg per m$^3$ (Nadian et al., 1996). Inoculation with arbuscular mycorrhizal fungi *viz.*, *Glomus clarum, Gl. etunicatum, Gl. manitrotis* and *Gigaspora margarita* significantly increased the concentration of P in *Phaseolus vulgaris* L. by 160-335 per cent (Ibibiliben et al., 1996)

In wheat, inoculation with AM fungus, *Glomus* species increased the P uptake by 154.5 per cent over the uninoculated plants (Mikhaeel et al., 1997). Infection of plant roots by arbuscular mycorrhizal fungi improved the soil P-utilization due to the development of dense network of hyphae in the soil (Keltijens, 1999). *Glomus fasciculatum*
inoculated in cassava at 75 kg $P_2O_5$ per hectare significantly increased the phosphorus content of the plant over the uninoculated plants (Tholkappian et al., 2000). Phosphorus content and root biomass were significantly more in AM inoculated wheat and chickpea than uninoculated plants (Mukherjee et al., 2000).

Rajasekaran and Nagarajan (2005) reported that vesicular arbuscular mycorrhizal inoculation in combination with phosphorus increased dry and fresh shoot weight, leaf area and leaf number of *Vigna unguiculata* (L.).

Bucher (2006) reported that mycorrhizae can increase the absorption of P since AMF are specialists in uptake and transport of this element to the plant cells by specialized fungal structure called arbusculaes.

Subramanian et al. (2006) reported that higher efficiency of mycorrhizal plants in taking up soil phosphate, and thus improving plant nutritional status, was suggested to be one reason for the positive impact of AMF mycorrhization on tomato plant productivity. It was also hypothesised that enhanced fruit setup and yield could also be related to an increase in pollen quantity and quality in mycorrhizal plants.

Improved P nutrition in AM inoculated plants may improve their growth rate, increase antioxidant production, and enhance nodulation and nitrogen fixation in legumes (Garg and Manchanda 2008).
Nell *et al.* (2009) found the phosphorus, in plants, has multifunctional roles as a constituent of nucleic acids or biomembranes. Furthermore, it is highly involved in the energy metabolism of cells and is therefore required for the biosynthesis of primary and secondary metabolites.

Selvaraj *et al.* (2009) reported that phosphorus concentration was positively correlated with all growth parameters and content of phytochemical constituents (except essential oil) and that *G. aggregatum* seemed to be the best AM fungi symbiosis the patchouli plant.

Rakshit and Bhadoria (2009) reported that highest phosphorus uptake occurs in mycorrhizal maize plants with added low Phosphorus than non–mycorrhizal as well as plants without added Phosphorus. Mycorrhizal inoculation consistently accumulated more quantities of phosphorus in their root than shoots.

Evelin *et al.* (2012) reported that under salinity stress, the uptake and concentration of Phosphorus in plant tissues decreases resulting in reduced and stunted growth, dark green coloration of the leaves, production of slender stems, and senescence of older leaves.

Tanwar *et al.* (2012) observed the increase in the activities of the acid and alkaline phosphates enzymes produced by the plant roots itself, extraradical hyphae of AM fungi as well as by *Pseudomonas fluorescens* that play an important role in the cycling of phosphorus from P deficient soils and helps in the phosphorus nutrition of plants.
2.11. STUDIES ON AM IN RELATION TO POTASSIUM

High levels of potassium slightly reduced the root colonization in woody ornamentals inoculated with mycorrhizae (Johnson et al., 1980). Krishna and Bagyaraj (1982) studied that AM association has neither increased nor decreased the potassium uptake in *Arachis hypogaea*. On the other hand, Howeler (1982) observed potassium fertilization favours the incidence of vesicles on cassava.

Potassium has no effect on either root colonization or spore production in *Bromus inermis* inoculated with *Glomus fasciculatum* (Bildusas et al., 1986). With pasture legumes too, but not with grasses, a positive effect on AM infection of increasing K levels (0, 10, 20, 40 kg K/ha as KCl) was reported in *Carimagna oxisols* (Saif, 1986).

Onion plants inoculated with *Gigaspora calospora* and fertilized with K\(^+\) increased the dry yield by 38 per cent and produced more number of spores (Furlan and Michele Bernier-Cardou, 1989).

Bethlenfalvay and Franson (1989) reported that remarkable differences in growth response of soybean to AM inoculation with different geographic isolates of *Glomus mosseae* seemed to be more related to improved K\(^+\) rather than P nutrition of the host plant.

AM increased total uptake of nitrogen, potassium and magnesium in French marigold (Balasubramanian, 1989) and in green gram (Shanthi and Kothandaraman, 1990).
Raju et al. (1990) reported that AM association has increased the level of potassium uptake in sorghum. The potassium content in shoots of sorghum inoculated with *Glomus fasciculatum* and *Glomus macrocarpum* was 10.8 and 156.0 mg plant$^{-1}$ respectively when compared to nonmycorhizal plant (3.6 mg plant$^{-1}$) at 25°C.

Inoculation with *Glomus fasciculatum* increased the plant growth, dry weight, nitrogen, phosphorus and potassium content in *Sesamum* (Manoharachary and Prakash, 1991).

George et al. (1992) demonstrated the capacity of external hyphae for uptake and transport of K$^+$ in compartmented pots. About 10 per cent of the total K$^+$ uptake in mycorrhizal coach grass *Agropyron repens* is attributable to hyphal uptake and transport.

Potassium uptake was significantly increased in shoots of coffee seedlings by AM, only with NH$_4^+$ – N addition than with NH$_4^+$ NO$_3^-$ – N or NO$_3^-$ – N (Vaast and Zasoski, 1992).

The inoculation of AM increased N, P and K uptake in Tomato (Arangarasan, 1994). Maximum K uptake was observed when the plants received K fertilizer in combination with N or P. Sorghum plants, colonized with *Glomus etunicatum* had higher shoot and root K concentration than plants colonized with *Glomus intraradices* (Mederios et al., 1995).
The K content of Cassava record at 100kg P$_2$O$_5$ per hectare with the inoculation of AM fungi (G. fasciculatum) was similar to that for 75 kg P$_2$O$_5$ Per hectare with inoculation of AM fungi (Tholkappian et al., 2000). Stella (2001) find that the soybean crop inoculated with AM fungi and Bradyrhizobium had shown highest K uptake. Perkins et al. (2003) described fruit red colour and ripening disorders are correlated with fruit K content.

2.12. STUDIES ON THE EFFECT OF AM ON MICRONUTRIENTS UPTAKE

Literatures revealed the positive correlation between uptake of micronutrients and the colonization of arbuscular mycorrhizal fungi. Micronutrients viz., zinc, copper, sulphur, boron and molybdenum are proven to be actively taken up by arbuscular mycorrhizal fungal hyphae and transported to the host plant. Other essential plant micronutrients such as iron, manganese and chlorine are also generally found in higher concentrations in arbuscular mycorrhizal plants than the nonmycorrhizal plants (Buwalda et al., 1983).

Arbuscular mycorrhizal inoculation increased Zn and Cu uptake in different crop species viz., cotton, cowpea and finger millet (Bagyaraj and Manjunath, 1980), in sorghum (Raju et al., 1990), in corn (Faber et al., 1990), in wheat (Thompson, 1990) and greengram (Sharma and Srivastava, 1991).
In calcareous soil, the *Glomus mosseae* hyphal contribution to the total uptake ranged from 16 to 25 per cent for Zn in maize (Kothari *et al.*, 1991) and 52 to 62 per cent for Zn in white clover (Li *et al.*, 1991).

The micronutrients, Fe, Mg and Mn have shown significance in both roots and leaves of arbuscular mycorrhizal fungi inoculated corn (Iwan Ho, 1993). Zn uptake has been increased by arbuscular mycorrhizal colonization in subterranean clover (Burkert and Robson, 1994).

Sorghum plants inoculated with *Glomus intraradices* had higher concentrations of shoot Ca, Zn and Cu and higher concentration of root Mg, Zn and Cu than plants inoculated with *G. etunicatum* (Medeiros *et al.*, 1995).

The contribution of arbuscular mycorrhizal fungus *Glomus mosseae* to plant uptake of minerals accounted for up to 37 per cent of the total Cd, 33 per cent of the total Cu and 44 per cent of the total Zn uptake in *Phaseolus vulgaris* (Guo *et al.*, 1996).

Inoculation of arbuscular mycorrhizal fungi influenced the mineral content of Mn and B to a lesser extent of Zn and Cu in grapevine (Biricolti *et al.*, 1997).