Chapter 2

REVIEW OF LITERATURE
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Root systems of most living plants have developed an endophytic symbiotic association designated as Vesicular Arbuscular Mycorrhizae (VAM). Nonseptate, zygomycetous fungi belonging to genera, Glomus, Gigaspora, Acaulospora, Sclerocystis, Scutellospora and Enterophosphora of the family Endogonaceae, form VAM association. VAM fungi are ubiquitous in nature and they colonise the roots of nearly all plants (Barea, 1991; Bolan, 1991). The relevance of mycorrhizal endophytes has been described as that of a fundamental link between plant and soil (Miller and Jastrow, 1994). VAM fungi are mainly distributed in the upper layers of soil and their highest density is encountered in the rhizosphere of plants (Schwab and Reeves, 1981; Bellgard, 1993). The importance of VAM fungi has been intensively investigated over the past four decades. It has been established that VAM fungi improve plant growth in terms of better nutrient uptake (Mosse, 1973a; Powell, 1982; Jeffries, 1987; Kumar et al., 2002), water potential (Sanchez-Dias and Hornrubia, 1994) and lesser chances of root diseases (Jalali and Thareja, 1981; Newsham et al., 1995). The symbiotic association increased the uptake of relatively immobile nutrients such as P, Cu, and Zn (Faber et al., 1990; Kothari et al., 1991). Mycorrhizae also enhanced the uptake of available nitrogen (Hamel et al., 1991; Tober et al., 1994) and in contrast often reduced Mn uptake (Kothari et al., 1991; Posta et al., 1994).
The symbiosis between VAM fungi and plant roots play a key role in plant ecology and productivity (Abbott and Robson, 1984). Ecological importance of VAM fungi had been studied in temperate regions but very little information is available on the tropical.

*Hevea brasiliensis* is a perennial tree crop grown extensively in the western side of the Western Ghats of India. *Hevea* was introduced into India a century ago and assumed an important position in the agricultural scenario of Kerala and plays a major role in the socio-economic condition of the state. Deforestation and planting of *Hevea* has lead to a change in the ecology of VAM fungi considerably. Nair and Girija (1988) recorded highest VAM infection in rubber compared to other tree crops of economic importance. Leguminous cover crops grown in the interspaces of *Hevea* are also found to be mycorrhizal (Joseph et al., 1988).

The factors, which influence the survival, infectivity, spread, and persistence of VAM inoculum in nature were only partially understood (Bagyaraj, 1991). If one moves closer to using mycorrhizal fungi to increase agricultural plant yield, a more thorough understanding of these factors will be essential. In this chapter effect of various factors, which influence the colonisation and spore population of VAM fungi are reviewed.
2.1. **Effect of location on VAM distribution**

The physico-chemical characters of soils vary considerably with respect to the geographical location. VAM occurs in plants in arctic, temperate and tropical regions including dense forests, open woodlands, scrub, savanna, grasslands, heaths, sand dunes and semideserts. VAM occurrence within these systems varies according to localised environmental conditions and plant cover (Hayman, 1982a). There are a number of reports of VAM endophyte from India (Godse et al., 1978; Bagyaraj et al., 1979; Kehri et al., 1987; Kaushal, 2000). However, very few attempts have been made to undertake regional surveys of mycorrhizal association with tree crops, soil and agroclimatic conditions in Kerala. Joseph (1997) studied the distribution of VAM fungi in rubber plantation soils from 16 localities spread over from Nagercoil in the south and Mangalore in the north on western side of Western Ghats and observed a wide variation of VAM population in these soils. Harikumar and Potty (1999) reported variation in the distribution of VAM species in southern and northern regions of Kerala. According to them the spore density, species richness and diversity index differed in these regions with a general increase in southern Kerala. Mohanan and Sebastian (1999) made a survey on the mycorrhizal status of bamboos in Kerala and could not observed any correlation with their ecological range of distribution.
2.2. Effect of season on VAM colonisation and spore population

Root colonisation, growth and sporulation of VAM depend on many environmental factors (Daniels, 1984). It was thought that spore production increased after periods of extensive root growth or as the host matured or senescenced (Mason, 1964; Mosse and Bowen, 1968). Many surveys had documented seasonal variations within VAM fungal populations (Daniels and Bloom, 1983). Hayman (1970) observed higher VAM spore numbers and root infection during summer in wheat under irrigated conditions. Sutton and Barron (1972) reported an increased VAM spore density in April in strawberry and maize field soils. Sparling and Tinker (1975) found that the root weight and per cent colonisation were high in summer. In California soils, chlamydomes were most abundant from November to May and least from June to September (Menge et al., 1981). According to Rolden et al. (1982) the extent of VAM infection and the number of endogonaceous spores in the rhizosphere of almond trees were low in winter, while Jakobsen and Nielsen (1983) reported that mycorrhizal infection levels in winter wheat, rye and barley were low in spring season. Michael (1983) reported that in Atriplex gardneri arbuscules were observed in April but were not found in June and the total VAM colonisation was highest (78 per cent) in April, 36 per cent in June and 3 per cent in July at kemmerer coal mine in Wyoming.
According to Daniels (1984) enough spores survived the winter season to initiate colonisation in spring. He also observed an increase in spore population during the active growth season, which declined by the following spring season. But Mohankumar and Mahadevan (1988) recorded an increased spore count from September (rainy season) to April (summer season) in Kalakad Reserve Forest, a tropical forest located in the Western Ghats of Tamil Nadu. They also observed a decrease in root colonisation as the summer progressed.

Iyer et al. (1988) observed a reduced root colonisation in the premonsoon samples of cardamom while the infection grading increased after the rains. A marked decrease of VAM mycorrhizal infection and spore number in summer was noticed in the study of seasonal variation of VAM in maritime sand dune at Pisa in Italy (Giovanetti, 1985).

The number of spores in the soil and infection of the roots of different plant species in Madras were more in summer than in the rainy season (Parameswaran and Augustine, 1988). According to Siguenza et al. (1996) root colonisation and arbuscle development started with the rainy season and as the soil dried the number of arbuscles declined and vesicle numbers increased. At this point, the levels of colonisation were also high and the fungus produced spores many of which remained in the soil until adequate moisture initiated their germination in the next growing season. It was found that post rainy (November) and winter (February) months soil
samples had more number of VA mycorrhizal spores than those of summer (May) and rainy (August) months of Tarai soils in Uttar Pradesh (Trimurtulu and Johri, 1998). Lakshman et al. (1999) while studying the seasonal influence of VAM fungi in some commonly cultivated crops of Dharwad district in Karnataka, observed high spore population in summer and low in rainy season. Schwob et al. (1999) reported a higher number of VAM spores in the rainy season than in dry season, although VAM colonisation of roots was unaffected by season. A seasonal study on AM fungi associated with Ipomoea pes-caprae established on the coastal sand dunes of the west coast of India reported highest spore density during summer season (Beena et al., 2000). But Kaushal (2000) observed that in Rajasthan soils the spore count was minimum in summer season, i.e. April, May and June and maximum in August and September.

2.3. Comparison of forest and rubber growing soils

In forests, the continued deposition of leaves and other debris creates a kind of organic mulch in surface soils, which results in a more stable microclimate and provides conditions for a wider spectrum of soil animals and microorganisms. Prichett (1979) had compared forest soils with agricultural soils. Under forest ecosystem, several hard wood trees are naturally infected with VAM as a microsymbiont (Kormanic, 1986) Mohankumar and Mahadevan (1987) observed an increased VAM spore population and per cent infection in an evergreen forest soil in
Tamil Nadu. The use of VAM can substantially favour growth in tree plantations (Bagyaraj et al., 1989; Behl, 1990). Various agromanagement practices in agriculture, inhibit colonisation of plant roots by VAM thereby inhibiting the production of VAM spores (Douds, 1994). Deka et al. (1998) also reported that the number of VAM spores was less in a rubber plantation soil in Tripura state, compared to those occurring in a nearby natural forest.

### 2.4. Effect of soil factors on the distribution of VAM fungi

#### 2.4.1. Soil temperature

Both temperature and light have been shown to have a significant influence on colonisation and sporulation by VAM fungi. Higher temperature generally resulted in greater root colonisation (Hayman, 1974) and increased sporulation. Studying the effect of soil temperature on VAM establishment, Schenck and Schroder (1974) observed maximum arbuscule development near 30°C while the mycelial colonisation of the root surface was greatest between 28 and 34°C and sporulation and vesicle development at 35°C. Periods of cold stress followed by maintenance of high soil temperature had also been shown to increase colonisation and sporulation (Ferguson, 1981). According to Daniels and Bloom (1984) the optimum temperature for root colonisation by VAM in wheat and red clover is 20-25°C. While investigating the factors influencing VAM in scrub jungle soil, Parameswaran and Augustine (1988)
found a positive influence of soil moisture and temperature on VAM activity. The number of VAM spores in a Brazilian rubber plantation was found to be greater at a temperature above 25°C (Schwob et al., 1999).

Schenck et al. (1975) reported that Gigaspora coralloidea had a higher optimum temperature (34°C) for its germination where as maximum germination of Glomus mossae occurred at 20°C. Daniels and Trappe (1980) observed an optimum temperature of 20-25°C for the germination of Glomus epigaeus spores. According to Koske (1981) the most rapid germination of Gigaspora gigantea occurred at 30°C. These studies suggested that increased soil temperature hastened the germination of spores of Gigaspora spp.

2.4.2. Soil moisture

Soil moisture had profound influence on VAM spore population as well as colonisation of host plants (Daniels and Trappe, 1980). Allen and Allen (1990) suggested that mycorrhizal status and succession could vary depending on the moisture and nutrient conditions of soil. High moisture resulted in decreased spore population and percentage of root colonisation by VAM fungi (Trinick, 1977; Vyas and Srivastava, 1988). Keeley (1980) reported that upland plants of black gum (Nyssa sylvatica) established fewer endomycorrhizae and survived flooded conditions poorly. Most wetland plants are reported as not infected or poorly infected (Søndergaard and
Laegaard, 1977; Anderson et al., 1984; Clayton and Bagyaraj, 1994). Stevens and Peterson (1996) while studying the effect of water gradient on vesicular arbuscular mycorrhizal status of *Lythrum salicaria* revealed that hyphal colonisation levels were significantly higher in the dry plots than in the wet regions.

*Glomus epigaeus* spores germinated best at moisture contents between field capacity and soil saturation (Daniels and Trappe, 1980). Below field capacity germination declined with no germination occurring below -31 bars. Koske (1981) made a detailed investigation on the germination of *Gigaspora gigantea* spores placed on sand to which concentrations of polyethylene glycol (PEG) were added and observed that in *Gigaspora gigantea* germination was strongly inhibited at -10 bars. He also observed that germ tube length was reduced at low water potential levels. These findings indicated that *Gigaspora* sp. delayed germination and reduced the hyphal growth from germinated spores at low water potential levels.

Maximum VAM colonisation and spore count of cowpea was observed when soil moisture was maintained at field capacity. Progressive stress reduced both spore count and colonisation and it was least when soil moisture was maintained at 50 per cent field capacity (Pai et al., 1993). Per cent infection and number of resting spores in the rhizosphere increased in sunflower plants grown under water stress condition of 10 per cent soil moisture level (Bolgiano et al., 1983 and Reddy et al., 1997).
2.4.3. Soil organic matter

Soil organic matter is an important edaphic factor that influences soil moisture, pH and water holding capacity, which in turn directly or indirectly influence VAM development and its efficiency. In rubber growing soils, the organic carbon status is high (1-2.5 per cent). The rubber plantations, being a closed ecosystem, recycles enormous biomass through litter decomposition which takes place rapidly thus producing considerable organic carbon in the surface layers of soil (Krishnakumar et al., 1991). Nicolson (1960) reported a decrease in mycorrhizal infection in the plants of graminæ with increasing soil organic matter. According to Sheikh et al. (1975) endogenous spore population was closely correlated with the level of organic matter in soil. Maximum spore numbers were recovered from soils containing 1-2 per cent organic matter and spores were sparse in tropical soils with 0.5 per cent organic matter. No such correlation had been observed in temperate soils with higher (2-18%) organic matter content although organic manure often enhanced mycorrhizal development in tropical soils (Johnson and Michelini, 1974; Sreelakshmi et al., 1999). Read (1993) reported that VAM predominated in ecosystem where the mineralisation is rapid enough to avoid the accumulation of organic matter.

Farmyard manure favoured VAM compared to inorganic fertilizers, as increased soil organic matter levels encouraged VAM (Harinikumar and Bagyaraj, 1989). Geethakumari et al. (1990) observed that application of organic amendment
(finger millet husk and farmyard manure mixed in the ratio 1:1 by weight) in addition to mycorrhizae increased the per cent mycorrhizal colonisation in finger millet. Wheat grown under organic farming was found to have VA mycorrhizal colonisation levels consistently 2 to 3 times higher than in the conventional farming (Ryan et al., 1994). Baby and Manibhushan Rao (1996) established that in rice plants VAM spore density and per cent infection were increased by organic matter amendments in soil especially green leaf manure. But in Rajasthan soils, the spore population and root colonisation were not favoured where organic carbon level in soil was high (Kaushal, 2000).

The mycorrhizal infectivity and spore density were greatly increased by the addition of composted farmyard waste (Noyd et al., 1996). A decreased VAM colonisation of roots as a result of high proportion (50-100 per cent) of vermicompost in the growth substrate was noted by Sainz et al. (1998) because of the enhanced P availability in vermicompost. Scullion et al. (1998) observed higher mycorrhizal infectivity under organic management, while intensive farming practices reduced the effectiveness of VAM population in Allium sp. The addition of organic matter reduced the density of spores and colonisation in an agro forestry system and increased in a monoculture system with Zea mays (Boddington and Dodd, 2000).

2.4.4. Soil pH

Soil pH significantly influenced VAM spore production and VAM activity (Kruckelmann, 1975; Vyas and Sreevastava, 1988). Hayman and Mosse (1971)
observed VAM formation in *Coprosoma robusta* in soils with pH of 3.3 to 4.6. Mosse (1972) obtained considerably high efficiency of VAM by increasing soil pH. However, very high and low pH decreased VAM infection. Abbott and Robson (1977) reported that the distribution of different types like honey coloured sessile and yellow vacuolate spores in western Australia was related to soil pH. Much VAM infection but few spores were reported in acid hill grasslands in Northern England (Sparling and Tinker, 1978), Mid-wales (Hayman and Mosse, 1979), Western United States and Canada (Molina et al., 1978). However, Mohankumar and Mahadevan (1987) could not find any definite correlation between soil pH and VAM development and sporulation. Zhaobin (1988) reported that *Glomus* sp. infected cotton root ramified extensively and formed more hyphae at high soil pH conditions. The intensity of colonisation and spore density has shown to depend on soil pH (Sylvia and Williams, 1992). Rathore and Singh (1995) also observed an increase in the VAM population with increasing pH. VAM colonisation of roots increased with increase in soil pH from 4.3 to 5 and further increases in pH did not influence colonisation (Soedarjo and Habte, 1995; Begho and Asawalam, 1999).

VAM symbiosis was hardly affected by a decrease in soil pH in heathland herb species (Heijne et al., 1995). A survey of different localities of Rajasthan revealed that VAM spore population and root colonisation in *Acacia nilotica* were positively correlated with soil pH (Kaushal, 2000).
The effect of soil pH on VAM spore germination and root colonisation has been studied in depth and documented profoundly. The influence is either direct or indirect. Green et al. (1976) reported that the influence of pH on spore germination was different for different species of the fungus. On the other hand, Green et al. (1976) observed an increased germination of *Gigaspora coralloidea* and *Gigaspora heterogama* in soil of acidic pH range. Most favorable pH for the germination of the above two species was found to be 4 to 6. There are also reports that the germination of spores occurred at a wide range of pH as in the case of *Glomus epigaeus*. Siqueira et al. (1982) reported that a soil pH of 6 was optimum for the spore germination in agar medium.

Even though considerable work has been done on the role of soil pH on VAM spore germination, the actual mechanism of pH affecting spore germination is yet to be understood. Daniels and Trappe (1980) suggested that the pH induced differences in nutrient availability in soil are responsible for stimulation or inhibition of VAM fungal spore germination.

### 2.5. Effect of cultural operations on VAM colonisation and spore population

Disturbances of soil started as cultivation of plants began. Tillage is the main cultural operation that disturbs the soil. Yocom et al. (1985) found that mycorrhizal
colonisation of winter wheat was considerably lower in fields subjected to intensive tillage. O’Halloran et al. (1986) observed an increased root colonisation of VAM in undisturbed soil. While having a direct influence on root colonisation, tillage also had an indirect influence. Tillage reduced soil fauna that influenced the dispersion of VAM fungi (Rabatin and Stinner, 1989). Kruckelmann (1975) and Douds et al. (1995) reported negative effect of tillage on mycorrhizal sporulation in pot culture experiments. Independently conducted field studies have established that soil disturbance by tillage or by hand reduced mycorrhizal colonisation of plants (Anderson et al., 1987; Vasatka and Dodd, 1998; Evans and Miller, 1990; McGonigle and Miller, 1993; Douds et al., 1995; Kabir et al., 1997). Entry et al. (1996) also observed that corn plants in no tillage treatments had higher root biomass infected with mycorrhizae than those in conventional tillage. But according to Gavito and Miller (1998) tillage had little effect on intraradical colonisation. However, the effect of tillage on mycorrhizal colonisation has been inconsistent in both pot and field studies (Miller et al., 1995; Addy et al., 1997). McGonigle and Miller (1993) and Boddington and Dodd (2000) also observed a negative effect of soil disturbance on VAM hyphal growth.

2.5.1. Fertilizer application

Changes in soil fertility due to application of mineral fertilizers or organic matter markedly affected the activity of soil mycorrhizal population in terms of the
amount of root infection and number of resting spores produced (Mosse, 1973b; Hayman, 1982a). Mycorrhizae were abundant under the entire natural range of soil fertility, although the degree of mycorrhizal colonisation increased as fertility declined (Jasper et al., 1979).

There are contradictory reports on the role of fertilizers in influencing VAM fungi in soil. Many reports indicated a negative influence (Hayman, 1975; Jensen and Jacobsen, 1980; Planchette and Corpron, 1987; Vivekanandan and Fixen, 1991) while a few reported a positive influence of fertilizers on VAM (Dehne, 1987; Gryndler et al., 1990). Johnson and Pfleger (1992) summarized the effect of fertilizers on VAM and attributed the variability due to the type and quantity of fertilizer, fertility of soil and the crop. The adverse effect of fertilizer is considered to be due to higher fertility of soil (Jasper et al., 1979; Hayman, 1982a; Dehne, 1987). Conversely, when soils were poor in nutrients, mycorrhizal colonisation and spore population were limited by poor growth of host plant and small additions of fertilizer can stimulate mycorrhizal colonisation, whereas large additions of fertilizer suppressed it (Porter et al., 1978; Bagyaraj and Sreeramulu, 1982; Hao and Lin, 1987; Thingstrup et al., 2000; Rajeswari et al., 2001).

The ratio of major nutrients in fertilizers was considered to have more influence on VAM. Among the major nutrients of plants, P is an important nutrient having a profound influence on VAM colonisation. The level and type of phosphatic
fertilizer influenced VAM spore population as well as root colonisation. Higher the level of phosphorus in soil, lower was the population of VAM spores (Hayman, 1975). Jasper et al. (1979) observed reduced mycorrhizal infection under high phosphatic fertilizer. Excess phosphorus reduced the root infection and spore production by VAM in *Abelmoscus esculentus* (Krishna and Bagyaraj, 1982), cardamom (Iyer et al., 1988) and black gram (Umadevi and Sitaramaiah, 1990). Kruckelmann (1975) while studying on VAM in soil reported a positive effect of fertilizers on spore population of VAM in soil and root infection. He also found that application of phosphate (220 kg P ha⁻¹) for seven subsequent years did not affect the frequency of VAM spores in soil. Powell and Daniel (1978) reported that P from poorly soluble rock phosphate only was available to mycorrhizal plants and colonisation increased with increase in the availability of P.

Application of rock phosphate at the graded levels of 1.5, 2.5, and 3.5 g kg⁻¹ soil significantly increased the per cent root colonisation (Veerawasmy et al., 1992). Phosphorus fertilization however reduced the mycorrhizal colonisation of maize in the field at early (Khan, 1972; Lu and Miller, 1989; Vivekanandan and Fixen, 1991) and late development stages (Guttay and Dandurant, 1989) but according to Gavito and Miller (1998) P fertilization had no effect on mycorrhizal development. A reduction in mycorrhizal colonisation by P fertilization was also observed by Chandrashekara et al. (1995) and Thingstrup et al. (1998). In a study of mycorrhizal colonisation of corn
hybrids with three P rates (0, 40 and 80 mg P kg\(^{-1}\) soil), Liu et al. (2000) observed that the colonisation was greatest at the lowest P level.

Gryndler et al. (1990) showed that a balanced fertilizer application stimulated mycorrhizal colonisation of corn while fertilization with unusually high or low levels of nitrogen decreased root colonisation. Saif (1986) showed that application of P alone reduced mycorrhizal infection in forage species, on the other hand NPK fertilizer did not show any adverse effect. The nutrients N, P and K interacted with the plants and helped VAM colonisation. N status of host plants influenced VAM in P absorption (Sylvia and Neal, 1990) and the same is mediated by K (Plenchette and Corpron, 1987). They also observed a negative influence of P and K when applied individually and a positive effect upon combined application of P and K.

Different species of VAM fungi differed in their response to fertilizers. *Gigaspora margarita* and *Scutellospora calospora* are highly sensitive to fertilizers while *Glomus intraradix* was insensitive to fertilizers (Sylvia and Schenck, 1983; Thomson et al., 1986; Douds and Schenck, 1990).

2.5.2. Fungicide application

Fungicides include a large number of synthetic compounds differing greatly in their mode of action and effects on VAM fungi and conflicting reports are common,
even within a single class of fungicide (Johnson and Pflegèr, 1992). The effect of fungicides on VAM depends considerably on the rate at which they are applied. Fungicides typically delayed or reduced VAM infections but rarely eliminated it altogether (Menge, 1982). Benomyl, ethirimol and thiabendazole applied as seed treatment had inhibitory effect on the development of VAM on wheat roots, even at the lowest concentration (Jalali and Domsch, 1975). The inhibitory effect of PCNB and benomyl was reported (Menge et al., 1979; Ocampo and Hayman, 1980). Nemec (1980) reported the adverse effect of captan at higher concentration (9 kg ha⁻¹) in sour orange. On the other hand Sreenivasa and Bagyaraj (1988) reported an increased root colonisation and spore production of VAM by captan at lower concentrations.

Benzimidazole fungicides such as benomyl, carbendazim, thiabendazole, thiophanate and thiophanate-methyl were highly detrimental to VAM irrespective of mode of application (Hale and Sanders, 1982; Manjunath and Bagyaraj, 1984; Kough et al., 1987). Non-systemic fungicide like thiram was consistently toxic to mycorrhizal fungi (Kumar and Jayaraman, 1987). Lu and Miller (1989) reported that application of fungicides generally reduced and disrupted VAM root colonisation and hyphal P transport. Both benomyl and Bavistin significantly reduced the degree of colonisation of cowpea by VAM (Gunasekaran et al., 1987; Pedersen and sylvia, 1997). Kehri and Chandra (1993) reported a damaging effect of Bavistin on mycorrhizal formation in green gram.
Benomyl was used at high (3.0 g l⁻¹) application rates as a control treatment in VAM fungal experimentation (Fitter and Nichols, 1988) and there is some evidence of adverse effects even at rates normally used in agriculture (Johnson and Pfleger, 1992). Benomyl inhibited mycorrhizal formation (Boatman et al., 1978; Carey et al., 1992) and both benomyl and carbendazim inhibited hyphal P transport and metabolic activity (Larsen et al., 1996; Kling and Jakobsen, 1997) and function (Thingstrup et al., 2000).

Fosetyl AL and metalaxyl, the antioomycete fungicides were reported to augment mycorrhizal colonisation (Jabaji-Hare and Kendrick, 1987). Other workers also reported the beneficial or neutral effect of metalaxyl on mycorrhizae (Groth and Martinson, 1983; Afek et al., 1990; Daniels and Wilson, 1991). But Anusuya and Dhaneswari (1995) reported a significant reduction in VAM infection at 500 and 1000 mg l⁻¹ of metalaxyl sprayed groundnut plants. Ridomil-72 WP application stimulated the colonisation and spore production of Sclerocystis coremioides in the rhizosphere of black pepper (Robert et al., 1995).

Vijayalaxmi and Rao (1993) reported that carbendazim and copper oxychloride treatment inhibited the mycorrhizal infection in sesame. But according to Vyas and Vyas (1995) carbendazim, fosetyl-Al and mancozeb significantly increased both mycorrhizal infection and chlamydomspore number and triadimefon adversely affected the growth of mycorrhiza. Anusuya (1995) reported that soil application of
carbendazim did not deleteriously affect VAM fungi. Carbendazim, a systemic soil fungicide had inhibited both VAM root colonisation and formation of resting spores in the earlier stages of growth in *Albezzia lebbeck*, but at later stages the percentage of infection recorded was almost at par with the control (Kumar *et al.*, 1999).

2.5.3. Pesticide application

Modern cropping technology involves the use of a number of pesticides for controlling the insects and nematodes. While affecting the target fauna they also had influence on the soil microbial population including VAM fungi (Hayman, 1982b; Moorman, 1989). Most of the pesticides inhibited the infection and development of VAM (Hayman *et al.*, 1978; Menge *et al.*, 1979; Trappe *et al.*, 1984; Parvathi *et al.*, 1985), although some increased mycorrhinal colonisation and development (Bird *et al.*, 1974).

VAM populations in field grown potatoes were reduced by the insecticide aldrin and in tomatoes by the insecticide metastox (Kruckelmann, 1973). The nematicide, dibromo chloropropene (DBCP) is an example of a pesticide that enhanced mycorrhizal colonisation (Bird *et al.*, 1974; Menge *et al.*, 1979). Aldicarb also seemed to stimulate both spore and mycorrhiza formation in barley (Ocampo and Hayman, 1980; Trappe *et al.*, 1984). It is possible that these pesticides indirectly
stimulated mycorrhizae by reducing population of nematodes or other predators, parasites or competitors of VAM fungi.

Backman and Clark (1977) reported a reduced mycorrhizal colonisation by carbofuran at recommended dose while at half dose the root colonisation increased (Sreenivasa and Bagyaraj, 1983). However, organophosphorus insecticides and nematicides like chlorfenvinphos, carbaryl, malathion and parathion generally had no effect or a slightly detrimental effect on VAM fungi (Ocampo and Hayman, 1980; Spokes et al., 1981; Parvathi et al., 1985). Similar is the case with carbofuran and oxamyl (Spokes et al., 1981; Nemec, 1985). But Venketeswarlu et al. (1994) reported that VAM colonisation and sporulation by Glomus clarum enhanced significantly at the recommended field dose of carbofuran and higher dose inhibited the mycorrhizal status of groundnut. The number of spores in the soil was reduced significantly at recommended and higher level of carbofuran application. Among the plant protection chemicals insecticides were least toxic to mycorrhizal fungi and spore production (Vyas and Vyas, 1995). According to them the descending order of toxicity towards mycorrhizae in maize was Thimnet > carbaryl > methylparathion > chlorpyriphos > quinalphos. Quinalphos has been found to enchance, both the per cent of mycorrhizal infection and the number of propagules (Kumar et al., 1999).
2.5.4. Weedicide application

Application of weedicides is a common practice in modern agriculture. Unlike insecticides and fungicides most of the weedicides are systemic and translocated to all parts of plants. They in turn influenced VAM association. The role of herbicides on VAM was reviewed by Trappe, et al. (1984).

The herbicide, simazine when applied at field rate had no effect on VAM formation in corn (Kruscheva, 1971), decreased VAM formation in Citrus species (Nemec and Tucker, 1983) and increased VAM formation in Chenopodium quinona (Schwab et al., 1982). Nemec and Tucker (1983) also found that in Florida citrus diuron and bromacil had no apparent effect on Glomus etunicatus. But application of diuron increased VAM fungal spores in soil (Smith et al., 1981). At recommended dose diuron did not have any adverse effect either on sporulation or root colonisation (Dodd and Jeffris, 1989).

According to Pope and Halt (1981) paraquat applied at 2 kg active ingredient/ha significantly reduced the mycorrhizal infection, vesicle development and chlamydomspore formation in white ash seedlings, while paraquat applied at 0.5kg ha⁻¹ promoted the hyphal development and spore production. Atrazine was reported to enhance mycorrhiza formation in Liquidambar styraciflua (Trappe et al., 1984). Anusuya and Shobha (1995) reported a positive response with respect to VAM spore
numbers and number of infective propagules upon the application of glyphosate on green gram. Trifluralin had no effect on VAM infection in roots (South, 1981; Nemec and Tucker, 1983). The hyphae of VAM fungi could remove atrazine from the soil and transfer it to corn plants (Nelson and Khan, 1992).

Rachel et al. (1996) while working with sunflower reported that application of 2,4-D had shown a negative effect on the mycorrhizal association. But Kumar et al. (1999) reported its positive effect on VAM colonisation with reference to two tree species viz. Sesbania grandiflora and Albizia lebbeck at nursery level.

2.6. Soil solarisation

There are only few reports on the effect of soil solarisation on VAM. The concept of soil solarisation stemmed from the possibility of raising soil temperature to lethal level, by mulching soil surface with plastic film (tarping) during hot summer months. Use of this method has been reported to control soil borne plant pathogens, weed seeds, insect larvae etc. (Katan, 1981; Morgan et al., 1991; Chattopadhyay and Sastry, 2001). The effect of solarisation on mycorrhizal colonisation was examined by Pullaman et al. (1981) and reported that the cotton roots from tarped soil showed mycorrhizal colonisation to a lesser extent than nontarped soil. According to Sharma and Sharma (2002) the total microbial population decreased due to solarisation treatments.
2.7. Dissemination of VAM spores

VAM fungi dispersal is an important aspect in their survival and function. The dispersal may take place by root contact as well as by water and wind blown particles. Animals and crop management practices also play a role in the dispersal of VAM fungi. The dispersal may be either active or passive (Bagyaraj, 1991).

2.7.1. Active dissemination

Active dispersal of VAM occurs as mycelia grow through the soil either alone or along with roots though it is effective over a limited range. Powell (1979) determined that an efficient mycorrhizal fungus would advance 65m in 150 years or 0.43 m year\(^{-1}\) under controlled conditions. Warner and Mosse (1982) have shown that plant species and root density significantly influenced the rate of VAM fungal spread. In clover the greatest rate of spread of *Glomus fasciculatum* was 1cm week\(^{-1}\) while in fescue, *Glomus fasciculaum* spread at only 0.7 cm week\(^{-1}\).

Mosse *et al.* (1982) conducted experiments in unsterile soil and demonstrated that *Glomus caledonium* was able to spread 7 to 13 cm from an inoculation point after 13 weeks. No correlation was observed between rate of spread and plant size, but spread rate was greater in non sterilized plots than in sterilized soils.
Whether VAM fungi grow towards a root stimulus or randomly in soil has been debated. Powell (1976) using the buried slide technique in partially sterilized soil, demonstrated little or no attraction of VAM hyphae to root until random contact occurred, except with hyphae from honey coloured spores (Acaulospora laevis) which frequently grew towards the roots. Koske (1981) has demonstrated chemotactic attraction of hyphae of Gigaspora margarita to host roots in vitro and the attractant is probably a volatile substance. Whether such chemotactic substances are produced under field conditions and can direct the mycelial growth in the field has not been studied.

2.7.2. Passive dissemination

Passive dispersal occurred through biotic agents like rodents, worms, insects and birds or through abiotic agents like wind and water.

2.7.2.1. Biotic agents

Both flora and fauna contributed to the passive dissemination of VAM spores. Animals appear to be the major vectors for dispersal of VAM fungi in many habitats (Marx, 1975; Allen, 1987). A wide variety of animals were known to have VAM spores in their gut tracts or faeces. Thaxter (1922) was the first to observe VAM spores in the digestive tracts of millipedes. VAM spores were reported in grasshoppers and crickets (Hansen and Uckert, 1970) and in earthworms and ant casts (Mc Ilveen and Cole, 1976). VAM spores remained viable following earthworm

VAM association did not develop in the roots of sunflower plants grown in steam treated check soil. However, in soils amended with air-dried worm cast or wasp mud pots, the roots developed mycorrhizal colonisation. (Lakshman and Raghavendra, 1990).

2.7.2.2. Abiotic agents

Wind and water are the two major abiotic agents of passive dissemination of VAM spores. Ponder (1980) reported VAM fungal spores in the droppings of leaf feeders like grasshopper and rabbit. The presence of VAM fungal spores in their digestive tracts or feces, therefore, implies that spores were present on leaves prior to feeding, probably as a result of wind dispersal. Taber (1982) has observed VAM fungal spores in Portulaca seed capsules, which are oriented on the plant towards wind. Mac Mohan and Warner (1984) collected airborne VA mycorrhizal spores from modified sticky traps, thus giving direct evidence of wind dispersal of VAM spores. The wind dispersal of spores up to 2 km was demonstrated by Warner et al. (1987).
Water irrespective of the source flowed through the surface of land and carried soil particles and microorganisms including spores of VAM (Powel, 1980). The number of spores carried by water depends on quantum of water from the source, rate of flow and the source. Irrigation water is the most potential source of passive VAM dispersal.