DISCUSSION
5. DISCUSSION

In the present investigation an attempt was made to assess the influence of different arbuscular mycorrhizal (AM) fungi and plant growth promoting rhizomicroorganisms (PGPR) on the growth and yield attributes of patchouli, the essential oil content and percent patchouli alcohol under varied combinations of treatments. Attempt was also made to develop a suitable ‘microbial consortia’ for inoculating patchouli and finally to work out the cost benefit ratio in comparison to chemical fertilizers.

The results obtained during the course of this investigation have been discussed in this chapter under the following headings.

5.1. Screening of AM fungi for their symbiotic efficiency with patchouli and selection of the most efficient fungi.

5.1.1. Plant height:

The plants inoculated with *G. etunicatum* (84.58 cm), *G. intraradices* (81.17 cm) and *G. macrocarpum* (81.75 cm) showed higher growth being on par with each other. The least growth was observed in *S. calospora* (57.5 cm). Uninoculated control (63.79 cm) followed by *A. laevis* (64.33 cm) and differing significantly from other treatments. The result of the present study is in conformity with the results obtained by Gupta and Janardhanan (1991) in palmarosa, Gupta *et al.* (2002) in mint and Boby and Bagyaraj (2003) in coleus. Rupam Kapoor *et al.* (2004) observed improved growth of *Foeniculum vulgare* due to inoculation with *G. macrocarpum* and *G. fasciculatum*. Increased plant growth was observed in *Stevia rebaudiana* a medicinal plant when inoculated with *G. macrocarpum* which performed best when compared to eleven
different AM fungi used in the study (Chitra and Balakrishna, 2006). Similarly improved
growth due to mycorrhizal inoculation was observed by many workers in many medicinal
and aromatic crops (Burrows et al., 1990; Laksmann, 1992; Bread et al., 1996; Mohan et
al., 1995; Oliveria et al., 1995, Sharma et al., 1997 and Srinivas and Gaddaginamani,
1993).

5.1.2. Number of branches:

In the present investigation, the number of branches were highest in plants receiving the treatment *G. etunicatum* followed by *G. intraradices* compared to other inoculated treatments and control. The plants treated with *G. margarita* showed the least number of branches including control. This is probably due to the preferential colonization showed by certain AM fungi towards the host (Vasantha Krishna et al., 1995) and it is possible that some turn hostile. This is in confirmation with the results obtained by earlier workers like Ulfath Jiaba et al., (2006a) in long pepper, Chitra and Balakrishna (2006) in *Stevia rebaudiana* and Tharun et al. (2006) in Kalmegh.

5.1.3. Plant spread:

All the inoculated treatments showed better spread. Plants treated with *G. intraradices* and *G. macrocarpum* showed very good spread followed by *G. etunicatum* in east–west direction. The plant spread in the treatments *G. leptotichum*, *G. fasciculatum*, *G. bagyarajii* and *G. margarita* did not differ significantly from control. The least spread was in *S. calospora* treatment.

In the north–south direction plants treated with *G. etunicatum* showed the highest spread followed by *G. intraradices*. All other treatments were on par with each other but differed significantly from the control except for *S. calospora* which showed the least
spread and statistically par with the control. This positive influence of mycorrhizal inoculation on plant spread might have altered the plant growth by their influence on the synthesis of plant hormones (Azcon, 1989). The results of the present study also upholds the earlier findings of Ajimuddin (2002) in sweet basil and Earanna (2001) in Phyllanthus amarus and Withania somnifera.

5.1.4. Plant Biomass:

The shoot, root and total dry weight of plants were maximum in all the treatments receiving mycorrhiza, except S. calospora. Highest biomass was observed in G. etunicatum followed by G. intraradices and G. macrocarpum.

The plant biomass is an important parameter for selecting a fungus for its symbiotic efficiency. Gracy Sailo and Bagyaraj (2005) studied the effectiveness of eleven fungi on Coleus forskohlii, among which G. bagyarajii was found to be the best AM symbiont recording higher biomass. Similar results were obtained by Ulfath Jaiba et al. (2006a) in long pepper and Tharun (2006) in kalmegh. Increased plant biomass because of AM fungal inoculation has also been reported in aromatic plants like palmarosa (Gupta and Janardhanan, 1991) eucalyptus (Oliveria et al., 1995) and bergamot mint (Kothari et al., 1999).

5.1.5. P uptake:

Plants treated with G. etunicatum showed highest shoot and root P followed by other inoculation treatments all being on par with each other but statistically differed from the control. The uninoculated control showed least P concentration.

Improved growth and biomass due to inoculation of soil with AM fungi has been demonstrated especially under P deficient conditions (Mosse, 1973). The growth
improved mainly because of enhanced P uptake. Similar increase in P uptake by AM fungi inoculated plants was observed in citronella java (Kothari and Singh, 1996), bergamot mint (Kothari et al., 1999); pepper (Demir, 2004) and mint (Gupta et al. 2002).

5.1.6. Mycorrhizal root colonization and spore numbers in root zone soil:

In the present investigation, high per cent mycorrhizal root colonization was observed in *G. intraradices*, *G. macrocarpum*, *G. etunicatum* and *G. fasciculatum* and all are on par with each other. All of the treatments showed statistically higher colonization compared to control.

Similarly spore numbers were higher in all inoculated treatments compared to control. The presence of spores in the control might be due to colonization by the native AM fungi and may also be due to the contamination that might have occurred during course of experiment.

Higher colonization was observed in those plants which had the higher spore count in soil around their root zone resulting in higher plant growth, thus confirming findings of Daft and Nicolson (1972). These results are also supported by the observations made by Burrows *et al.* (1990) in asparagus, Gupta *et al.* (2002) in mint.

5.1.7. Essential oil concentration and percent patchouli alcohol:

As far as essential oil concentration is concerned plants inoculated with *G. etunicatum* topped the list of treatments and differed significantly from all other treatments. Other inoculated treatments, except *S. calospora*, were statistically on par with the control. *S. calospora* recorded least oil content.

The oil obtained was of good quality with more than 47 % alcohol. Similar results were recorded earlier by Rupam Kapoor *et al.* (2002) in *Anethum graveolens.* L and
Trachyspermum ammi (Linn), the concentration of essential oil increased over their respective controls because of mycorrhizal inoculation. The constituents of essential oil were also enhanced by treatment with AM fungi. A significant increase in essential oil in coriander due to application of AM fungi G. macrocarpum and G. fasciculatum was observed by Kapoor et al. (2002). Similar results were obtained by Rupam Kapoor et al. (2004) in Foeniculum vulgare.

5.2. Interaction between AM fungi and PGPR and their effect on growth, nutrition (N and P) and essential oil:

5.2.1. Growth parameters:

The combined inoculation of AM fungi and PGPR influenced the growth characters of patchouli during the growth period, resulting in improved growth and development of plants.

Plant height varied with different treatments throughout the growth period. Plants receiving combined inoculations of AM fungi and PGPRs recorded better growth compared to uninoculated control. Plants treated with Ge + Ac + Th + Bc gave the best result followed by Ge + Th + Bc + Mm and Ge + Ac + Th + Bc + Mm, all the three treatment showed higher height though not differing significantly from other treatments. The least height was observed in control.

Many bacteria are known to stimulate plant growth through direct or indirect interactions with plant roots. In addition, most plant roots are colonized by mycorrhizal fungi and their presence stimulates plant growth. The results obtained in the present are supported by earlier works done by Azcon et al. (1976) in lavender, Meyer and Linderman (1986) in clover, Ratti and Janardhanan (1996) in palmarosa. Earanna (2001)
reported improved growth and yield of *Withania somnifera* by application of *G. mosseae* and *B. coagulans*.

**Number of branches:**

The number of branches in patchouli plants were more in *Ge + Th + Bc + Mm* treated plants followed by *Ge + Ac + Th + Bc + Mm* and *Ge + Mm*, all being statistically on par with each other. All other treatments showed slightly higher number of branches compared to control and were statistically on par with each other but not significantly different. The least number of branches was observed in control.

These results are in conformity with the earlier results obtained by Earanna *et al.* (1998) in *Coleus aromaticus* to inoculation with AM fungi and PGPR. Similar results were obtained in *Datura metel* and *Adathoda vasica* (Tanuja, 2000); neem (Sumana *et al.* 2003); citronella java (Naik 1998) and in palmarosa (Gupta and Janardhanan, 1991).

**Plant spread:**

In the present study, plant spread in east – west and north – south direction followed similar trend as plant height and number of branches. In east – west direction plants inoculated with *Ge + Ac + Th + Bc, Ge + Th + Bc + Mm* and *Ge + Ac + Th + Bc + Mm* showed significantly higher spread compared to control and all the three being statistically on par with each other. Similar observations were recorded in north – south direction supporting the work done by earlier workers in *Calamus thwaitessi* and *Adathoda vasica* by Lakshmipathy *et al.* (2002) and Anantha Naik and Earanna (2006) respectively.
5.2.2. Yield parameters:

5.2.2.1. Plant Biomass:

The yield parameters of crops are distinctive indication of the entire growth response of that crop in terms of height, number of branches, plant spread, flowering etc.

All the inoculated treatments showed higher shoot weight compared to control. Plants inoculated with \( Ge + Ac + Th + Bc \) showed highest shoot dry weight. This was followed by \( Ge + Th + Bc + Mm, Ge + Ac + Th + Bc + Mm \) and \( Ge + Mm \) all being statistically on par with each other. The remaining treatments did not differ significantly from the control but found to be on par with each other. The least shoot dry weight was observed in control.

The root dry weight was highest in plants treated with \( Ge + Ac + Th + Bc \) followed by \( Ge + Th + Bc + Mm \) and \( Ge + Ac + Th + Bc + Mm \) all the three being statistically on par with each other and significantly differed from control. Least dry weight was observed in control. Similar trend was observed in the case of total biomass of the plants.

Earanna (2001) observed improved growth and yield of \( W. somnifera \) when inoculated with \( Glomus mosseae \) and \( B. coagulans \). According to Sumana et al., (2003) Neem seedlings responded well to triple inoculation with \( G. mosseae, A. chroococcum \) and \( B. coagulans \) with maximum plant biomass. Chitra and Balakrishna (2007) observed that coinoculation of \( A. chroococcum \) with \( G. macrocarpum \) was best for inoculating stevia. Improved growth and biomass was observed in \( Ocimum sanctum \) by Vinutha et al., (2007) when they were inoculated with \( G. fasciculatum, A. chroococcum \) and
Aspergillus awamori. All these findings support the results of the present investigation on patchouli.

5.2.2.2. Essential oil content:

Triple inoculation that is, combined inoculation of AM fungi and PGPRs resulted in higher oil content compared to dual inoculation and control. This indicates synergistic interaction between the PGPRs and AM fungi resulting in higher yields. The essential oil content was highestand significantly different from control in plants inoculated with Ge + Th + Bc + Mm and Ge + Ac + Th + Bc + Mm both being on par with each other.

Ratti and Janardhanan (1996) have reported similar results in palmarosa, where in application of A. brasilense along with AM fungus G. aggregatum increased the oil content. This crop was also found to give higher oil content with inoculation of Azotobacter as reported by Sen (1995) and Maheshwari et al. (1998). All these three combinations gave higher oil content in sweet basil (Ajimuddin, 2002) compared to control.

5.2.3. Nutrient parameters:

5.2.3.1. P uptake:

The principal way in which AM fungi benefit plant growth is mainly through uptake of P and other micronutrients (Sreenivas et al., 1993). It is also known that AM fungi have their most significant effect on plant growth when little available phosphate is present in the soil (Harley and Smith, 1983).

In the present investigation, plants receiving treatments Ge + Ac + Th + Bc, Ge + Th + Bc + Mm , Ge + Ac + Th + Bc + Mm and Ge + Mm showed higher shoot P concentration. Similarly root P concentration was higher in plants receiving the combined
inoculation of AM fungi and PGPRs as mentioned above. The least P concentration was observed in uninoculated control. These findings are in confirmation with earlier works in pepper mint (Sirohi and Singh, 1983), marigold (Bagyaraj and Powell, 1985), neem (Sumana et al., 2003) and Kalmegh (Arpana and Bagyaraj, 2007).

5.2.3.2. N concentration:

AM fungi show synergistic interaction with N fixers like A. chroococcum and encourage their proliferation in the rhizosphere (Anuradha, 2003). In the present investigation combined inoculation with AM fungi and PGPRs showed increased N concentration in shoot and root of patchouli plants compared to dual inoculations and control. Thus supporting the earlier findings in tuberose (Shivalingappa, 1998) and in sweet basil (Ajimuddin, 2002).

Ratti and Janardhanan (1996) observed increased N and P content in leaf tissue of palmarosa plants inoculated with G. aggregatum and Azospirillum brasilense. Similar observation was made in neem by Sumana et al.,( 2003).

5.2.4. Mycorrhizal parameters:

In the present investigation, percent mycorrhizal root colonization and spore numbers in the soil around the root zone were significantly more in plants treated with Ge + Ac + Th + Bc and Ge + Th + Bc + Mm followed by Ge + Ac + Th + Bc + Mm all the three not differing significantly. The least mycorrhizal colonization and spore numbers was observed in control plants.

The higher percentage mycorrhizal colonization and spore count in the treatments inoculated with PGPRs and AM fungi could be attributed to the fact that these PGPRs in the rhizosphere of mycorrhizae can modify or alter the establishment of mycorrhizal

5.2.5. PGPR population in the rhizosphere soil of patchouli:

In the present investigation, the treatments receiving \textit{Ge + Ac + Th + Bc + Mm} showed higher populations of all the PGPRs. This indicates that synergistic interactions exist only among these organisms. The uninoculated treatment recorded no PGPRs.

Similar observations were made with \textit{Azotobacter} co-inoculated with \textit{G. fasciculatum} by Mohan Das (1987). The quantitative changes in the rhizosphere population induced by AM fungi are possible through indirect effects on host physiology and changes in root exudation (Kothari \textit{et al.}, 1999). Higher populations of free living nitrogen fixing bacteria have been recorded in the rhizosphere of mycorrhizal Java citronella (Naik., 1998). The PGPR \textit{Methylobacterium mesophylicum} is found to be compatible with other beneficial organisms like \textit{Rhizobium, Azospirillum lipoferum, B. megatherium, P. fluoresens T. viride} and \textit{T. harzianum}. The compatible nature of these organisms established the potential of the bacteria as a new component to prepare mixed bioinoculants for various crops (Senthil Kumar \textit{et al.}, 2002).

Taking into account the growth, biomass, and essential oil content of patchouli, two consortia i.e. \textit{Ge + Ac + Th + Bc} and \textit{Ge + Ac + Th + Bc + Mm} were selected in the present study.
5.3. Effect of ‘microbial consortia’ along with fertilizers on growth and yield parameters of patchouli.

In the present investigation an attempt was made to assess the influence of AM fungi and various PGPRs on the growth, nutrition and yield attributes of patchouli under microplot conditions. The two selected ‘microbial consortia’ Ge + Ac + Th + Bc and Ge + Ac + Th + Bc + Mm were combined with recommended level of NPK fertilizers (150:50:50 Kg NPK / ha / year) and 50 % level of N & P and full K.

5.3.1. Growth parameters:

5.3.1.1. Plant height:

AM fungi and PGPRs influenced the growth characters of patchouli resulting in improved growth and development of plants.

At first harvest i.e. at 150 DAP, all the treatments showed higher plant growth all being on par with each other. Ge + Ac + Th + Bc + Mm with 50 % NP + full K recorded highest plant height followed by Ge + Ac + Th + Bc + Mm with 100 % NPK and Ge + Ac + Th + Bc alone. The least height was observed in the treatments receiving recommended NPK alone as well as in control.

There was not much difference among the treatments and control beyond 180 DAP till harvest i.e. up to 240 DAP. Plants receiving the treatment with microbial consortia Ge + Ac + Th + Bc + Mm alone and at 100 % recommended NPK and 50 % NP + full K measured slightly higher plant height compared to control. Earanna et al. (1998) noticed improved growth response of Coleus aromaticus to inoculation with AM fungi and PGPRs. Similar results were also observed in Datura metel and Adathoda vasica (Tanuja, 2000); neem (Sumana et al., 2003) and Java citronella (Naik, 1998).
Improved growth due to mycorrhizal inoculation was observed by many workers in many medicinal and aromatic crops (Burrows et al., 1990; Lakshman, 1992; Bread et al., 1996; Mohan et al., 1995; Oliveria et al., 1995).

The increased plant height reveals the obvious benefits of AM fungi and its synergistic interactions with PGPRs which are involved in various beneficial activities apart from absorbing atmospheric N. They may also supply growth promoting substances which help in improving the vigor and productivity of the crop.

5.3.1.2. Number of branches:

The number of branches per plant at 150 DAP recorded higher number in the treatment $Ge + Ac + Th + Bc + Mm$ with 50 % NP + full K, though it did not differ significantly from other inoculated treatments and control.

Similar trend was observed at 240 DAP, suggesting a possibility of reducing chemical fertilizers by almost 50 % by using microbial consortia. Similar observations were made by Anuradha (2003) in rosemary, Ajimuddin (2001) in sweet basil and Earanna (2001) in Phyllanthus amarus and Withania somnifera.

Interestingly, the treatments receiving all the microbial consortia along with 50% NP + full K showed good results compared to control and treatments receiving only recommended NPK. These findings are in confirmation with the earlier work done by Ramaswamy et al. (1995) in tuberose and Arpana and Bagyaraj (2007) in kalmegh. Application of Azospirillum brasilense along with AM fungi increased the number of tillers in palmarosa (Ratti and Janardhanan, 1996) and citronella (Naik 1998). Application of Azotobacter chroococcum, Azospirillum lipoferum and Bacillus
megatherium applied with chemical fertilizers increased vegetative growth compared to chemical fertilizer treatments alone in fennel plants (Mahfouz and Sharaf Eldin, 2007).

5.3.1.3. Plant spread:

In the present study, patchouli plants inoculated with Ge + Ac + Th + Bc + Mm with 100% NPK followed by Ge + Ac + Th + Bc + Mm with 50% NP + full K showed increased spread in east–west direction compared to control. Similar observations were recorded in north–south direction. At 240 DAP; plant spread in both the directions was highest in Ge + Ac + Th + Bc + Mm with 50% NP + full K compared to control. The results are supported by earlier findings in sweet basil (Ajimuddin, 2002); Phyllanthus amarus and Withania somnifera (Earanna, 2001); rosemary (Anuradha, 2003) and kalmegh (Arpana and Bagyaraj, 2007).

5.3.2. Yield parameters:

The yield parameters of crops are distinct indication of the entire growth response of that crop in terms of height, number of branches, plant spread, flowering etc. The growth responses are influenced by the varied externally imposed treatments. This experiment involves the use of microbial consortia with different levels of chemical fertilizers (NPK) and their effect on the growth responses which in turn contributed to the yield and essential oil content in patchouli.

In the present investigation, during the first harvest, highest fresh weight/ha was recorded in Ge + Ac + Th + Bc + Mm with 50% NP + full K followed by the treatment recommended NPK alone. At second harvest, the fresh weight of shoot and root per hectare did not show significant difference among the various treatments including control.
Similarly shade dry weight is an important parameter being crucial for extraction of essential oil. At first harvest the treatment $Ge + Ac + Th + Bc$ with 50 % NP + full K recorded higher weight followed by recommended NPK alone, $Ge + Ac + Th + Bc$ alone and $Ge + Ac + Th + Bc + Mm$ with 50 % NP + full K all being on par with each other and differing significantly from other inoculated treatments and the control. The least shade dry weight per hectare was observed in control. At second harvest, shade dry weight/ha did not show significant difference among the various treatments including control, though the lowest weight was recorded in control compared to other treatments.

When cumulative shade dry weight after two harvests per hactare was combined, the treatments receiving $Ge + Ac + Th + Bc$ recorded the highest biomass followed by $Ge + Ac + Th + Bc + Mm$ with 50 % NP + full K and $Ge + Ac + Th + Bc$ with 50 % NP + full K all being on par with each other. The least height was observed in control. This could be attributed to the fact that plants take some time to recuperate and show slow growth after first pruning.

In the two harvests, the treatment involving all the microbial consortia at 50% NP + full K showed better herbage yield when compared to the treatments recommended NPK alone and control.

The results indicate that the integrated supply of plant nutrients through microbes and fertilizers (NPK) played a significant role in sustaining soil fertility and crop productivity (Chand *et al*., 2006). This also supports the studies done by earlier workers in tuberose (Shivalingappa, 1998); sweet basil (Ajimuddin 2002); rosemary (Anuradha, 2003); ashwagandha (Mahadevswamy *et al*., 2006) and kalmegh (Arpana and Bagyaraj, 2007).
From this study, giving weightage to increased shoot biomass which is the economically important part of the plant, it was concluded that AM fungus *G. etunicatum* is the best mycorrhizal symbiont for patchouli and its performance can be further enhanced through coinoculation with beneficial soil microflora like *A. chroococcum, T. harzianum, B. cepacia* and *M. mesophylicum*. Synergistic interaction might occur through the production of the growth hormones which stimulated biomass yield. These results are in agreement with the findings of Sirohi and Singh (1983) in pepper mint, Kothari *et al.* (1999) in bergamot mint.

5.3.2.2. Essential oil content:

The average oil content of the plants has been recorded to be around 0.85 – 1.55 % (v/w) under good management conditions (Gopal *et al.*, 2000). In the present microplot experiment, at the first harvest, the inoculated treatments recorded higher oil content compared to control. The essential oil content was higher in treatments Ge + Ac + Th + Bc + Mm alone followed by Ge + Ac + Th + Bc + Mm with 100 % NPK and Ge + Ac + Th + Bc + Mm with 50 % NP + full K all being on par with each other. The least oil content was in control.

At second harvest, the treatment Ge + Ac + Th + Bc + Mm with 50 % NP + full K showed highest oil content and least was in control. However, it could be concluded that the oil content of plants receiving the ‘microbial consortia’ were significantly superior over recommended NPK alone and control. These are in line with observations made in rosemary (Anuradha, 2003; Munnu Singh and Ramesh, 2000). Maheshwari *et al.*, (1991) also obtained 42 % enhanced oil yield by using *Azotobacter* and reduced level of N i.e, 80 kg N ha⁻¹ in palmarosa. Similarly *Azospirillum brasiliense* along with reduced
level of P i.e, 40 kg P ha\(^{-1}\) recorded higher oil yield in CO-3 coriander (Subramanian and Vijayakumar, 1996). Combination of three biofertilizers AM, *Azotobacter* and phosphate solubilizing bacteria (PSB) along with chemical fertilizers enhanced oil yield of sweet basil (Ajimuddin, 2002) over control with only recommended NPK alone.

5.3.3. Influence of microbial consortia with varied levels of fertilizers on available P and N content in plants.

The nutrient uptake was found to be better in the plants which received microbial consortia along with different doses of NPK. At first harvest, with regard to the phosphorus concentration in plants, under the present study it was observed that all the plants receiving the microbial consortia at both the levels of NP + full K (i.e, 100% and 50% NP + full K) showed similar concentration of P not differing significantly along with control. At second harvest, the highest shoot P concentration was observed in the treatment receiving *Ge + Ac + Th + Bc + Mm* at 100 % NPK being on par with other inoculated treatments but differing significantly from the treatments receiving only NPK and control. Similar observations were recorded in root P concentration.

The principal way in which AM fungi benefits plant growth is mainly through uptake of P and other diffusion limited micronutrients (Sreenivasa *et al.*, 1993). The present investigation it showed that plants receiving microbial consortia performed better than recommended NPK alone and control. This further confirms the additive effect of these organisms suggested by the earlier works in pepper mint (Sirohi and Singh, 1983); marigold (Bagyaraj and Powel, 1985); black pepper (Shivashankar and Iyer 1989); rosemary (Anuradha, 2003) and kalmegh (Arpana and Bagyaraj, 2007).
The N concentration at first harvest, was highest in the treatment \( Ge + Ac + Th + Be + Mm \) at 100 \% NPK, followed by \( Ge + Ac + Th + Be \) at 100 \% NPK and \( Ge + Ac + Th + Be + Mm \) at 50 \% NP + full K all being on par with each other and significantly differing from control.

At second harvest, the shoot N concentration was high in all the treatments receiving the microbial consortia alone or along with 100\% NPK or 50 \% NP + full K. Treatment receiving chemical fertilizer alone and uninoculated control showed low concentration of N and differed significantly from other treatments. The root N concentration followed a similar trend. These results uphold the earlier findings in sweet basil (Ajimuddin, 2002) and rosemary (Anuradha, 2003). This could be due to the increased availability of nitrogen in the rhizosphere soil by the two nitrogen fixing organisms \( A. chroococcum \) and \( M. mesophilicum \).

5.3.4. Mycorrhizal parameters:

5.3.4.1. Mycorrhizal colonization and spore number:

In the present study, at first harvest, the chlamydospore count in all the treatments was on par with each other. The maximum count of spores were observed in the treatment receiving \( Ge + Ac + Th + Be + Mm \) at 50 \% NP + full K but significantly differed from control. The least number of spores was recorded in the uninoculated treatment.

At second harvest, the per cent mycorrhizal colonization was highest in the treatment \( Ge + Ac + Th + Be + Mm \) at 100 \% NPK followed by other treatments all being on par with each other. The least colonization was observed in the control. Similarly the number of spores in the root zone soil of patchouli was high in the
treatments receiving microbial consortia \( Ge + Ac + Th + Bc \) at 100% NPK and \( Ge + Ac + Th + Bc + Mm \) at 100% NPK both being on par with each other followed by other treatments. The lower number of spores was observed in recommended NPK alone and in the uninoculated treatments.

These results prove the efficiency of introduced AM fungus in the field against native AM fungi. Higher colonization was observed in those plants which had the higher spore count in soil around their root zone and hence more plant growth, thus confirming the findings of Daft and Nicolson (1972).

The uninoculated control also showed some AM colonization and spore count however, substantially lower mycorrhizal infection and spore count was observed. This might be due to the colonization by native AM fungi. The higher percentage mycorrhizal colonization and spore count in the treatments involving AM fungi and PGPRs could be attributed to the fact that these PGPRs in the rhizosphere of mycorrhizae can modify or alter the establishment of mycorrhizal symbiosis. They are known to help by improving the growth of mycelium either indirectly by detoxifying the substrate or directly by producing organic acids used by the fungus as carbon source and by emitting volatile substances responsible for specific selectivity (Duponnois and Garbaye, 1991). These organisms might alter plant growth by the plant hormones they synthesize (Azcon, 1989).

Increased root colonization and spore number in root zone soil due to the inoculation of AM and its coinoculation with beneficial soil microflora have been reported by earlier workers in many medicinal and aromatic crops (Earanna 2001; Ajimuddin 2002; Anuradha, 2003, Vinutha et al., 2004; Chitra and Balakrishna, 2006; Tharun et al., 2006; Arpana and Bagyaraj, 2007). Thus it could be concluded that inoculation of plants with
AM fungus along with beneficial microflora helps in better root colonization, in turn improving the growth and yield of the crop.

**Glomalin secretion by AM fungi:**

Mycorrhizal fungi secrete certain proteins known as glomalin in the soil, which plays an important role in soil aggregation (Allison, 1968). In the present investigation, the protein was found to be high in all the treatments receiving the mycorrhizal fungus and was on par with each other, but differing significantly from control.

Glomalin protects hyphae from nutrient loss, glues together soil aggregates, stabilizes aggregates, reduces wind and water erosion, increases water infiltration, increases water retention near roots and improves nutrient cycling (Allison, 1968). The direct effect of glomalin was much stronger than the direct effect of AM fungal hyphae themselves, suggesting that this protein is involved in a very important hypha-mediated mechanism of soil aggregate stabilization (Rillig, 2002).

**5.3.5. Rhizosphere microbial count of patchouli:**

It is a well known fact that high microbial activity and nutrient concentrations are found in the rhizosphere region. Any change in this region might affect the rhizosphere microflora and in turn the plant growth.

In the present investigation, at first harvest, the treatments receiving microbial consortia recorded higher microbial load. The treatment $Ge + Ac + Th + Bc + Mm$ at 50% NP +full K recorded highest numbers of PGPRs, when compared to the treatments recommended NPK alone and control.

Similarly at second harvest, the maximum number of colonies of PGPRs was observed in the treatments $Ge + Ac + Th + Bc + Mm$ alone and along with 100% NPK.
and at 50 % NP +full K all the three being on par with each other and significantly differing from other treatments.

Ratti and Janardhanan (1996) observed stimulation of AM root colonization and spore production in the root zone soil by *Azospirillum brasilense* inoculated with *G. aggregatum* in palmarosa. Kothari et al. (1999) observed qualitative changes in the rhizosphere microbial population induced by AM fungi through indirect effect on host physiology and changes in root exudation. Higher populations of free living nitrogen fixing bacteria have been recorded in the rhizosphere of mycorrhizal Java citronella (Naik, 1998).

These results suggest a synergistic or additive influence of AM fungi on bacterial and fungal population. The PGPRs not only supply nutrients and growth hormones to the crop plants but also inhibit some pathogenic fungi present in the soil (Boby and Bagyaraj, 2003). This could be the reason for the decreased incidence of soil borne diseases. The response due to such effects of PGPRs would get reflected in the stand and vigor of the crop thereby in its increased productivity by protecting the crop from pathogenesis by a variety of soil - borne diseases.

5.3.6. Economics of cultivation:

In the present investigation, the use of microbial consortia along with partial chemical fertilization has resulted in saving 50 % of inorganic nitrogen and phosphorus from the recommended dose of fertilizers for patchouli. Similar results have been reported by Pareek et al. (1996) where in, the use of biofertilizer (*Azotobacter*) saved expenditure on use of inorganic fertilizer costing Rs. 300 per ha (40 kg N/ ha) in opium poppy.
The treatments with microbial consortia and fertilizers involved slightly higher cost of cultivation compared to control. However, higher gross income was recorded by the treatments receiving microbial consortia and with recommended NPK alone compared to control. These results support the earlier findings of Maheshwari et al., (1998) in palmarosa and Anuradha (2003) in rosemary.

The cost benefit ratio is an important factor that decides the optimum levels of input to be used in the production of any crop. The cost benefit ratio was calculated with essential oil obtained after distillation of shade dried biomass. The cost benefit ratio worked out for biofertilizers with different levels of NPK fertilizers varied from 1:3.9 to 1: 6.4. the cost benefit ratio was highest in the treatment combination Ge + Ac + Th + Bc alone (1: 6.4) followed by Ge + Ac + Th + Bc + Mm at 50% NP + full K (1: 6.1), treatment with only recommended NPK (1: 5.9) and with Ge + Ac + Th + Bc at 50% NP + full K (1: 5.5). The least cost benefit ratio was observed in the treatment with Ge + Ac + Th + Bc + Mm at 100% NPK (1:1.3) and control (1:1.3).

Small farmers with no access for distillation of oil sell the shade dried biomass in which the returns is less compared to that of oil, though the cost of cultivation is similar in both the cases. The gross revenue varied from Rs. 22.24 to 40.48 per plot after 2 harvests. Highest cost benefit ratio was estimated to be in the treatment with Ge + Ac + Th + Bc alone (1: 1.9), followed by recommended NPK (1: 1.8), Ge + Ac + Th + Bc + Mm at 50% NP + full K (1: 1.7) and with Ge + Ac + Th + Bc at 50% NP + full K (1:1.7). The least was in control (1: 1.3).
In general, the biofertilizers along with reduced levels of nitrogen and phosphorus (50% N, P and 100% K) was found to be highly remunerative and economical by recording maximum net returns.

Similar results have been reported by Wange et al. (1995) in tuberose, while application of 75% NPK plus biofertilizers produced highest net profit in sweet basil (Ajimuddin, 2002). The biofertilizers (Azotobacter + Azospirillum + AM) along with reduced levels of N and P (50% N P and 100% K) was found to be highly remunerative and economical dose as worked out by Anuradha (2003) in rosemary.

It can be concluded that patchouli a highly export oriented perennial crop, could be grown profitably in marginal and dry lands, enriched effectively and productively through the application of biofertilizers, which are also known to act as bioprotectants.