4. SECTION-2

Comparative efficacy of different arbuscular mycorrhizal (AM) fungal species and to select the appropriate propagules/spores number of the efficient AM fungi strain on chickpea var. Avrodhi

4.1 INTRODUCTION

Mycorrhizal associations are symbiotic relationship between arbuscular mycorrhizal fungi (AMF) and the roots of majority of vascular plants (Sylvia, 2005; Castillo et al., 2009). The major benefits of this mycorrhizal association include enhanced plant growth (Pfleger and Linderman, 1994; Jeffries et al., 2003) through improved access to the plants of mineral nutrients and water (Jakobsen et al., 2003; Bohra et al., 2007). Through extensive root external mycelia networks, the fungi improve the capture of relatively immobile nutrients such as P (Mosse, 1981; Ananthakrishnan et al., 2004; Karandashev and Bucher, 2005; Souchie et al., 2006), Cu and Zn, as well as improving water absorption (Auge, 2004), capturing at the same time C fixed as hexose from the apoplast of the root cortical cells (Douds et al., 2005). Mycorrhizal symbiosis plays a key role in nutrient cycling in the ecosystem and also protects plants against environmental and cultivation stress (Barea and Jeffries, 1995), increased resistance and tolerance to drought, and root pathogens in many leguminous crops (Powell et al., 1980; Singh, 1994; Siddiqui and Mahmood, 1995; Akhtar and Siddiqui, 2008, 2010). Many reviews about the importance of AM fungi in agriculture have been published (Ryan and Graham, 2002; Harrier and Watson, 2004; Gosling et al., 2006; Mahmood and Rizvi, 2010). A wide variation was observed among different species of AM fungi in their ability to promote plant growth (Sreenivasa, 1992).

AM fungi vary in their physiological interaction with different hosts and hence in their effect on plant growth. Species and strains of AM fungi have been shown to differ in the extent to which they increase nutrient uptake and plant growth (Powell et al., 1980; Bagyaraj et al., 1989). Thus AMF differ in their ability to promote the growth of a particular host (Carling and Brown, 1980; Krishna and Dart, 1984; Haripriya and Sriramchandrasekharan, 2002). These observations have led to the introduction of the term ‘efficient’ or ‘effective strains’ (Munns and Mosse, 1980; Abbott and Robson, 1981). Generally, those fungi that infest and colonize the root
system more rapidly are considered efficient (Munns and Mosse, 1980). The usefulness of mycorrhizae is especially appropriate in the development of sustainable systems of agriculture (Mosse, 1986), so as to produce the desirable effect in improving the productivity of leguminous crops (Krishna and Bagyaraj, 1984; Hazarika et al., 2000; Charitha and Reddy, 2001; Kumar and Kumar, 2003; Chalk et al., 2006; Bhat et al., 2010). The information to select efficient AM fungi for inoculating chickpea var. Avarodhi to achieve better growth is still meagre. Under natural soil, chickpea is reported to be mycorrhizal (Jalali and Thareja, 1981; Singh and Verma, 1987). Hence, there is a need to identify specific host AM association and to define conditions under which these associations function efficiently. The present study is a step towards the identification of efficient AM fungi for chickpea.

Different AM fungi species induce differential growth responses, in terms of biomass production and clonal growth patterns of coexisting plant species (vander Heijden et al., 1998). Furthermore, the biomass produced by most of the plant species varied significantly among treatments with different single AMF taxa, indicating that different plant species benefited to different extents from different AMF taxa. This led to the concept of host preference by AM fungi (Mosse, 1973).

However, not all AMF/plant combinations are compatible, with some fungi being more beneficial to a host and adapting themselves to determined edapho-climatic conditions, showing marked structural and functional differences among species and even among morphotypes of the same fungal species (Linderman and Davis, 2004). To achieve a satisfactory inoculation effect, it is necessary to know the compatibility between a determined host and the AMF, in order to select the appropriate fungal strain for the specific plant cultivar (Rodriguez et al., 2004).

Phosphorus deficiency is a major limiting factor for growth of legumes in various soils, where P stress may be accompanied by N stress, due to high P requirement of nodule activity. Inoculation with vesicular arbuscular mycorrhizae (VAM) has been shown to increase nodulation, root colonization, dry matter accumulation in shoot, nutrient uptake in legumes and also increase soil fertility status (Singh and Singh, 1993, Alloush et al., 2000; Turk et al., 2006).
Hence, an attempt has been made for the selection of most suitable and efficient AM fungi for chickpea var. Avrodhi from the seven AM species isolated during the survey (Section-I) and also to select the appropriate propagules/spores number of that efficient AM fungi strain on chickpea in order to harness the maximum benefit from the fungus.

4.2 MATERIALS AND METHODS

4.2.1 Preparation and sterilization of soil mixture

Soil, river sand and organic manure were mixed in a ratio of 3:1:1 (v/v/v), divided and kept in jute bags. Little water was poured into each bag to wet the soil after transferring them to an autoclave for sterilization at 137.9 KPa for 20 minutes. Sterilized soil was allowed to cool down at room temperature before filling 15cm diameter clay pots with 1kg of sterilized soil.

4.2.2 Production of AM fungal inoculum

4.2.2a Collection of soil sample

In order to collect spores of AM fungi from each site, soil samples were collected from the crop fields in and around Aligarh with the help of soil auger upto a depth of 15cm from the rhizosphere of the plants. Different types of AMF spores recovered were identified as described in Section-1 and were collected separately.

4.2.2b Isolation of spores

Spores of different species of AM fungi were isolated from the soil as described in Section-1. The following species were found to be of common occurrence in the agricultural fields of the Aligarh district:

- *Glomus fasciculatum*
- *Glomus mosseae*
- *Glomus intraradices*
- *Glomus constrictum*
- *Glomus aggregatum*
Spores of arbuscular mycorrhizal fungi (AMF)

Glomus mosseae

Glomus fasciculatum

Glomus intraradices
Spores of arbuscular mycorrhizal fungi (AMF)

*Glomus constrictum*

*Glomus aggregatum*
Gigaspora gigantea

Acaulospora scrobiculata

All the above mentioned species were evaluated for their potential as effective AMF inoculant for chickpea (var. Avrodhi).

The study was carried out in two parts:

4.2.3 Experiment 2A. To select efficient strain among seven different arbuscular mycorrhizal (AM) fungal species on chickpea:

4.2.3.1 Maintenance of different AM fungi inoculum

Pure culture of seven AM fungi viz., Glomus fasciculatum (Thaxter) Gerdemann and Trappe, Glomus mosseae Gerdemann and Trappe (Nicol. and Gerd.), Glomus intraradices (Schenck and Smith), Glomus constrictum (Trappe), Glomus aggregatum (Schenck and Smith), Gigaspora gigantea Nicol. and Gerd. (Gerd. and Trappe) and Acaulospora scrobiculata (Trappe) collected during the survey (Section-1) were raised separately on Rhode’s grass (Chloris gayana Kunth) grown in sandy loam soil mixed with washed river sand and farmyard manure in the ratio of 3:1:1 (v/v/v) pots under glasshouse conditions. To raise Rhode’s grass, seeds were surface sterilized with 0.01% solution of mercuric chloride (HgCl₂) and sown (5 seeds per pot) in 9cm diameter clay pots, containing sterilized soil. A quantity of 50g inoculum with soil was added around the seeds to inoculate 500 infective propagules of each species of AM fungi per pot (1g inoculum contains 10 infective propagules). The crude inoculum consists of soil, extra-matrical spores, hyphal fragments and infective Rhode’s grass segments. After emergence, seedings were thinned so as to maintain one seedling per pot. After 90 days, the plants were uprooted and the spores were isolated by wet sieving and decanting method from the pot soil and the roots were stained and examined for AM colonization. The population of different AM fungi in the inoculum was assessed by the most probable number method (Porter, 1979).

4.2.3.2 Growth and maintenance of test plant

Seeds of chickpea (Cicer arietinum L.) var. Avrodhi were surface sterilized with 0.01% mercuric chloride for 2 min and then washed three times with distilled
Spores of arbuscular mycorrhizal fungi (AMF)

Gigaspora gigantea

Acaulospora scrobiculata
water. Five sterilized seeds of chickpea were then sown in 15 cm diameter earthen pots containing 950 g sterilized soil and later thinned to one seedling per pot. After germination, the seedlings were inoculated with 50 g soil inoculum containing 500 infective propagules of different AM fungi maintained on Rhode’s grass, as described earlier.

4.2.4 Experiment 2B. To select the appropriate propagules/spores number of the efficient AM fungi strain on chickpea

4.2.4.1 Preparation of efficient AM fungus (Glomus fasciculatum) inoculum

*Glomus fasciculatum* (Thaxter) Gerdemann and Trappe, inoculum was maintained and multiplied on Rhode’s grass (*Chloris gayana*) as described earlier.

4.2.4.2 Growth and maintenance of test plant

Seeds of chickpea (*Cicer arietinum* L.) cv. Avrodhi were surface sterilized with 0.01% mercuric chloride for 2 min and then washed three times with distilled water. Five sterilized seeds of chickpea were then sown in 15 cm diameter earthen pots containing 1 kg sterilized soil and later thinned to one seedling per pot. After germination, the seedlings were inoculated with different inoculum densities (100, 200, 400, 8000 and 1200 spores plant\(^{-1}\)) of *Glomus fasciculatum*.

4.2.5 Inoculation of AM fungi

For inoculation of AM fungus, soil around the roots of the plant was carefully removed without damaging the roots. The inoculum with infective propagules of different species of AM fungi and different inoculum densities (100, 200, 400, 8000 and 1200 spores plant\(^{-1}\)) of *Glomus fasciculatum* were placed around the plant roots and the soil around the roots was replaced.

4.2.6 Experimental design

Both the experiments A and B were carried out in a completely randomized block design. For each treatment, 15 replicates were maintained. A control series was also maintained where no inoculum of AM fungi was added to the soil. The pots were
watered upto the soil capacity and maintained on a glasshouse bench with air temperature ranging from 22±3 °C.

**4.2.7 Observations**

In both the experiments A and B, the plants were terminated 90 days after the inoculation for determining the plant growth, chlorophyll content, nutrient status and mycorrhization parameters of the plants. The samples of the roots and soil were processed as described earlier in Section-I. The performance of the crop raised with added inoculum of selected seven AM fungi were compared with that of control and the AM fungus causing maximum improvement in the performance over control, was selected as efficient AM inoculant for the chickpea var. Avrodhi. The spore level of *Glomus fasciculatum* at which significant increase in plant growth and other parameters recorded was selected as appropriate level of efficient AM inoculant for chickpea.

**4.2.8 Parameters studied**

After termination, the following parameters were determined for each treatment in both the experiments:

- Plant length (cm)
- Plant fresh weight (g)
- Plant dry weight (g)
- Pods plant⁻¹
- Nodules plant⁻¹
- Chlorophyll content (mg g⁻¹ fresh leaves)
- Nutrient contents (mg g⁻¹ fresh leaves)
- Mycorrhization parameters

**4.2.9 Plant growth parameters**

Plant growth parameters were studied in terms of length, fresh weight as well as dry weight of shoots and roots, number of pods and nodules. Plants from each treatment were taken out from the pots and soil particles adhering to roots were
removed by washing in tap water and properly labelled. In the laboratory, shoot and root length were measured by measuring tape and fresh and dry weight of shoots and roots were determined with the help of physical balance. For determining dry weight, plants from each treatment were wrapped in blotting paper sheets, labelled and dried in a hot air oven running at 60 °C for 24-48 h till a constant weight is obtained. The number of pods and nodules were counted manually.

4.2.10 Chlorophyll content (mg g⁻¹ fresh leaves)

Chlorophyll content was estimated by the method of Arnon (1949). 1g finely cut fresh leaves were homogenized in a mortar in the presence of sufficient quantity of 80% acetone. The extract was filtered and supernatant was collected in the volumetric flask. The process was repeated thrice and each time supernatant was collected in the same flask. Finally the volume was made upto 10ml with 80% acetone and kept at 4 °C overnight in dark. After chlorophyll was completely extracted, 5ml chlorophyll solvent was transferred to a transparent cuvette and the absorption values were recorded at 645 and 663 nm in a spectrophotometer against the solvent (80% acetone) blank. The following formula was used to calculate the total chlorophyll content per gram fresh leaves

\[
\text{Total chlorophyll content (mg g}^{-1}\text{) } = 20.2 (A_{645}) + 8.02 (A_{663}) \times \frac{V}{1000} \times w
\]

where \(A_{663}\) = solution absorbance at 663 nm
\(A_{645}\) = solution absorption at 645 nm
\(V\) = volume of solution (taken in cuvette)
\(W\) = weight of leaf tissue used for extraction of pigments i.e. 1g

4.2.11 Nutrient Status (N, P & K) (mg g⁻¹ fresh leaves)

Plant samples of each treatment from the glasshouse experiment were processed for estimating nitrogen (N), phosphorus (P), and potassium (K) contents of plants.
**Estimation of Nitrogen, Phosphorus and Potassium**

For estimation of nitrogen, phosphorus and potassium in plant materials from each treatment, samples were digested in the following way. Estimations were done from the mixed powder of plants of various treatments, in a given experiment. Hundred mg of oven dried powder of plants from each treatment was transferred separately in a 50ml Kjeldahl flask, then 2ml of chemically pure H$_2$SO$_4$ was added and flask was heated on Kjeldahl assembly for about 2h, till dense fumes were given off and the contents turned black. Then 0.5ml of pure 30% H$_2$O$_2$ was added after 15 min of cooling. Heating was continued till the colour changed to light yellow. Extract was heated again for half an hour and cooled for 10 min for getting it clear and then 3-4 drops of 30% H$_2$O$_2$ was added drop wise followed by heating for 15 minutes. After that, the digested material was transferred in 100ml volumetric flask with 3-4 washing and volume was made upto capacity. This digested material was used for estimating N, P and K (Lindner, 1944; Lundegardh, 1951).

**4.2.11a Nitrogen (N)**

Prior to estimating nitrogen present in the digested plant material, standard curve was prepared by the following method:

*Nitrogen standard curve*

Different dilutions in 10 test tubes (0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9 and 1.0 ml) were made from the solution prepared by dissolving 0.236g of ammonium sulphate in 100ml of distilled water. The volume was then made upto 5 ml in each test tube by adding distilled water. A control was also run side by side. After that 0.5ml Nessler’s reagent was added followed by 5ml of distilled water. Percent transmittance was read at 525nm from spectrophotometer on developing yellow orange colour after half an hour. Then a curve was drawn between concentration in X axis and O.D. obtained in Y axis.

*Estimation of N in plant material*

An aliquot of 10ml was transferred to 100ml volumetric flask to which 2ml of 2.5 N NaOH was added so as to neutralize the excess of acid. 1ml of 10% sodium silicate was added to prevent turbidity. The volume was made upto capacity with
distilled water. 5ml of aliquot was taken in three test tubes followed by the addition of 0.5ml of Nessler’s reagent with shaking. Then 10ml volume was made by adding distilled water. After waiting for 5 min, the per cent transmittance was read at 525nm. The concentration was read with the help of O.D. from standard curve (Lindner, 1944).

**4.2.11b Phosphorus (P)**

Prior to estimating phosphorus present in the digested plant material, standard curve was prepared by the following method:

*Phosphorus standard curve*

Different dilutions of potassium dihydrogen orthophosphate (KH$_2$PO$_4$) viz. 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9 and 1.0ml concentrations were taken in separate test tubes and final volume was made upto 5ml by adding required amount of distilled water. 1ml of ammonium molybdic acid and 0.4ml of 1-amino-2-naphthol-4-sulphonic acid were added in each test tube and the volume was made upto 10ml with distilled water. After half an hour, the per cent transmittance was read at 625nm. Standard curve was drawn between concentration and O.D. in X and Y axis respectively.

*Estimation of P in plant materials*

Five ml of aliquot of digested plant material was taken in three test tubes, to which 5ml of distilled water was added. After that 1ml of ammonium molybdic acid was added, with shaking, followed by addition of 0.4ml of 1-amino-2-naphthol-4-sulphuric acid and the volume was made upto 10ml. The control was run side by side and per cent transmittance was read at 625nm after half an hour. The P concentrations in plant materials was calculated from the standard graph using O.D. (Fiske and Subbarow, 1925).

**4.2.11c Potassium (K)**

Prior to estimating potassium present in the digested plant material, standard curve was prepared by the following method:
Potassium standard curve

Potassium was estimated using flame photometer. Different dilutions of potassium chloride viz., 1, 2, 3, 4, 5, 6, 7, 8, 9 and 10 ppm were prepared by dissolving 19mg of oven dried KCl in 100 ml of distilled water and diluting 0, 1, 2, 3, 4, 5, 6, 7, 8, 9 and 10ml of the stock solution to 100ml. The flame photometer was calibrated to zero using distilled water and to 100 using 10ppm KCl solution and readings for other standard solutions were taken. A standard graph was drawn taking concentration in X axis and reading obtained from the flame photometer in Y axis.

Estimation of K in plant materials

The digested plant materials were diluted with distilled water so as to maintain the K concentration in the final solution ranged between 2 to 8 ppm and the reading was taken in the flame photometer and with the help of the standard graph, the concentration of K in plant materials was calculated.

4.2.12 Mycorrhization parameters

Mycorrhization was recorded in terms of external colonization (%), internal colonization (%), per cent arbuscules, number of chlamydomspores in 1cm root segment and number of chlamydomspores recovered from 100g rhizosphere soil.

4.2.13 Statistical analysis

All the data related to plant growth, mycorrhization and nutrient contents were analyzed statistically in simple randomized design by the method of Panse and Sukhatme (1985). Minimum difference required for significance (C.D.) at $P=0.01$ and $P=0.05$ was calculated by the ANOVA model 2 given in Appendix.

4.3 RESULTS

4.3.1 EXPERIMENT-2A

4.3.1.1 Plant length (cm)

Different AM fungi inoculated in the study behaved differently in supporting the growth of chickpea. All the species of Glomus induced better plant growth in terms of shoot, root and total length of chickpea plant (Table 9).

Glomus fasciculatum treated plants showed highest increase in shoot length as compared to control and other AMF inoculated plants (Fig. 4). Plants inoculated with
*G. aggregatum*, *Gigaspora gigantea* and *Acaulospora scrobiculata* did not show a significant increase in shoot length as compared to control.

The root length was also promoted by *G. fasciculatum*. Root length in control as well as in plants inoculated with *Gigaspora gigantea* and *Acaulospora scrobiculata* were significantly lower as compared to the ones treated with *G. fasciculatum*.

The highest increase in total plant length was recorded in case of *G. fasciculatum* (23.74%), followed by *G. mosseae* (20.12%), *G. intraradices* (17.29%) and *G. constrictum* (14.36%). No significant increase in total plant length of chickpea was observed in the plants inoculated with *G. aggregatum, Gigaspora gigantea* and *Acaulospora scrobiculata* (Table 9 and Fig. 4).

### 4.3.1.2 Plant fresh weight (g)

*Glomus fasciculatum* and *G. mosseae* were most effective in increasing plant fresh weight in terms of shoot, root and total fresh weight compared to those treated with other AM fungi and control (Table 9 and Fig. 4).

*G. fasciculatum* promoted the highest value of shoot fresh weight (55.07) as compared to other AM fungi and control. Inoculation of plants with *Gigaspora gigantea* and *A. scrobiculata* however, resulted in no significant increase in shoot fresh weight over control.

Root fresh weight showed the similar trend as that of shoot fresh weight in chickpea plant.

A glance at the data given in table 9 indicates that the total fresh weight of chickpea plants got improved by inoculation with *G. fasciculatum* (27.03%) although it was at par with *G. mosseae* and *G. intraradices*. *G. gigantea* and *A. scrobiculata* treatments did not result in significant increase in total fresh weight of plants over control. *G. fasciculatum* showed a significant increase in total fresh weight of the plants over the control as well as other AM fungi viz., *G. gigantea* and *A. scrobiculata* (Table 9).
4.3.1.3 Plant dry weight (g)

Plant dry weight was studied in terms of shoot, root and total dry weight of chickpea plants (Table 9).

*G. fasciculatum* inoculation resulted in significantly superior shoot dry weight than all other AM fungi inoculations. The inoculation of *G. fasciculatum, G. mosseae, G. intraradices* and *G. constrictum* resulted in almost the same amount of dry weight of shoots (Fig. 4).

Root dry weight in the control plants was found to be at par with those inoculated with *A. scrobiculata* and *G. gigantea*. Highest root dry weight was observed in plants inoculated with *G. fasciculatum*.

*G. fasciculatum* proved to be significantly superior to other AM fungi species in increasing the total plant dry weight. No significant difference could be recorded in plants inoculated with *A. scrobiculata* and *G. gigantea* compared to control. The highest plant dry weight was observed in *G. fasciculatum* (28.54%), followed by *G. mosseae* (24.72%), *G. intraradices* (20.54%), *G. constrictum* (17.59%) and *G. aggregatum* (10.70%) (Table 9 and Fig. 4).

4.3.1.4 Pods plant

*Acaulospora scrobiculata* did not cause significant increase in the number of pods as compared to control. Highest number of pods were recorded in the plants inoculated with *G. fasciculatum* (50) as compared to other AM fungi (Table 9 and Fig. 4).

4.3.1.5 Nodules plant

All AM fungi caused a significant increase in the number of nodules plant, while inoculation of *A. scrobiculata* resulted in the same number of nodules as in control. *G. aggregatum* and *G. constrictum* possess same number of nodules i.e. 6 and *G. fasciculatum* and *G. mosseae* observed highest number of nodules i.e. 8 (Table 9 and Fig. 4).
Table 9. Effect of different arbuscular mycorrhizal fungi on the growth parameters of chickpea plant

<table>
<thead>
<tr>
<th>Treatments</th>
<th>Plant length (cm)</th>
<th>Plant fresh weight (g)</th>
<th>Plant dry weight (g)</th>
<th>Pods plant¹</th>
<th>Nodules plant¹</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Shoot</td>
<td>Root</td>
<td>Total</td>
<td>Shoot</td>
<td>Root</td>
</tr>
<tr>
<td>Control</td>
<td>43.64±2.18</td>
<td>21.82±1.09</td>
<td>65.46±3.27</td>
<td>43.36±2.17</td>
<td>10.84±0.54</td>
</tr>
<tr>
<td>Glomus mosseae</td>
<td>52.44±2.62</td>
<td>26.19±1.31</td>
<td>78.63±3.93</td>
<td>53.81±2.69</td>
<td>13.42±0.67</td>
</tr>
<tr>
<td>Glomus fasciculatum</td>
<td>53.99±2.70</td>
<td>27.01±1.35</td>
<td>81.00±4.05</td>
<td>55.07±2.75</td>
<td>13.78±0.69</td>
</tr>
<tr>
<td>Glomus intraradices</td>
<td>51.25±2.56</td>
<td>25.53±1.28</td>
<td>76.78±3.84</td>
<td>52.45±2.62</td>
<td>13.10±0.66</td>
</tr>
<tr>
<td>Glomus constrictum</td>
<td>49.94±2.50</td>
<td>24.92±1.25</td>
<td>74.86±3.74</td>
<td>51.18±2.56</td>
<td>12.77±0.64</td>
</tr>
<tr>
<td>Glomus aggregatum</td>
<td>48.53±2.43</td>
<td>24.26±1.21</td>
<td>72.79±3.64</td>
<td>49.94±2.50</td>
<td>12.48±0.62</td>
</tr>
<tr>
<td>Gigaspora gigantea</td>
<td>46.74±2.34</td>
<td>23.30±1.16</td>
<td>70.04±3.50</td>
<td>47.13±2.36</td>
<td>11.75±0.59</td>
</tr>
<tr>
<td>Acaulospora scrobiculata</td>
<td>45.18±2.26</td>
<td>22.59±1.13</td>
<td>67.77±3.39</td>
<td>45.64±2.28</td>
<td>11.40±0.57</td>
</tr>
<tr>
<td>C.D. (P=0.05)</td>
<td>4.15</td>
<td>2.07</td>
<td>6.23</td>
<td>4.23</td>
<td>1.06</td>
</tr>
<tr>
<td>C.D. (P=0.01)</td>
<td>5.76</td>
<td>2.88</td>
<td>8.64</td>
<td>5.87</td>
<td>1.47</td>
</tr>
</tbody>
</table>

Data mean±SD of five replicates
Fig. 4 Effect of different arbuscular mycorrhizal fungi on the growth parameters of chickpea plant
4.3.1.6 Chlorophyll content (mg g\(^{-1}\) fresh leaves)

The highest increase in chlorophyll content was observed in plants inoculated with *G. fasciculatum* (21%), followed by *G. mosseae* (17.0%). *G. intraradices*, *G. constrictum*, *G. aggregatum*, *G. gigantea* and *A. scrobiculata* failed to cause a significant increase in the chlorophyll content of plants (Table 10 and Fig. 5).

4.3.1.7 Nutrient contents (N, P & K) (mg g\(^{-1}\) fresh leaves)

No significant difference in N content was noted in the plants inoculated with all AM fungi over control. However, maximum N content (13.81%) was obtained in plants treated with *G. fasciculatum* (Table 10).

The phosphorus (P) content of the plants inoculated with *G. fasciculatum* was the highest (17.08%) followed by *G. mosseae* (13.75%). No significant increase in P content was observed in the plants inoculated with *G. intraradices*, *G. constrictum*, *G. aggregatum*, *Gigaspora gigantea* and *A. scrobiculata* over control.

The potassium (K) content of *G. fasciculatum* inoculated plants (17.71%) was found to be significantly superior to those inoculated with other AM fungi except *G. mosseae* as compared to control. The plants treated with *G. gigantea* and *A. scrobiculata* did not show any significant difference in their K content (Table 10 and Fig. 5).

4.3.1.8 Mycorrhization

The mycorrhization was studied in terms of external colonization (%), internal colonization (%), percent arbuscules, number of chlamydospores in 1cm root segment and number of chlamydospores recovered from 100g rhizosphere soil. The highest increase in all the mycorrhization parameters were observed in case of plants inoculated with *G. fasciculatum* (69%, 62.3%, 58%, 40.4 and 930 respectively), followed by *G. mosseae*, *G. intraradices*, *G. constrictum* and *G. aggregatum*. The values of mycorrhization in case of *Gigaspora gigantea* and *A. scrobiculata* were lesser than the *Glomus* spp. No mycorrhization was found in control (Table 10 and Fig. 5).
Table 10. Effect of different arbuscular mycorrhizal fungi on the chlorophyll content, nutrient status and mycorrhization parameters in chickpea plant

<table>
<thead>
<tr>
<th>Treatments</th>
<th>Chlorophyll content (mg g⁻¹)</th>
<th>Nutrient contents (mg g⁻¹)</th>
<th>External colonization (%)</th>
<th>Internal colonization (%)</th>
<th>Per cent arbuscules</th>
<th>No. of chlamydospores in 1cm root segment</th>
<th>No. of chlamydospores recovered from 100 g rhizosphere soil</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>2.402±0.120</td>
<td>2.68±0.13</td>
<td>0.240±0.012</td>
<td>1.92±0.10</td>
<td>0.0±0.00</td>
<td>0.0±0.00</td>
<td>0.0±0.00</td>
</tr>
<tr>
<td><em>Glomus mosseae</em></td>
<td>2.810±0.141</td>
<td>2.91±0.15</td>
<td>0.273±0.014</td>
<td>2.21±0.11</td>
<td>66.6±3.33</td>
<td>57.0±2.85</td>
<td>52.0±2.60</td>
</tr>
<tr>
<td><em>Glomus fasciculatum</em></td>
<td>2.905±0.145</td>
<td>3.05±0.15</td>
<td>0.281±0.014</td>
<td>2.26±0.11</td>
<td>69.0±3.45</td>
<td>62.3±3.12</td>
<td>58.0±2.90</td>
</tr>
<tr>
<td><em>Glomus intraradices</em></td>
<td>2.701±0.135</td>
<td>2.88±0.14</td>
<td>0.268±0.013</td>
<td>2.13±0.11</td>
<td>60.4±3.02</td>
<td>53.1±2.65</td>
<td>45.1±2.25</td>
</tr>
<tr>
<td><em>Glomus constrictum</em></td>
<td>2.684±0.134</td>
<td>2.84±0.14</td>
<td>0.263±0.013</td>
<td>2.10±0.10</td>
<td>57.2±2.86</td>
<td>52.4±2.62</td>
<td>40.4±2.02</td>
</tr>
<tr>
<td><em>Glomus aggregatum</em></td>
<td>2.613±0.131</td>
<td>2.80±0.14</td>
<td>0.256±0.013</td>
<td>2.04±0.10</td>
<td>52.0±2.60</td>
<td>41.0±2.05</td>
<td>33.0±1.65</td>
</tr>
<tr>
<td><em>Gigaspora gigantea</em></td>
<td>2.522±0.126</td>
<td>2.75±0.14</td>
<td>0.251±0.013</td>
<td>1.99±0.10</td>
<td>45.1±2.25</td>
<td>25.6±1.28</td>
<td>11.8±0.59</td>
</tr>
<tr>
<td><em>Acuulospora scrobiculata</em></td>
<td>2.514±0.126</td>
<td>2.73±0.14</td>
<td>0.248±0.012</td>
<td>1.97±0.10</td>
<td>34.5±1.73</td>
<td>13.3±0.66</td>
<td>6.3±0.32</td>
</tr>
<tr>
<td>C.D. (<em>P</em>=0.05)</td>
<td>0.224</td>
<td>NS</td>
<td>0.022</td>
<td>0.176</td>
<td>4.64</td>
<td>3.90</td>
<td>3.36</td>
</tr>
<tr>
<td>C.D. (<em>P</em>=0.01)</td>
<td>0.310</td>
<td>NS</td>
<td>0.030</td>
<td>0.244</td>
<td>6.44</td>
<td>5.42</td>
<td>4.66</td>
</tr>
</tbody>
</table>

Data mean±SD of five replicates
Fig. 5 Effect of different arbuscular mycorrhizal fungi on the chlorophyll content, nutrient status and mycorrhization parameters in chickpea plant

T1 = Control; T2 = *Glomus mosseae*; T3 = *Glomus fasciculatum*; T4 = *Glomus intraradices*
T5 = *Glomus constrictum*; T6 = *Glomus aggregatum*; T7 = *Gigaspora gigantea*
T8 = *Acaulospora scrobiculata*
4.3.2 EXPERIMENT-2B

4.3.2.1 Plant length (cm)

The effect of different inoculum levels of *Glomus fasciculatum* (100, 200, 400, 8000 and 1200 spores plant$^{-1}$) was studied in terms of shoot, root and total length of chickpea plant (Table 11).

Shoot length progressively increased with an increase in the spore numbers of *G. fasciculatum* However, significant increase in shoot length was found only when 800 or more chlamydospores of *G. fasciculatum* plant$^{-1}$ were inoculated.

With an increase in the spores number of *G. fasciculatum*, the root length also increased. 100, 200 and 400 spores of *G. fasciculatum* plant$^{-1}$ failed to cause a significant increase in root length over control (Fig. 6).

Maximum increase in the total plant length (27.16%) was observed when the highest inoculum level (i.e. 3200 spores plant$^{-1}$) of *G. fasciculatum* was applied. No significant increase in total length of chickpea plant was observed when plants were inoculated with 100–400 spores plant$^{-1}$ of *G. fasciculatum* (Table 11 and Fig. 6).

4.3.2.2 Plant fresh weight (g)

Plant fresh weight in terms of shoot, root and total weight increased with increasing inoculum levels of *G. fasciculatum* (Table 11).

Highest increase in shoot fresh weight (30.69%) was recorded in plants inoculated with 1200 spores and the lowest (4.01%) at an inoculum level of 100 spores plant$^{-1}$ of *G. fasciculatum*. However, significant increase was first observed at 800 spores plant$^{-1}$.

Inoculation of plants with 100, 200 and 400 spores did not cause a significant increase in root fresh weight. Higher spores level i.e. 800 and 1200 spores of *G. fasciculatum* plant$^{-1}$ showed a significant increase in root fresh weight (Table 11).

Total plant fresh weight (25.00%) significantly increased at 800 spores of *G. fasciculatum* plant$^{-1}$. However, when plants were inoculated with 100, 200 and 400 spores of *G. fasciculatum*, there was no significant increase in total fresh weight of chickpea plant over control (Fig. 6).
4.3.2.3 Plant dry weight (g)

With the increase in the spores number of *G. fasciculatum*, plant dry weight in terms of shoot, root and total plant dry weight also increased (Table 11 and Fig. 6).

Different spore numbers of *G. fasciculatum* increase the shoot dry weight. 800 spores plant$^{-1}$ brings significant increase in dry weight of shoot (27.03%) over control.

Root dry weight also showed the similar trend as that of shoot. 100, 200 and 400 spores plant$^{-1}$ failed to cause a significant increase in the dry weight of root. Significant increase (27.16%) was noted at 800 spores of *G. fasciculatum* plant$^{-1}$ (Fig. 6).

Significant increase in total plant dry weight with respect to control was found only when 800 or more spores of *G. fasciculatum* plant$^{-1}$ were inoculated. Maximum increase in total plant dry weight (32.23%) of chickpea was observed in plants receiving the highest spore inoculum i.e. 1200 spores plant$^{-1}$ (Table 11).

4.3.2.4 Pods plant$^{-1}$

All the inoculum levels (100, 200, 400, 800 and 1200 spores plant$^{-1}$) of *G. fasciculatum* increase the pods number in chickpea plant. However, no significant increase was observed at 100 spores plant$^{-1}$ level as compared to control. Highest pods number (54) were recorded at 1200 spores plant$^{-1}$ while lowest (34) being recorded at 100 spores of *G. fasciculatum* plant$^{-1}$ (Table 11 and Fig. 6).

4.3.2.5 Nodules plant$^{-1}$

Root nodulation increased significantly at all the spore densities of *G. fasciculatum* as compared to control. Highest, 10 and lowest, 5 being recorded at 1200 and 100 spores plant$^{-1}$ respectively in chickpea (Table 11 and Fig. 6).

4.3.2.6 Chlorophyll content (mg g$^{-1}$ fresh leaves)

It was evident from the table 12 that different spore densities of *G. fasciculatum* increased the chlorophyll content in chickpea plant. But this increase/variation was not found significant at 100, 200 and 400 spores plant$^{-1}$ level.
Table 11. Effect of different spore numbers of arbuscular mycorrhizal fungus, *Glomus fasciculatum* on the growth parameters of chickpea plant

<table>
<thead>
<tr>
<th>Treatments</th>
<th>Plant length (cm)</th>
<th>Plant fresh weight (g)</th>
<th>Plant dry weight (g)</th>
<th>Pods plant(^1)</th>
<th>Nodules plant(^1)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Shoot</td>
<td>Root</td>
<td>Total</td>
<td>Shoot</td>
<td>Root</td>
</tr>
<tr>
<td>Control</td>
<td>43.64±2.18</td>
<td>21.82±1.09</td>
<td>65.46±3.27</td>
<td>43.36±2.17</td>
<td>10.84±0.54</td>
</tr>
<tr>
<td>100 spores</td>
<td>45.39±2.27</td>
<td>22.73±1.14</td>
<td>68.12±3.41</td>
<td>45.10±2.25</td>
<td>11.23±0.56</td>
</tr>
<tr>
<td>200 spores</td>
<td>46.69±2.34</td>
<td>23.35±1.17</td>
<td>70.04±3.50</td>
<td>46.05±2.30</td>
<td>11.51±0.58</td>
</tr>
<tr>
<td>400 spores</td>
<td>48.96±2.45</td>
<td>24.41±1.22</td>
<td>73.37±3.67</td>
<td>48.92±2.45</td>
<td>12.26±0.61</td>
</tr>
<tr>
<td>800 spores</td>
<td>53.67±2.68</td>
<td>26.84±1.34</td>
<td>80.51±4.03</td>
<td>54.18±2.71</td>
<td>13.57±0.68</td>
</tr>
<tr>
<td>1200 spores</td>
<td>55.49±2.77</td>
<td>27.75±1.39</td>
<td>83.24±4.16</td>
<td>56.67±2.83</td>
<td>14.16±0.71</td>
</tr>
<tr>
<td>C.D. (P=0.05)</td>
<td>4.57</td>
<td>2.29</td>
<td>6.86</td>
<td>4.58</td>
<td>1.14</td>
</tr>
<tr>
<td>C.D. (P=0.01)</td>
<td>6.50</td>
<td>3.25</td>
<td>9.75</td>
<td>6.51</td>
<td>1.63</td>
</tr>
</tbody>
</table>

Data mean±SD of five replicates
Fig. 6 Effect of different spore numbers of arbuscular mycorrhizal fungus, *Glomus fasciculatum* on the growth parameters of chickpea plant.

T1 = Control
T2 = 100 Spores
T3 = 200 Spores
T4 = 400 Spores
T5 = 800 Spores
T6 = 1200 Spores
Significant increase (19.73%) was observed when 800 spores of *G. fasciculatum* plant$^{-1}$ were inoculated (Fig. 7).

**4.3.2.7 Nutrient contents (N, P & K) (mg g$^{-1}$ fresh leaves)**

The nutrient contents were studied in terms of N, P and K in chickpea plants (Table 12 and Fig. 7).

With an increase in the spore densities of *G. fasciculatum* (100, 200, 400 800 and 1200 plant$^{-1}$), the nitrogen content considerably increased. 100 and 200 spores plant$^{-1}$ did not cause a significant increase in N content of the plants. Significant increase being observed at 400 spores plant$^{-1}$ and above spore densities of *G. fasciculatum*.

The phosphorus (P) content also showed the similar trend as that of nitrogen content. Highest increase in P (45.42%) being observed at 1200 spores plant$^{-1}$ and lowest (5.00%) at 100 spores plant$^{-1}$ of *G. fasciculatum* (Fig. 7).

Significant increase in potassium (K) content of chickpea plants was observed at 800 (21.35%) and 1200 (25.52%) spores plant$^{-1}$ level as compared to control. Lower inoculum densities of *G. fasciculatum* i.e. 100, 200 and 400 spores plant$^{-1}$ failed to cause a significant increase in K content of the plants (Table 12).

**4.3.2.8 Mycorrhization**

The mycorrhization of different spores number of AM fungi, *G. fasciculatum* plant$^{-1}$ were estimated by using five parameters as given in table 12. Significant increase in all the mycorrhization parameters was observed at 400 spores plant$^{-1}$ except at 200 spores plant$^{-1}$ level in case of external colonization (%). Lower level of spores number i.e. 100 and 200 spores plant$^{-1}$ failed to cause a significant increase in the mycorrhization in chickpea plant. The highest percentage of external colonization (70.0%), internal colonization (66.3%), arbuscules (65.1%), average number of spores/chlamydomspores in 1cm root segment (63.4) and average number of spores/chlamydomspores recovered from 100g rhizosphere soil (940) were recorded in plants inoculated with 1200 spores plant$^{-1}$ (Fig. 7).
Table 12. Effect of different spore numbers of arbuscular mycorrhizal fungus, *Glomus fasciculatum* on the chlorophyll content, nutrient status and mychorrization parameters in chickpea plant

<table>
<thead>
<tr>
<th>Treatments</th>
<th>Chlorophyll content (mg g⁻¹)</th>
<th>Nutrient contents (mg g⁻¹)</th>
<th>External colonization (%)</th>
<th>Internal colonization (%)</th>
<th>Per cent arbuscules</th>
<th>No. of chlamydospores in 1cm root segment</th>
<th>No. of chlamydospores recovered from 100 g rhizosphere soil</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>2.402±0.120</td>
<td>2.68±0.13</td>
<td>0.240±0.012</td>
<td>1.92±0.10</td>
<td>0.0±0.00</td>
<td>0.0±0.00</td>
<td>0.0±0.00</td>
</tr>
<tr>
<td>100 spores</td>
<td>2.498±0.125</td>
<td>2.79±0.14</td>
<td>0.252±0.013</td>
<td>1.98±0.10</td>
<td>28.5±1.42</td>
<td>31.1±1.55</td>
<td>30.5±1.52</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>27.6±1.38</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>725.0±36.3</td>
</tr>
<tr>
<td>200 spores</td>
<td>2.556±0.128</td>
<td>2.93±0.15</td>
<td>0.263±0.013</td>
<td>2.04±0.10</td>
<td>37.3±1.87</td>
<td>35.4±1.77</td>
<td>33.2±1.66</td>
</tr>
<tr>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td>32.5±1.63</td>
</tr>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>761.0±38.0</td>
</tr>
<tr>
<td>400 spores</td>
<td>2.661±0.133</td>
<td>3.15±0.16</td>
<td>0.284±0.014</td>
<td>2.12±0.11</td>
<td>45.4±2.27</td>
<td>43.2±2.16</td>
<td>40.4±2.02</td>
</tr>
<tr>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>37.1±1.85</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>804.0±40.2</td>
</tr>
<tr>
<td>800 spores</td>
<td>2.876±0.144</td>
<td>3.61±0.18</td>
<td>0.329±0.016</td>
<td>2.33±0.12</td>
<td>62.7±3.13</td>
<td>61.7±3.09</td>
<td>59.3±2.97</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>58.0±2.90</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>893.0±44.7</td>
</tr>
<tr>
<td>1200 spores</td>
<td>2.957±0.148</td>
<td>3.79±0.19</td>
<td>0.349±0.017</td>
<td>2.41±0.12</td>
<td>70.0±3.50</td>
<td>66.3±3.32</td>
<td>65.1±3.25</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>63.4±3.17</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>940.0±47.0</td>
</tr>
<tr>
<td>C.D. (P=0.05)</td>
<td>0.248</td>
<td>0.294</td>
<td>0.027</td>
<td>0.199</td>
<td>4.18</td>
<td>4.09</td>
<td>3.94</td>
</tr>
<tr>
<td></td>
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<td>3.77</td>
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<tr>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>70.40</td>
</tr>
<tr>
<td>C.D. (P=0.01)</td>
<td>0.353</td>
<td>0.419</td>
<td>0.038</td>
<td>0.283</td>
<td>5.95</td>
<td>5.81</td>
<td>5.61</td>
</tr>
<tr>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>5.36</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>100.13</td>
</tr>
</tbody>
</table>

Data mean±SD of five replicates
Fig. 7 Effect of different spore numbers of arbuscular mycorrhizal fungus, *Glomus fasciculatum* on the chlorophyll content, nutrient status and mycorrhization parameters in chickpea plant.
4.4 DISCUSSION

In the present study, it has been found that the mycorrhizal status and growth responses due to mycorrhizal treatments are considerably high in all the treatments compared to control and the different strains of AM fungi differ in their capability to promote plant growth and nutrient levels. Wide variations in the growth promoting efficiency of different AM fungi have already been brought to light in the past (Kuo and Haung, 1982; Luis and Brown, 1986; Umadevi and Sitaramaiah, 1990; Sundaram and Arangarasan, 1995). There are reports of the past to indicate the difference between the three major genera of AM fungi in their ability to stimulate plant growth and P uptake on soybean and pearl millet (Carling and Brown, 1980; Krishna and Dart, 1984). Bagyaraj et al. (1989) reported that different strains of AM fungi have different capability to increase the nutrient uptake and plant growth, and therefore there is a need for selecting the efficient ones. It has been found in the present study, that the extent of mycorrhization in soil varies with different AM fungi species. They also vary in their preference to the host. Root colonization has been found to facilitate more host fungal contact and exchange of nutrients, resulting in better plant growth. A parallel case has been reported by Abbott and Robson (1982).

The usefulness of AM fungi is demonstrated by the enhanced value of plant growth parameters. Enhanced plant growth and yield resulting from the use of AM fungi has been reported by many workers (Manjunath and Bagyaraj, 1984; Ramraj and Shanmugam, 1990; Reddy and Bagyaraj, 1990; Jothi and Sundarababu, 2000; Earanna et al., 2002; Haripriya and Sekharan, 2002; Anilkumar and Kurup, 2003; Estauna et al., 2003; Gazey et al., 2004; Wu and Xia, 2006; Borde et al., 2009). The mycorrhizal association is found to be beneficial to the plants in terms of better nutrient uptake and better water potential which lead the plants to become more healthy and productive than the non-mycorrhizal plants (Khaliq et al., 2001). AM fungi also enhance the concentration of different organic compounds in roots and can improve the productivity of host plants (Selvaraj et al., 1995).

Out of the seven AM fungi investigated, *G. fasciculatum* promoted better plant growth, and nutrients uptake of chickpea plants compared to others. *G. fasciculatum* inoculated plants also recorded the highest mycorrhization parameters over other AM fungi. Earlier studies also showed such a trend for other plants subjected to AM
inoculation (Bukhari and Rodrigues, 2008; Rajeshkumar et al., 2008; Ndiaye et al., 2009; Nisha and Rajeshkumar, 2010). Sundaram and Arangarasan (1995) reported that out of four cultures of AM fungi, *G. fasciculatum* gives the highest fruit yield in tomato plants.

The results in the present study are in agreement with those who found that the AM fungi improve plant growth mainly through increased P uptake and other nutrients, resulting in better growth, yield and dry matter. This has also been reported for many crops such as barley, onion, soybean, rice and blackgram (Kuo and Haung, 1982; Luis and Brown, 1986; Jeffries, 1987; Umadevi and Sitaramaiah, 1990). The nutritional status of chickpea viz. nitrogen, phosphorus and potassium content was also significantly higher in plants raised in soil inoculated with AM fungi. The extent of increase in plant nutrient content varied among the fungi studied. Seedlings grown in the presence of *G. fasciculatum* had significantly higher content of nutrients followed by *G. mosseae*. Such variation in plant nutrient status in relation to the fungal species for other plant species are well documented (Rajan et al., 2004; Rajeshkumar et al., 2008; Ndiaye et al., 2009). Differences on N, P and K uptakes recorded with *Glomus* species, confirmed that genetic factors play a role in translocation of mineral elements (Diop et al., 2003). The enhancement in growth and nutritional status is also related to the per cent root colonization apart from several soil and environmental factors. Improved phosphorus nutrition has been found to decrease membrane permeability which reduces the root exudation (Graham et al., 1981). A significant increase in P level has been reported by Sulochana et al. (1995) in cassava and in chickpea by Singh and Verma (1987), where *G. fasciculatum* and *G. etunicatum* proved to be most effective ones for the respective crops. These mycorrhizal mycelia coupled with increased nutrient uptake resulted in the better performance of the mycorrhizal plants. It has been reported by Rhodes and Gerdemann (1975) that the mycorrhizal plants can exploit several times the volume of soil available to a non-mycorrhizal plants and achieve more active translocation of minerals.

Similar observations pertaining to the increased phosphorus uptake by VAM treated plants have been reported by early workers (Ratti et al., 2002; Game and Navale, 2006; Ojha et al., 2008). The external VAM hyphae reach beyond the
depletion zone around the root hairs, absorb soil P and translocate it, perhaps in the form of polyphosphate granules, to the arbuscules where P is transferred to the plant cell in exchange of carbon (Mago and Mukerji, 2003).

It was also observed that *Glomus fasciculatum* inoculated chickpea seedlings showed significantly greater amount of chlorophyll content than uninoculated control plant. Significant increase in chlorophyll content, shoot and root length and total biomass of different plants was observed following inoculation with *Glomus* species (Matsubara and Sakurai, 2000; Ratti et al., 2002; Reddy et al., 2006). Thus, mycorrhizal fungi offer an environmentally sound biological alternative to chemical fertilizers and pesticides for maintaining plant quality and productivity in agriculture, horticulture and forestry (Wood, 1992; Singh, 2002).

Species and strains of AM fungi were different in their ability in the nutrient uptake and influencing growth (McGraw and Schenck, 1980; Bagyaraj, 1992). Interspecific differences in the effectiveness of AM have been reported in *Paspalum notatum* (Mosse, 1973), onion and cloves (Powell, 1975) and soybean (Carling and Brown, 1980). Such variation in efficiency of AM could be attributed to their intrinsic ability to explore more soil area for nutrients, plant fungal compatibility and the interaction between endophytes and their environment (McGraw and Schenck, 1980; Bagyaraj, 1992). This finding emphasizes the need to screen and select AM fungi for different mycotrophic crop plants (Ananthakrishnan et al., 2004).

This study clearly shows an efficient biological response of chickpea plant seeding towards different AM fungi, with *G. fasciculatum* conferring greater benefits compared to all other fungi used. The results clearly indicate that AM fungal inoculation can substantially reduce fertilizer requirement in seeding production. Application of efficient AM fungal symbionts can be effective in obtaining healthy seeding which could be used commercially.

4.5 CONCLUSION

In the present study, the most abundant mycorrhizal species recovered from the twelve sites in Section-I, i.e. *G. fasciculatum*, *G. mosseae*, *G. intraradices*, *G. constrictum*, *G. aggregatum*, *Gigaspora gigantea* and *Acaulospora scrobiculata* were selected, inoculated and screened for their symbiotic response with chickpea. In
general, the seedlings inoculated with AM fungi responded better than the uninoculated control. Plants inoculated with *G. fasciculatum* has significantly greater growth parameters, chlorophyll and nutrient contents compared to other six AM fungi and control treatments. The mycorrhization parameters also varied within the species. *G. fasciculatum* @ 800 spores plant\(^{-1}\) could be, therefore, designated as the potential AM inoculant for chickpea var. Avrodhi for successful plant growth and yield.

### 4.6 SUMMARY

1. A study was conducted to screen and select potential arbuscular mycorrhizal fungi (AMF) and the appropriate propagules/spores number of that efficient AM fungi strain on chickpea for chickpea var. avrodhi in sandy clay loam soil of aligarh.

2. Seven different AMF were evaluated for their efficacy in terms of growth characteristics, chlorophyll content, nutrients status and mycorrhization parameters.

3. Inoculation with AMF species resulted in higher plant growth, biomass, chlorophyll and nutrient status (N, P & K).

4. Measurement of chickpea plant harvested at 90 days after inoculation responded to its best with *Glomus fasciculatum* inoculation followed by *G. mosseae, G. inraradices, G. constrictum, G. aggregatum, Gigaspora gigantea* and *Acaulospora scrobiculata* in terms of plant length, fresh and dry weight, pods and nodule number, chlorophyll and nutrient contents and mycorrhizal colonization.

5. Out of seven AM fungi screened, *Glomus fasciculatum* @ 800 spores plant\(^{-1}\) was found to be the most efficacious AMF for chickpea which can be used as biofertilizer and potential biocontrol agent.