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Chapter

Mycorrhizae Applications in Sustainable Forestry

Dayakar Govindu, Anusha Duvva and Srinivas Podeti

Abstract

Arbuscular mycorrhizal (AM) association is the most common symbiotic association of plants with microbes. AM fungi occur in the majority of natural habitats and they provide a range of important biological services, in particular by improving plant nutrition, abiotic resistance, and soil structure and fertility. AM fungi also interact with most crop varieties and forest plants. The possible benefit of AM fungi in forestry can be achieved through a combination of inoculum methods. The mycorrhizal inoculum levels in the soil and their colonization in different forest plant roots which leads to reduce the fertilizers, pathogen effects and fungicides and to protect topsoil, soil erosion, and water-logging. Currently, several reports were suggested that AM symbiosis can improve the potential for different plant species. Two steps could be used to produce high yielding of different plant biomass that would be both mycorrhizal dependency and suitability for sowing into the field with high inoculum levels Therefore, the wide-scale inoculation of AM fungi on forest trees will become economically important. The successful research is required in the area of mass production of AM fungal inoculum and AM fungi associated with roots which will contribute to sustainable forestry.

Keywords: mycorrhizae, sustainable forestry, mycorrhizal dependency, biomass

1. Introduction

Arbuscular mycorrhizal fungi are ubiquitous soil microorganisms. AM fungi have great potential to increase plant growth and soil aggregate formation which improves soil quality and development of plant health [1] AM fungi and microorganisms in the rhizosphere contaminate roots and fabricate rich nutrients condition for plant development [2]. The advantage of AM growths in the field conditions with singular organisms is commonly identified with the rate and degree of mycorrhiza arrangement [3]. Management of AM fungi is required in forestry for high yielding and biomass production to be derived from economic and environmental conditions. Determining the magnitude of benefits from improved AM fungi management the three important factors are required. 1. Mycorrhizal dependency 2.Nutrient status of soil 3. Potential of AM fungal inoculum. The terrestrial plant roots develop AM fungi with natural resources of 80–90% symbiosis [4] Global occurrence in forest ecosystems and form 50% of microbial biomass in the tropical ecosystem. [5]. Among different important functions of the plant-fungal symbiosis, plant growth promotion activity is stimulated by the phosphorus uptake [6]. AMF increase nutrient uptake for the plants, particularly immobile nutrients such as phosphorus (P), copper (Cu), and zinc (Zn) in the soil which are not accessible to plant roots in normal condition due to slow immobility [7].

Moreover, AM fungi support tolerance to the plants from different environmental stresses such as salinity, drought, heat, and pollutants in the rhizosphere soil [8, 9]. Presently, effective management of AM fungi is possible by agronomic practices.

Mycorrhizal dependency (MD) is the most important in developing the management of crop plants and forest trees. Forest plant species derive profit from AM fungi to facilitate equally, another crop species is highly dependent on AM fungi for nutrition, biomass, and growth [10]. The most agricultural plants and forest tree species are hosts of AMF, not all benefit equally. The RFMD (relative field mycorrhizal dependency) proposed by Plenchette et al. [11] expresses the difference in dry biomass between mycorrhizal and non-mycorrhizal treatments as a percentage of the biomass of mycorrhizal treatment. This method is very useful in the ranking of different host plants with an individual experiment but absolutely the values of RFMD will depend on the nutrient status of the soil. Abbot and Robson [12] have suggested the need to assess the importance of AM to a host across a full range of soil P levels by determining the response curves for mycorrhizal and non-mycorrhizal plants.

In some forest soils, the response of some crop species to AM fungi is expressed as N as well as phosphate benefits [13]. AM inoculation did not significantly increase shoot dry matter of rice, but it produced significantly higher in biomass than the non-mycorrhizal ones.

A perusal of the **Table 1** reveals that all the 10 tree saplings have shown mycorrhizal infection. However, the percent of colonization varied with the tree species. Maximum colonization was observed in *Azadirachta indica* followed by *Albizia lebbeck, Gliricidia maculate.* Least colonization was observed in *Tamarindus indica.* The differences in infection are due to edaphic conditions and the age of the plant. With few exceptions, a direct correlation can be observed between the percent of mycorrhizal colonization and phosphorus content of the plants. Although the saplings with a high percent of colonization show high MD, there is no direct correlation between these two parameters. For instance, the *Leucaena leucocephala* with 78 colonization has shown more MD than *Azadirachta indica* with the highest AM fungal colonization. Thus it is obvious

S. No.	Plant species	% of colonization	P content (%)				Mycorrhizal Dependency (MD)
			Mycorrhizal		Non-mycorrhizal		
			Shoot	Root	Shoot	Root	
1	*Acacia nilotica*	67	0.20	0.30	0.12	0.20	170
2	*Albizia lebbeck*	88	0.80	0.90	0.60	0.70	240
3	*Albizia procera*	72	0.70	0.90	0.50	0.60	210
4	*Hardiwikia binata*	76	0.50	0.70	0.23	0.28	196
5	*Gliricidia macula*	80	0.70	0.80	0.30	0.40	215
6	*Leucaena leucocephala*	78	0.60	0.80	0.31	0.70	213
7	*Acacia melanoxylon*	71	0.40	0.40	0.20	0.26	183
8	*Azadirachta indica*	90	0.90	0.90	0.71	0.80	253
9	*Tamarindus indica*	54	0.10	0.10	0.09	0.12	104
10	*Tectona grandis*	78	0.60	0.80	0.70	0.83	212

Table 1.
Mycorrhizal dependency of some foresty tree species saplings.

that the extent of mycorrhizal colonization has no relation with MD. The plants even with moderate infection may also exhibit high Mycorrhizal dependency. Mycorrhizal dependency of *Acacia nilotica* lowers as the P-level in soil was increased [14].

2. Distribution of AM fungi in forestry

Forests play a progressively more crucial role in gathering the demand for timber and ecological protection, nearly 25% (one fourth) of India's total land area is now under forest land and tree cover. The diminishing soil quality is the main warning to sustainable forest management, mostly in planted forests. Microorganisms show significant functions in soil formation, aggregation nutrient cycling, nutrient uptake, and reclamation of ecosystems [15]. The arbuscular mycorrhizal fungi (AMF) form symbiotic associations by the plant roots of more than 80% of plants [16], and they play a crucial role in the successful organization and maintenance of plant communities [17]. AMF hyphae can add phosphorous (P), which cannot be absorbed by root hairs, and the AMF soil mycelial arrangement provides many profits to host plants [18] as well as plant growth promotion [19, 20] and development of plant resistance to abiotic stress and disease [21]. Additionally, AM fungi can be favorable to soil aggregation as the outcome of the activities of hyphae and glomalin protein secretion [22] therefore, the incidence and colonization of AM fungi would be helpful to the survival of forest seedlings and the sustainable managing of forests. Furthermore, the AM fungal species associated with plant species have elucidated different functions to host plants and influences on the distribution, diversity, and restoration of plant community [23] The diversity of AM fungi is significantly important to forest ecosystems and can be important for plant community and productivity [24, 25] Though, information about the diversity of AMF associated with tree species in forest plants is inadequate. It is a known fact the AM fungi are extensive in different ecosystems, and their colonization and spore propagules are also affected by soil physicochemical characteristics [26]. The abiotic factors could influence on root colonization and fungal spore population.

The AM fungi colonization and spore commune compositions in the rhizosphere of the tree species were estimated. The outcome of this study would provide close on the utilization and supervision of AM fungi to keep sustainable management of forests [27].

2.1 Forest soils

Table 2 reveals that AM fungal spore population was found highest in Kothagudem soil of *Albizia lebbeck*, while it was lowest in Godavarikhani soils of *Acacia nilotica*. The AM fungal spore population range was varying in the rhizosphere soils of Kothagudem followed by Yellendu, Bhopalpally, and Kothagudem. On other hand, rhizosphere soil showed a great variation in the incidence of different AM fungi both qualitatively and quantitatively. *Glomus* species was dominating in all the rhizosphere soils, followed by *Gigaspora* species was recorded highest in the rhizosphere of *Acacia nilotica* of Bhopalpally soil and it was least in Kothagudem. Similarly, *Sclerocystis* species was found highest in Kothagudem soil of *Acacia nilotica*, while it was least in Godavarikhani soil of *Acacia nilotica*. *Acaulospora* species was recorded highest in Bhupalpally and it was lowest in Godavarikhani soil. No *Acaulospora* species was observed in Godavarikhani and Yellandu the soils of *Albizia lebbeck*. *Scutellospora* was least in Godavarikhani and Bhupalpally soils. In the rhizosphere soils of the analyzed tree species, bountiful spore numbers, and high decent varieties of AMF species were found (**Figure 1**) [28].

Location	Plant species	Cumulative spore number	Individual spore incidence				
			Glomus	*Gigaspora*	*Sclerocystis*	*Aculospora*	*Scutellospora*
Kothagudem	*A.lebbeck*	155.0 ± 1.53	98	21	32	4	—
	A.nilotica	92.7 ± 1.45	63	12	11	6	—
Bhupalpally	*A.lebbeck*	106.7 ± 1.20	76	12	9	6	3
	A.nilotica	137.0 ± 1.73	72	35	16	9	5
Godavarikhani	*A.lebbeck*	82.3 ± 0.88	48	16	12	—	6
	A.nilotica	63.7 ± 1.45	39	13	8	3	—
Yellandu	*A.lebbeck*	98.2 ± 0.33	57	23	18	—	—
	A.nilotica	118.7 ± 1.45	80	15	10	7	6

Table 2.
Incidence of AM fungi in two Agroforestry tree species of four forest sites of North Telangana. Forest soils.

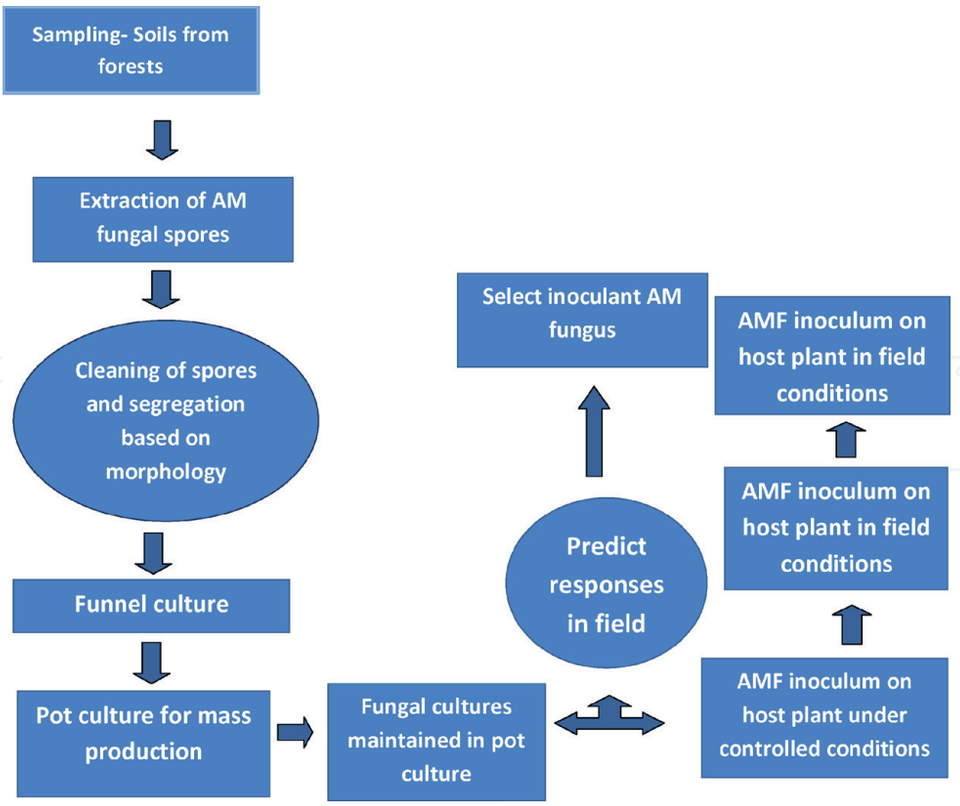

Figure 1.
Isolation and selection of AM fungi for host plant.

2.2 Coal mine soils

Table 3 results showed that AM spore number in rhizosphere soil was studied in different Coal mine sites of North Telangana. The results are depicted that AM spore population was observed in two different plant species. AMF root colonization is presented in **Figure 2**, highest root colonization was recorded in the Kothagudem sample of *Albizia lebbeck*, while it was a significantly higher level of AM fungal spore population was also seen in the same sample. The lowest colonization was found in *Acacia nilotica* of Godavarikhani, but the moderate spore population was observed. The lowest level of mycorrhizal colonization was found in Godavarikhani and Bhopallpally rhizosphere samples of *Albizia lebbeck* and *Acacia nilotica* respectively. However, the AM fungal spore population incidence varies. The highest AM fungal spore population was recorded in Kothagudem soil followed by Bhopalpally and the same trend was observed in Godavarikhani and Yellandu. The AM fungal spore population varied from species to species. *Glomus* species was dominated in all the rhizosphere soil samples of two plants. Past investigations have additionally detailed *Glomus* and *Acaulospora* to be the dominant genera in different woods [26, 29] *Gigaspora* species was highest in the rhizosphere of *Albizia lebbeck* of Kothagudem, while it was significantly lowest in Yellandu soils followed by *Sclerocystis, Acaulospora,* and *Scutellospora*. Similarly, *Acaulospora* species was found highest in the rhizosphere of *Albizia lebbeck* of Bhopalpally. *Sclerocystis* species was found highest in Kothagudem soils, while it was lowest in Bhopalpally soils. *Scutellospora* spore incidence was observed more in the rhizosphere of *Acacia nilotica* than *A.lebbeck*, but it was found less number in other samples. Interestingly, No *Scutellospora* species was recorded in the rhizosphere of *Albizia lebbeck* in Godavarikhani soil as shown in **Table 4**.

Some AM fungi react diversely to soil disturbances, for instance, Hart and Reader [30] identified that species from the suborder Glomineae were substantially

Location	Plant species	Cumulative spore number	Individual spore incidence				
			Glomus	*Gigaspora*	*Sclerocystis*	*Aculospora*	*Scutellospora*
Kothagudem OCS	*A.lebbeck*	79.7 ± 1.45	31	26	11	8	3
	A.nilotica	61.3 ± 1.76	26	15	9	6	4
Bhupalpally OCS	*A.lebbeck*	55.7 ± 2.33	33	11	4	5	2
	A.nilotica	63.3 ± 0.88	29	12	10	9	3
Godavarikhani OCS	*A.lebbeck*	73.0 ± 1.73	44	14	10	5	—
	A.nilotica	48.7 ± 1.20	17	15	6	6	4
Yellandu OCS	*A.lebbeck*	53.7 ± 1.45	29	10	7	5	2
	A.nilotica	44.3 ± 0.88	15	13	10	4	2

Table 3.
Incidence of AM Fungi in two Agroforestry tree species of four coal mine Opencast sites(OCS) of North Telangana.

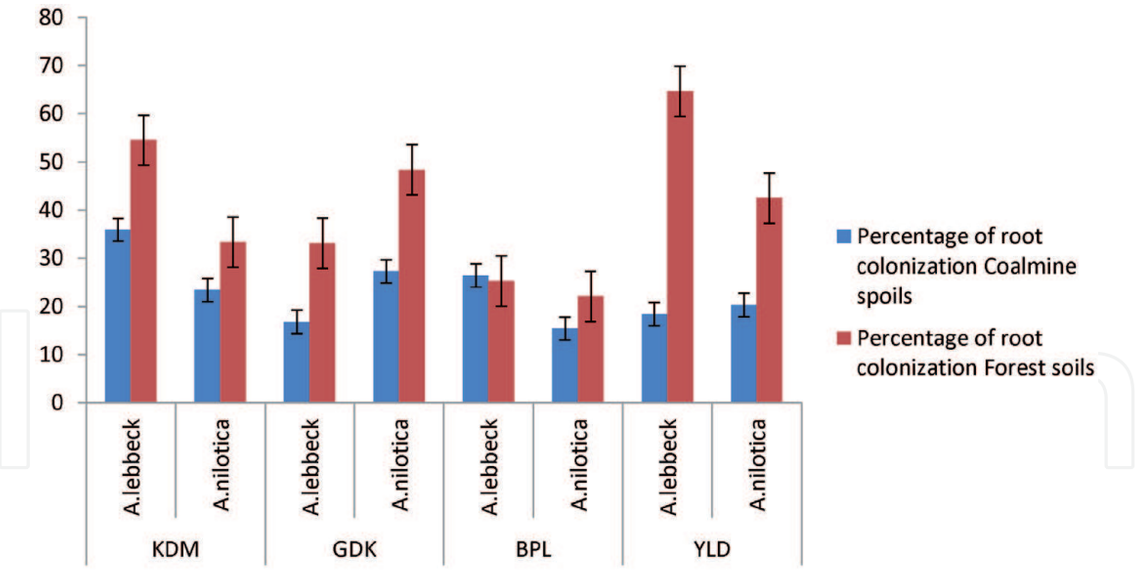

Figure 2.
Percentage of root colonization in two different soil types. KDM-Kothagudem, GDK- Godavarikhani, BPL-Bhopallaly, YLD-Yellandhu.

S. No	Treatments	Root colonization (%)	Height of plant (cm)	Biomass (g)		Phosphorus (mg/g)	
				Fresh wt.	Dry wt.	Shoot	Root
Albizia lebbeck							
1	*Glomus fasciculatum (Rhizophagus fasciculatum)*	72.6	112.1	125.2	108.8	0.36	0.12
2	*Glomus aggregatum (Rhizophagus aggregatus)*	76.4	120.2	142.6	116.3	0.42	0.38
3	*Gigaspora gigantea*	50.2	83.2	111.1	86.2	0.36	0.16
4	*Acaulospora foveata*	52.4	96.6	128.3	110.6	0.26	0.18
5	*Sclerocystis sp.*	39.7	86.5	98.2	65.3	0.14	0.10
6	*Control*	—	76.0	90.0	62.4	0.32	0.15
Acacia nilotica							
1	*Glomus fasciculatum (Rhizophagus fasciculatum)*	70.0	160.1	168.1	141.9	0.46	0.34
2	*Glomus aggregatum (Rhizophagus aggregatus)*	62.4	148.9	152.6	133.6	0.32	0.27
3	*Gigaspora gigantea*	69.6	154.2	156.1	139.2	0.41	0.29
4	*Acaulospora foveata*	50.4	120.2	136.2	99.3	0.25	0.16
5	*Sclerocystis sp.*	37.6	97.0	111.2	84.5	0.32	0.22
6	*Control*	—	68.8	72.8	59.1	0.22	0.12

Table 4.
Screening of Albizia lebbeck and Acacia nilotica for efficient strains of AM fungi.

less tough to soil disturbances than species from the suborder Gigasporineae, likely because of the qualities of either colonizing plant roots generally by hyphae or by spores.

Figure 2 shows the highest root colonization in the rhizosphere of *Albizia lebbeck* of Yellendu, while it was least in Bhopalpally soil. The percentage of root colonization was significantly varied with the type of soil. AM colonization was recorded moderately in the soil of Godavarikhani. No correlation could be observed between AM colonization and the spore population.

3. AM fungal inoculum development

AMF resting spores collected by stereo binocular microscope were surface sterilized with 200 ppm streptomycin for 15 min and washed in sterile distilled water for several times. The starter culture was prepared by soil funnel techniques [31]. A glass funnel was filled (3/4th) with autoclaved soil and sand (1:1) and the neck was loosely plugged with cotton wool. The funnel was kept over a conical flask (filled with sterile water). Spores were spread near the neck and covered with a thin layer of soil. Seeds of *Pennisetum glaucum* (surface-sterilized) were evenly sown and watered (sterile). After 10–15 days, the roots can be seen sprouting from the neck. Meanwhile, they get infected by AMF spores at the neck. After 25 days, roots were examined for root colonization.

When an adequate amount of growth was obtained by frequent sowing of seeds, this inoculum was transferred into small plastic pots filled with sand and soil (2:1) and mixed uniformly. Pots were transferred to the greenhouse and seeds of *Zea maize* and *Pennisetum glaucum* were sown. Pots were watered now and then with Hoagland nutrient solution without phosphorus and placed under uniform daylight. At the time of flowering of plants, the upper shoot system was cut off and fresh seeds were sown. After 2–3 months, the roots were mixed with soil and employed as inoculum for further experiments. **Figure 1** explains the isolation and screening of AM fungi for the selected host plants.

4. Screening of AM fungal species for efficiency

The effect of native AM fungi on the mycorrhizal intensity in terms of root colonization and spore number in rhizospheric soil of *Albizia lebbeck* and *Acacia nilotica* has been presented in **Table 4** respectively. In the comparative studies, all the *Glomus* species showed a significant difference in colonization.

Biomass of treated plants in the form of fresh weight recorded in *Albizia lebbeck* (*A.l)* and *Acacia nilotica* (*A.n)* is ranging from 90.0 to 142.6 g and 72.8 to 168.1 g, respectively. Likewise, root/shoot dry weight ranging from 62.4 to 116.3 g and 59.1 to 141.9 g, respectively, at the time of growth in the transplanted site. Minimum root/shoot growth was recorded in control plants. In comparison to control, all other treated plants showed the highest root/shoot growth. The maximum root/shoot growth of *Albizia lebbeck* (142.6 g) was recorded in *Glomus/Rhizophagus aggregatus* treatment. In *Acacia nilotica* (168.1), the highest growth was observed in *Glomus fasiculatum* and followed by *Gigaspora gigantea.*

In this study, all the five treatments gave the best results when compared with control (non inoculated tree species) *Glomus/Rhizophagus aggregatus* supports *Albizia lebbeck* showed the highest root colonization and helps the plants to uptake the nutrients such as root/shoot Phosphorus content (0.42/0.38 mg/g). In *Acacia nilotica* the highest shoot/root phosphorus content (0.46/0.34 mg/g) showed by treatment with *Glomus fasiculatum*.

Among all the five monoculture treatments *Glomus/Rhizophagus fasciculatum* and *Rhizophagus aggregatus* gave the best plant growth in all the parameters records plant height, biomass, and Phosphorus content. In this study percentage of AMF root colonization is directly proportional to the biomass and phosphorus content.

5. NPK fertilizers

The use of NPK fertilizers to enhance crop plant production include fertilization is specified to the soil and liquid forms of NPK that are sprayed on top of crop plants. In this time, plants are mostly fulfilled by giving solid fertilizers containing macronutrients, especially N inorganic continuously and without pains to restore the nutrients and absorb the essential elements with plants and causing the decrease of soil fertility [32, 33]. The use of extreme fertilizer is a waste of money and disturbs the stability of nutrients in the soil and increases environmental pollution [34, 35] To improve the crop productivity and quality of outcome is required to be useful by reasonable fertilizer influences as a result that the proportion of nutrient absorption by plants is balanced and use of one type of fertilizer based on site-specific suggested doses [36]. The site-specific nutrient considers the potential of soils to give usual nutrients recovery [37]. To develop the nutrient status in the soil which administers the N-inorganic fertilizers in the required amounts of P, and K fertilizers are essential to increase crop production.

The compound fertilizers are containing the mineral elements, which need for the successful growth and development of plants. Mineral elements are necessary for optimal doses. Nitrogen, phosphorus, and potassium have enormous effects on plant growth and development. The deficiencies results indicate clear effects on the growth and yield of the crop plants. Nitrogen is a chlorophyll element, which promotes green color and vegetative growth of plants [44]. In agricultural systems, the most important crop nutrients are nitrogen (N), phosphorus (P), and potassium (K) [37].

Nitrogen fertilizing doses increase the protein levels and crop plant biomass, but the completion of N elements only without P and K will cause plants to simply drop, very sensitive to pest attacks disease, and reduced the quality of crop production [38]. Phosphorus nutrients in the soil absorbed by plants will be supported by P elements specified during fertilization [39]. Nutrient uptake of N, P, and K plants increases with an increasing dosage level of K fertilizer. Potassium is an important component involved in maintaining plant water conditions; it is responsible for regulating stomata opening and closing activities [40]. The multiple inorganic fertilizers added to plants can be either solid form or liquid. The spray of liquid fertilizer to the plants can play a role in improving the properties of the soil and supporting to enhance crop production [41, 42]. The application of liquid inorganic fertilizers is to make it an easy and efficient use of fertilizers by crop plants.

6. Effect of agrochemicals on interactions of Rhizobium and AM fungi on the growth of two forest trees

Different combination of agrochemicals (Captan, Sevin, TCP, Urea, 2, 4-D, DAP) along with Rhizobium and AM fungi were inoculated to test plants combinations are as follows Captan + *Glomus fasiculatum (G.f.)* **(A)**, Sevin + *G.f.***(B)**, TCP + *G.f.***(C)**, Urea + *G.f.* + *Rhizobium sp*.**(D)**, 2,4-D+ *G.f.* + *Rhizobium sp*.**(E)**, DAP + *G.f.* +Rhizobium sp.**(F)**, Control+ SS+ *Rhizobium sp*.**(G).**

AM fungal infection was maximum in plants receiving treatment of E followed by D and F in descending order, while it was low in plants receiving treatment of A and B (**Table 5**). The spore population also increased in the presence of C, D, and F. Treatments C and D, promoted the plant growth. However, E promoted the maximum height followed by F and D plants, while it was least in B treated plants. Similarly, the treatment of E stimulated nodulation and biomass production. On the other hand, F and D influenced nodulation to an intermediate degree. The addition of tricalcium phosphate adversely affected growth-promoting activity. The degree of nodulation

Trestments	Infection(%)	No. of spores/ 100 g soil	Plant height (cm)	No.of nodules/ plant	Biomass		Phosphorus content (mg/plant)	
					Fresh wt.	Dry wt.	Shoot	Root
Albizia lebbeck								
Captan + G.f (A)	47.8 ± 1.28	83.0 ± 0.82	53.0 ± 0.82	—	22.5 ± 0.22	15.4 ± 0.16	0.15 ± 0.01	0.17 ± 0.01
Sevin+Gf.(B)	49.0 ± 0.54	104.0 ± 1.63	37.3 ± 1.25	—	20.8 ± 0.29	17.5 ± 0.25	0.28 ± 0.01	0.34 ± 0.02
TCP + G.f.(C)	42.5 ± 0.21	114.0 ± 0.82	54.3 ± 1.25	—	35.1 ± 0.53	26.3 ± 0.34	0.22 ± 0.01	0.35 ± 0.02
Urea + G.f. + Rhizobium sp.(D)	56.5 ± 1.25	118.0 ± 0.82	62.0 ± 1.63	46.0 ± 1.63	28.0 ± 1.30	18.7 ± 0.17	0.24 ± 0.01	0.34 ± 0.02
2,4-D+ G.f. + Rhizobium sp.(E)	58.5 ± 0.22	127.3 ± 1.70	66.0 ± 1.63	56.0 ± 1.63	38.3 ± 0.39	26.6 ± 0.42	0.36 ± 0.02	0.23 ± 0.02
DAP+G.f. + Rhizobium sp.(F)	56.4 ± 0.15	112.0 ± 1.63	64.0 ± 1.63	55.3 ± 2.49	37.3 ± 0.70	29.1 ± 0.29	0.14 ± 0.02	0.28 ± 0.01
Control+ SS + Rhizobium sp.(G)	46.5 ± 1.25	104.0 ± 1.63	48.0 ± 0.82	—	27.2 ± 0.82	16.4 ± 0.25	0.44 ± 0.22	0.47 ± 0.01
Acacia nilotica								
Captan + G.f (A)	55.2 ± 0.78	129.0 ± 0.82	52.9 ± 0.29	—	7.06 ± 0.01	3.92 ± 0.02	0.12 ± 0.01	0.15 ± 0.01
Sevin+Gf.(B)	64.5 ± 0.50	183.6 ± 2.05	64.4 ± 0.17	—	7.45 ± 0.02	4.14 ± 0.03	0.17 ± 0.01	0.14 ± 0.02
TCP + G.f.(C)	61.2 ± 0.49	165.6 ± 2.05	67.4 ± 0.87	—	8.75 ± 0.02	4.56 ± 0.01	0.21 ± 0.01	0.16 ± 0.02
Urea + G.f. + Rhizobium sp.(D)	68.1 ± 0.37	212.3 ± 1.70	67.6 ± 0.59	34.0 ± 1.63	9.16 ± 0.02	5.06 ± 0.01	0.22 ± 0.01	0.14 ± 0.01
2,4-D+ G.f. + Rhizobium sp.(E)	57.8 ± 1.25	154.3 ± 1.25	63.0 ± 0.62	37.6 ± 1.25	8.05 ± 0.03	6.26 ± 0.01	0.17 ± 0.01	0.13 ± 0.01
DAP+G.f. + Rhizobium sp.(F)	54.5 ± 0.68	122.6 ± 1.25	48.3 ± 1.03	27.6 ± 1.25	6.94 ± 0.01	3.72 ± 0.02	0.13 ± 0.01	0.91 ± 0.01
Control+ SS + Rhizobium sp.(G)	33.0 ± 0.62	109 ± 0.82	42.7 ± 0.37	—	5.42 ± 0.02	3.03 ± 0.02	0.91 ± 0.01	0.61 ± 0.01

Mean ± S.D. G.f. Glomus fasiculatum, and SS = Sterile soil.

Table 5.
Effect of agrochemicals on interactions of rhizobium and AM fungi on the growth of two forest trees.

decreased in the presence of captan and sevin which may also partly be due to the absence of *Rhizobium*. The biomass production varied with the agrochemicals tried. The maximum biomass production was recorded in the treatment E, while it was low in sevin treated plants. Similarly, the phosphorus content in shoot and root increased. The increase was more in root than in shoot. Treatments of F and C have adversely affected both the tree species. Maximum root infection was observed in *A. nilotica* plants receiving treatment D followed by B (**Table 5**). Root infection was least in E and F treatments. The stimulatory effect was comparatively more in treatment B than A. similar trend was observed in the spore population. The maximum spore population was recorded in plants receiving D treatment followed by B. It was low in F treated plants. Treatments A, C, and F adversely affected the AM infection and spore population.

The biomass production varied with the agrochemicals tried. The maximum AMF root colonization and biomass production was observed in the treatment E, while it was low in sevin treated plants. Similarly, Maximum plant height was recorded with fertilizers, while it was low in F treated plants. Nodulation increased in plants treated with E along with Rhizobium, while it was low in D and F. Treatments of A, B and C were responsible for inhibition of nodulation. On the other hand, the increased biomass production was recorded in plants treated with D and least in F. [43, 44] have recorded the adverse effect of some agrochemicals on AM colonization and growth and development of plants studied by them. Marginal change in physico-chemical characteristics of soils with the addition of different agrochemicals. The pH of the soils ranged between 7.0 and 8.1, and in C, E, and B soil was comparatively more alkaline. Maximum EC was recorded in D plants, while it was least in C plants. Organic matter was maximum in E plants, while it was low in B treated plants. Available phosphorus was also considerably increased in soils receiving different agrochemicals. Maximum available phosphorus was recorded in E treated soils followed by F and D treated plants. Available potassium was maximum in *G. fasciculatum* treated plants, followed by F plants and it was considerably low in D.

The root-based hyphal network in soils is the primary inoculum for seedlings that become established on natural grasslands. However, the inoculants colonized roots have some profound disadvantages since they may contain more than one mycorrhizal fungus and may also contain pathogenic organisms. Spores are possibly the best inoculants for laboratory experiments because the features diagnostic of individual species are present only in the spores developed primarily on extra metrical hyphae. Natural soil of crops and forests may contain varying numbers of spores of different AM fungal species. The dual culture using sterile soil with some kind of quality control is believed a practical approach to produce a high level of inoculants for commercial applications. A pot culture of *Glomus versiforme* on Sudan grass (*Sorghum vulgare*) can produce up to 107 spores per month over an extended period [45]. Spores from colonized soil near the colonized roots collected from field or pot cultures can be extracted using the traditional wet-sieve method. This approach and the later modified techniques are widely used in extracting spores from soils with modifications.

7. Applications of AM fungi

Arbuscular mycorrhizae show up as an exceptionally encouraging and monetarily reasonable device for the foundation of practical models of rural creation, because of their ability to expand the assimilation of fundamental supplements to plant development and increment their resistance to unfavorable ecological conditions, consequently keeping up soil quality and its gainful potential. Although enhancements in soil quality and plant nutritional status, for mycorrhizae application, was less investigated [46]. Various investigations have indicated that AM

Fungi can expand plant health and yield [47, 48]. These symbionts offer an eco-accommodating natural sound substitute to compound composts and pesticides for managing both plant quality and quantity in farming, cultivation, and ranger service. AM Fungi is currently viewed as the base of sustainable farming; so, there is a need to speed up its management in rural establishment frameworks [49].

The development of AM fungal hyphae is promoted by root exudates and is dependent on the arrangement of an appressorium increases the chance of hyphal entrance in the root framework. Dry weight and mycorrhizal dependence are the two most commonly utilized methods for assess AM fungal impact on plants [50]. Fungal impacts on plant physiology, for example, mineral nutrition especially phosphorus, plant execution, and plant assurance are significant segments in surveying contagious productivity.

AM fungi may similarly have connections among plant development advancing rhizosphere (PGPR) life forms. The impact of AM immunization may shift since numerous elements can impact the event of AM fungi [12].

8. Conclusion

The plant root infection and spore population were good in the forest soils and they were less in the overburden coal mine spoils. AMF exhibit different distribution patterns between these two soil types, where *Glomus* is dominant among all the species, *Scutellospora* and *Aculospora* were least in population. The high Mycorrhizal dependency value suggests that mycorrhizal inoculation would be useful in producing vigorous seedlings. In the nursery, which establish better and withstand some amount of drought and pathogenic infection. Seedlings inoculated with the indigenous AMF monoculture showed the highest biomass and phosphorus content when compared to non-mycorrhizal (controls), those plants grew very poorly. Within the AM fungi selection of perfect efficient indigenous mycorrhiza inoculations are needed for revegetation of disturbed sites. By the efficient AMF inoculation, the agroforestry tree species showed the best results in the form of increasing biomass and phosphorus uptake.

AM fungi and Plant Growth Promoting Rhizobacteria (PGPR) are significant parts in forest development and helps to increase biomass production [51]. There is a need of long term field studies to screen the efficent AM fungi in the revegetation sites and synergistic effects on indigenous microflora on tree growth.

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