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Full Length Research Paper

Periodic changes in *Prosopis cineraria* associated AM population at different soil depth and its relationship with organic carbon and soil moisture

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Arbuscular mycorrhizal fungi (AMF) spore population was studied at eight levels of soil depth under two different sites *viz., P. cineraria* under agro forestry area (with moong bean) and *P. cineraria* as sole crop at four different quarters of the year (July, October, January, April). In agro forestry areas the spore population recorded higher as compared to *P. cineraria* grown as sole crop. The upper layer (0-30 cm) contains more number of AMF population in comparison to deeper layers. The trend in decrease of spore population to soil depth was as follows: 11 - 20 cm > 0 - 10 cm > 21 - 30 cm > 31 - 40 cm > 41 - 50 cm > 51 - 60 cm > 61 - 70 cm > 71 - 80 cm. AMF population was also correlated with organic carbon content at different soil depths. The per cent organic carbon content varied between sites and among the soil depths. The more organic carbon content was recorded at upper layers and decreasing towards deeper layers. The maximum moisture content was found in first quarter, that is, in month of July and minimum in fourth quarter, that is, in April. However, spore population was positively correlated with soil organic matter throughout the year but not with soil moisture. The results demonstrated that status of AMF population under *P. cineraria* depends on soil depth, soil organic carbon, soil moisture content and the site of plantation.

Key words: Arbuscular mycorrhiza, organic carbon content, *Prosopis cineraria,* soil depth, soil moisture.

INTRODUCTION

Prosopis cineraria (L.) Druce, (Mesquite) is commonly known as "Khejri" in Rajasthan, India. *P. cineraria* occur naturally in the dry and arid regions of India, Pakistan, Afghanistan, Iran and Arabia. They provide fodder, fuel for timber and shade, as well as affecting soil improvement and sand dune stabilization. It is commonly used in dry land agro forestry in India and Pakistan. It is a slow growing tree species affected by the paucity of water, erratic rainfall and extremes of temperature under desert conditions. During hot summer season, unlike other trees *P. cineraria* produce lush green profuse leaves, which is a major source of fodder for cattle's of this region. Leaves contain 13.8 percent crude protein, 20 per cent crude fibre and 18 per cent calcium. *P. cineraria* provide excellent firewood (calorific value, ca. 5,000 kcal/kg) and charcoal. The wood is favoured for cooking and domestic heating (Mahoney, 1990), Since wood of *P. cineraria* is hard and reasonably durable, the wood has a variety of uses for house building, posts, tool handles and boat frames. The natural regeneration of khejri is very difficult due to modernization of agricultural implements (Tractor ploughing), the economy of farmers depend upon existing trees on their field. In recent past, mortality of khejri trees due to frequent attack of insects and fungus *Ganoderma* creating a major problem, therefore, the density of trees is decreasing day by day.

In arid-ecosystems, arbuscular mycorrhizal fungi (AMF) are major and significant component of rhizosphere microflora. Mycorrhizal association plays an important role in decomposition of soil organic matter, mineralization of plant nutrients and nutrient recycling (Tarafdar and Rao, 1997; Pare et al., 2000). The population pattern of AMF varies greatly and their diversity is affected by various factors including soil, environmental condition, host plant and agricultural practices (Sanders, 1990;

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Table 1. Periodic changes in AMF population at different soil depths.

Soil depth (cm)	AM population (spore 100 g-1)							
	July, 2003		October, 2003		January, 2004		April, 2004	
	1	2	1	2	1	2	1	2
0 - 10	278	249	124	112	96	85	78	66
11 - 20	334	311	175	160	146	110	100	79
21 - 30	145	118	110	91	78	65	69	56
31 – 40	90	63	63	48	37	28	32	23
41 - 50	58	41	50	32	30	22	27	18
51 - 60	41	32	36	27	26	14	20	11
61 - 70	30	22	22	16	15	12	13	10
71 - 80	19	15	12	9	10	8	8	7
LSD (P = 0.05)	4.51	4.18	4.57	4.53	7.46	5.15	7.35	5.30

1: *P. cineraria* under agroforestry area, 2: *P. cineraria* as sole crop.

McGonigle and Miller, 1996). Recently, Verma and co-workers (2008) studied diversity and spatial distribution of AMF associated with *P. cineraria* , however, the vertical distribution pattern of spore population to the soil profile has not yet been reported. Keeping this information in mind, the aim of this present investigation is to examine vertical distribution of AMF population at different soil profile under *P. cineraria* grown in agroforestry area and as sole crop and its relation with soil organic carbon and soil moisture under arid environment.

MATERIALS AND METHODS

To examine the AMF populations distribution at different soil depth, the soil samples were collected from the underneath of canopy of *P. cineraria* plantations of same age group (approx 12 years) from agroforestry area (with moong bean) and *P. cineraria* as sole crop from Ecology Field of AFRI (Jodhpur). Soil samples were collected quarterly (July 2003, October 2003, January 2004 and April 2004) at the base of randomly selected five trees of each site with three replications with the help of GI auger upto 80 cm depth. The experimental soil was typical Camborthid with sandy loam in texture. Soil pH ranged between 7.90 and 8.36, EC 0.17 - 0.29 dSm^{-1}, organic carbon 0.05 - 0.45%. The total rainfall received during the duration under study was 351.7 mm out of which 260.3 mm received during the quarter end in July and 66.9 mm received during quarter end October. The least rainfall (0.7 mm) received during the quarter end January and 23.8 mm rainfall received during February-April. The samples were also categorized on soil depth basis (0 - 10 cm; 11 - 20 cm; 21 - 30 cm; 31 - 40 cm; 41 - 50 cm; 51 - 60 cm; 61 - 70 cm; 71 - 80 cm) and collected with in the radius of 10 cm from the base. All the samples were kept in sealed moisture polybags immediately after collection to avoid loss of moisture. The soil moisture was determined gravimetrically in hot air oven at 104°C for 48 - 72 hours till weight become constant.

The soil samples were processed for AM spores by using wet sieving and decanting technique's of Gerdemann and Nicolson (1963) and sucrose centrifugation technique as described by Jenkins (1964). Leica Kombistereo Microscope counted the AMF propagules. Organic carbon was determined by Walkley-Black Method (1934). Standard errors of means were calculated and appropriate analysis of variance was carried out and means were separated by the least significant difference (LSD) test and paired t test (Sokal and Rohlf, 1981). Correlation and regression analysis was done using Microsoft Excel 2000 software.

RESULTS

Periodic changes in AMF population at different soil depths

It was apparent from Table 1 that spore population varied significantly ($P < 0.01$) with the depth of the soil in the areas *viz*., *P. cineraria* under agroforestry area (with moong bean) and *P. cineraria* as sole crop. Considering the entire soil depth (0 - 80 cm) the spore population was 21 per cent higher under agroforestry as compared to *P. cineraria* as sole crop during the study period. The upper layer (0 - 30 cm) contains more number of AM fungal propulation as compared to the soil samples analysed from deeper layers. In both the sites, maximum spore population was recorded from 11 - 20 cm soil depth. The spore population varied from 19 (minimum) to 334(maxi-mum) under agro forestry areas and 15 (minimum) to 311 (maximum) under *P. cineraria* as sole crop in the month of July (Table 1). Subsequently, the population was gradually decreased in second (October), third (January) and fourth (April) quarters. The results of paired 't' test indicate that spore population had significantly ($P < 0.01$) different between the sites and among the quarters, which recorded minimum in April, that is, fourth quarter at both the areas. The spore population decreases with increase in soil depth except 11 - 20 cm depth. The trend of spore population at different soil depths were as follows: - 11 - 20 cm > 0 - 10 cm > 21 - 30 cm > - 31 - 40

Table 2. Periodic changes in soil moisture at different soil depths.

Soil depth (cm)	Soil moisture (%)							
	July, 2003		October, 2003		January, 2004		April, 2004	
	1	2	1	2	1	2	1	2
0 -10	8.71	8.40	0.43	0.33	0.22	0.21	0.20	0.21
11 - 20	9.40	8.66	0.67	0.44	0.35	0.32	0.31	0.30
21 - 30	9.60	8.77	0.88	0.64	0.55	0.43	0.46	0.41
31 - 40	8.59	6.23	1.05	0.98	1.01	0.77	1.00	0.69
41 - 50	7.12	6.06	1.54	1.07	1.30	0.97	1.23	0.89
51 - 60	6.44	5.62	2.77	2.26	2.26	1.08	1.68	1.01
61 - 70	6.27	4.38	3.17	2.79	3.06	2.00	1.79	1.89
71 - 80	6.15	3.58	3.90	3.19	3.35	2.88	2.02	2.36
LSD (P = 0.05)	0.02	0.10	0.10	0.05	0.11	0.08	0.06	0.08

1: *P. cineraria* under agroforestry area, 2: *P. cineraria* as sole crop

cm > 41 - 50 cm > 51 - 60 cm > 61 - 70 cm > 71 - 80 cm. Pearson correlation coefficient indicates that the spore population has significantly and negatively correlated ($r = -0.71$, $P < 0.01$) with soil depth. The results indicate that crops grown under agro forestry with *P. cineraria* as tree component influences more AM spore than *P. cineraria* grown as sole crop and more spore population was expected between 11 and 20 cm of soil depth.

Relationship between AMF population and soil moisture at different soil depths

The maximum moisture content was recorded in first quarter, that is, in month of July 2003 and minimum in the fourth quarter, that is, in April 2004 (Table 2). The soil moisture content was significantly different ($P < 0.05$) among the season/quarters. In the month of July, soil moisture content showed positive effect on spore population, where as in second, third and fourth quarters soil moisture content showed negative influence on spore population at different soil depths. Soil moisture was differing significantly ($p < 0.01$), when compared after applying paired 't' test (Sokal and Rohlf, 1981), between *P. cineraria* grown under ago forestry and as a sole crop. Except in first quarter, that is, in July, deeper layers containing more soil moisture content (between 2.02 to 3.90 per cent), where the spore population was recorded minimum.

Regression equation between spore population and percent of soil moisture at different depths had been worked out for the year 2003 - 2004. The results showed that spore population varies with percent of soil moisture at different depths ($R^2 = 0.1403$) but only 14.03 percent of total variation can be explained by this equation, which cannot be termed as satisfactory (Figure 1). Similarly for site *P. cineraria* as sole crop ($R^2 = 0.2092$) only 20.92 per cent of total variation can be explained under present situation.

Regression equations were also worked out between spore population and percent of soil moisture at different depths for *P. cineraria* under agroforestry area and *P. cineraria* as sole crop (Table 3) separately under different quarters. The best regression equation ($R^2 = 0.8971$) was observed for April 2004, where 89.71% of total variation for site *P. cineraria* under agro forestry area can be explained for spore built up. The result showed that soil depth was also an important factor with the soil moisture for spore regeneration. "Explain what is meant by best regression"

Relationship between AMF population and soil organic carbon content at different soil depths

Perusal of Table 4 indicates that organic carbon content varied significantly ($P < 0.01$) between sites and among the soil depths. Organic carbon content was observed more in agroforestry area compared to *P. cineraria* as sole crop in deeper layers. Soil organic carbon was significantly ($n = 32$, $P < 0.01$) differing between agroforestry area and *P. cineraria* as sole crop in all quarters except April 2004.

The results revealed positive correlation ($r = 0.69$, $n = 8$, $P < 0.05$) between organic carbon and spore population at both the study areas. Organic carbon content was recorded in decreasing trend with increase of soil depths in all the quarters. The relationship between spore population and organic carbon content at different soil depths, that is, 0 - 10 cm to 70 - 80 cm for the entire year (2003 - 2004) (Figure 2) showed a strong positive correlation ($n = 32$, $P < 0.01$) between the organic carbon

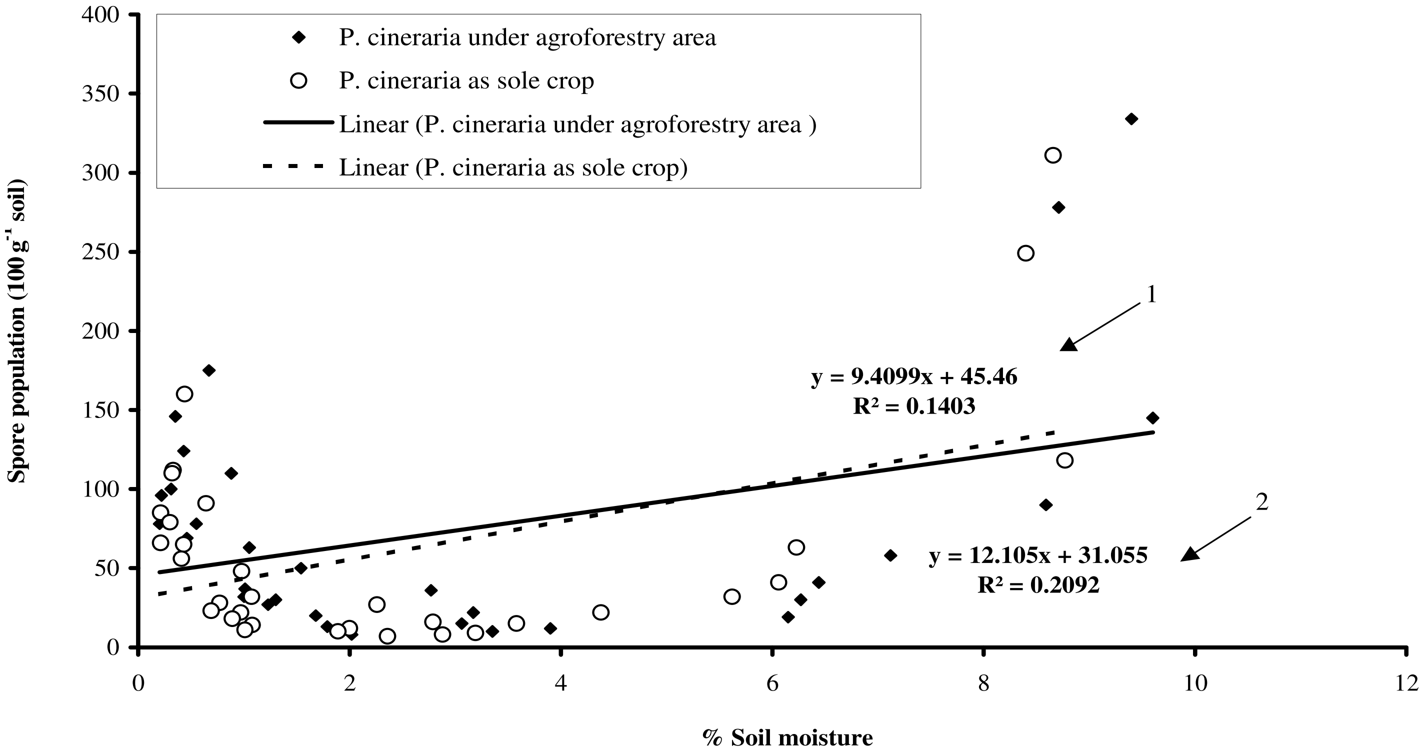

Figure 1. Regression equation between spore population and per cent soil moisture at different depth during 2003 – 2004; 1: *P. cineraria* under agroforestry area; *P. cineraria* as sole crop.

Table 3. Regression equations between spore population and per cent soil moisture for *P. cineraria* under agroforestry area and *P. cineraria* as sole crop in different seasons.

Seasons	*P. cineraria* under agroforestry area	*P. cineraria* as sole crop
July, 2003	Y = 65.771x – 387.65 R^2 = 0.6294^{NS}	Y = 46.981x – 197.24 R^2 = 0.6776*
October, 2003	Y = -37.068x + 140.77 R^2 = 0.7182**	Y = -39.057x +119 R^2 = 0.6629^{NS}
January, 2004	Y = -31.47x + 102.35 R^2 = 0.6585^{NS}	Y = -31.306x + 76.889 R^2 = 0.5592^{NS}
April, 2004	Y = -45.45x + 92.746 R^2 = 0.891**	Y = -29.241x +62.114 R^2 = 0.626^{NS}

* Significant at 5%, ** Significant at 1%, NS Non significant.

build-up and spore population.

The regression equation between spore population and organic carbon content under different quarters (Table 5) were presented for both the sites. The results indicate a strong and positive correlation between the organic carbon build up and spore population under all the seasons in both the sites. The best correlation (R^2 = 0.9093) under *P. cineraria* alone was observed during July 2003, where as when *P. cineraria* grown under agro forestry area, most significant relation (R^2 = 0.8971) were observed during April 2004.

DISCUSSION

The spore population was studied at different depths of soil at two sites *viz., P. cineraria* under agroforestry area (with moong bean) and *P. cineraria* as sole crop under

Table 4. Period changes in carbon content at different soil depths.

Soil depth (cm)	Percent organic carbon							
	July, 2003		October, 2003		January, 2004		April, 2004	
	1	2	1	2	1	2	1	2
0 - 10	0.26	0.39	0.24	0.43	0.20	0.38	0.23	0.40
11 - 20	0.23	0.33	0.22	0.32	0.20	0.31	0.21	0.31
21 - 30	0.19	0.17	0.19	0.17	0.19	0.17	0.19	0.17
31 - 40	0.13	0.14	0.13	0.13	0.13	0.15	0.13	0.15
41 - 50	0.13	0.12	0.13	0.10	0.12	0.10	0.12	0.10
51 - 60	0.08	0.09	0.12	0.08	0.12	0.08	0.12	0.07
61 - 70	0.07	0.06	0.07	0.06	0.09	0.06	0.09	0.06
71 - 80	0.06	0.05	0.06	0.05	0.05	0.05	0.05	0.04
LSD (P = 0.05)	0.01	0.02	0.00	0.01	0.00	0.12	0.02	0.01

1: *P. cineraria* under agroforestry area, 2: *P. cineraria* as sole crop.

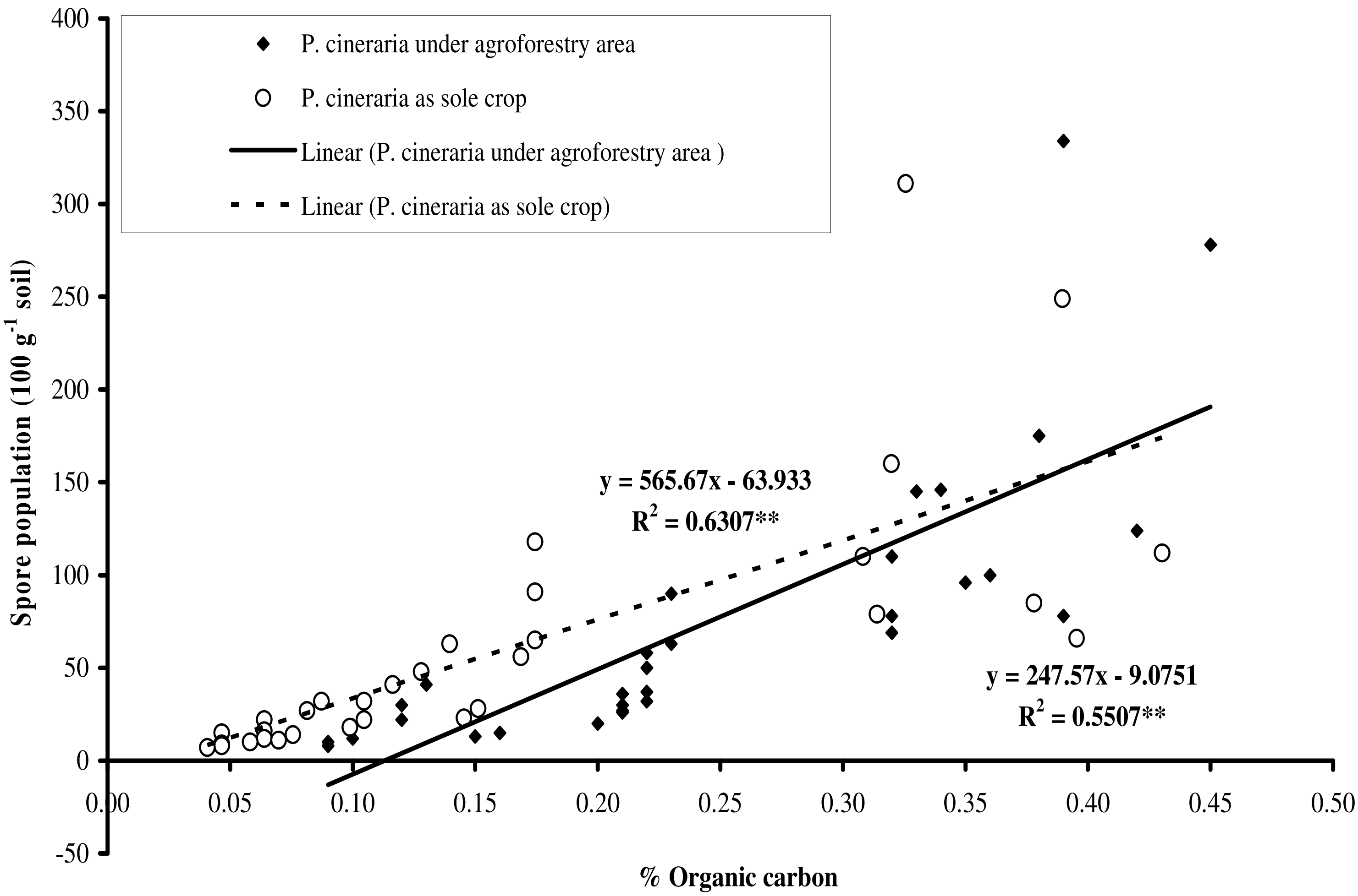

Figure 2. Regression equation between spore population and per cent organic matter at different depth during 2003 – 2004 (** P < 0.01).

Table 5. Regression equations between spore population and percent organic matter for *P. cineraria* under agro forestry area and *P. cineraria* as sole crop in different seasons.

Seasons	*P. cineraria* under agroforestry area	*P. cineraria* as sole crop
July, 2003	Y = 847.04x – 84.209 R^2 = 0.8636**	Y = 501.11x – 38.321 R^2 = 0.9093**
October, 2003	Y = 458.82x – 40.704 R^2 = 0.863**	Y = 199.92x + 3.8975 R^2 = 0.7645**
January, 2004	Y = 459.7x –54.428 R^2 = 0.7912*	Y = 171.58x – 5.0438 R^2 = 0.8513**
April, 2004	Y = 309.22x – 31.61 R^2 = 0.8971**	Y = 118.09x + 0.9803 R^2 = 0.8322**

* Significant at 5%, ** Significant at 1%, NS - Non significant.

different quarters for the entire year. The higher spore population was observed in agroforestry area as compared to *P. cineraria* as sole crop. This may be due to AM fungi getting alternate host under agroforestry system throughout the year for multiplication. The upper layer (0 - 30 cm) contains more number of AM fungal propagules as compared to the soil samples analyzed from deeper layers. The less spore population in the deeper layer may be due to the less oxygen level and presences of hard pan at lower layers. In both the sites, maximum spore population was recorded from 11 - 20 cm soil depth. The trend of spore population in decreasing order was as follows: 11 - 20 cm > - 0 - 10 cm > 21 - 30 cm > 31 - 40 cm > 41 - 50 cm > 51 - 60 cm > 61 - 70 cm > 71 - 80 cm. Sampling depth had a significant effect on spore density and the percentage of total arbuscular colonization (He et al., 2002). Sieverding (1991) have also reported maximum spore population at 0 - 20 cm soil depth at CIAT, Colombia. According to Jakobsen and Nielsen (1983) a majority of AM spore population (70 - 85 per cent of spores) is found in the top 40 - 45 cm.

In the present study moisture content of soil varied at different soil depths as well as sites. The soil moisture content and spore population were higher under agroforestry as compared to *P. cineraria* as sole crop in all quarters and soil depths. The soil moisture content was different among the season/quarters. In the month of July, soil moisture content showed positive effect on spore population while in second, third and fourth quarter's soil moisture content showed negative effect on spore population at different soil depths. Earlier studies also reported that spore formation commonly occurs in water stress conditions but extremely stress conditions are favourable for spore formation (Vyas, 1988; Chandel, 1991). The soil moisture was differing between agroforestry and *P. cineraria* as sole crop except April 2004. In general, deeper layers containing high soil moisture content between 2.02 to 3.90 per cent while the spore population was recorded minimum. It showed that soil depth and soil moisture is also an important factors for spore regeneration.

The fertility status of the soil around the tree rhizosphere is rich with humified organic matter due to its mixing with the mineral soil, makes it useful to AM. Soil organic matter is the main energy source for soil microbial community evolves in the process of mineralization results that the plants derives benefit from rhizodeposition. Thus, the status of organic matter plays a major role in determining the micro-organisms status in soil (Presscott et al., 1993) and thereby plants growth varies. Variation in organic matter content, in our experiment, was observed between sites and also in soil depths. In agroforestry area organic matter content was observed higher than in *P. cineraria* as sole crop in deeper layers. However, organic matter content was observed higher in 0 - 10 cm and 11 - 20 cm soil depths in *P. cineraria* as sole crop. The soil organic matter was differing between agroforestry area and *P. cineraria* as sole crop in all season except April 2004. It may be due to cultivation of crops and deep ploughing and soil porosity (Neville et al., 2002), leads to downward movement of organic matter.

Conclusion

In arid areas maximum sporulation of AMF occurs after first rain in the month of July since it favours sporulation. The variation in spore population was observed at different depths as well as sites. In agroforestry areas spore population recorded higher as compared to *P. cineraria* as sole crop. The spore population was more between 11 and 20 cm soil depth. Soil moisture and organic carbon content was found positive influence on AM fungal population. Status of AM fungi population under *P. cineraria* depends on soil depth, soil organic carbon, soil moisture content and site of plantation.

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