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Relationship of arbuscular mycorrhizal fungi and *Azotobacter* with plant growth, fruit yield, soil and leaf nutrient status of mango orchards in north-western Himalayan region of India

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Abstract

The present investigation was undertaken with the objective to find out the nutritional status of mango orchards cv. Dashehari located in north- western Himalayan region of India and to establish the relationship of soil microflora especially, arbuscular mycorrhizal (AM) fungi and *Azotobacter* with growth, fruit yield, and soil and leaf nutrient contents. The study revealed that the correlation between AM spore population and shoot extension growth, leaf area, fruit yield, available Cu and Zn content and leaf N, P, Cu, Zn and Mn contents was found to be positive and significant, whereas, the relationship with soil as well as leaf K content was negative but significant. *Azotobacter* count was positively and significantly correlated with fruit yield, soil organic carbon (OC) and leaf Fe content, while, it was negative and significant with leaf K content. The relationship of per cent root colonization with soil OC and available N content of orchard soil was found to be positive and significant, and with shoot extension growth, leaf area, fruit yield, electrical conductivity, available P, K, Cu, Zn and Mn content and P, K and Cu contents of leaf, it was negative but non-significant.

Key words: AM fungi, *Azotobacter,* root colonization, correlation, mango.

Introduction

Arbuscular mycorrhizal (AM) fungi form mutualistic symbiosis in roots of several horticultural crops (Nemec and Vu, 1990). AM fungi promote growth of host plants by enhancing minerals, mainly P and water uptake (Marschner and Dell, 1994). Mycorrhizal fungi can absorb, accumulate and transport a large quantity of phosphates within their hyphae and release it to cells of the root tissues. It has been shown that mycorrhizal plants can absorb and accumulate several times more phosphate from the soil solution than non-mycorrhizal plants (Smith and Dowd, 1981). These plants also accumulate P, K, Ca, Cu and Mn in the leaf in higher concentration than non-mycorrhizal plants (Nopamornbodi *et al.*, 1987). Besides this, AM fungi also improve growth of horticultural plants in part, by enhancing the acquisition of mineral nutrients especially, P, Cu and Zn (Morin *et al.*, 1994). AM inoculation has been reported to improve growth, dry matter production and concentrations of Ca and Fe in the leaves (Skinner *et al.*, 1988). The increase in uptake of nutrients by mycorrhizal plants attributed to solubilization of the elements by increased root surface resulted by hyphal strands in soil regions inaccessible by the root hairs.

Azotobacter, a non-symbiotic, free-living, aerobic nitrogen fixing diazotroph, is known to add nitrogen to the soil through biological nitrogen fixation. It also results in production of plant growth regulators *viz.*, indole acetic acid and gibberellins, enhances the uptake of NO_3, NH_4, H_2PO_4 and Fe and improves nitrate reductase enzyme activity (Wani, 1990). Dual inoculation of AM fungi and *Azotobacter* is of great significance to fruit crops and is well documented in the literature. Therefore, the objective of the present study was to establish the relationship of AM fungi and *Azotobacter* with plant growth, fruit yield and nutritional status of mango orchards of north- western Himalayan region of India particularly, Himachal Pradesh.

Materials and methods

Ten full bearing mango orchards of cultivar Dashehari at each of the nineteen locations namely. Dadd, Gehrwin, Kalol, Jukhala, Jarol, Kotlu, Berthin, Bari, Nihari, Dashlera, Railli, Talai and Dadhol of Bilaspur district, Bijjar, Railli- Jajjri of Hamirpur district and Nagrota, Nagni, Utreh and Jachh of Kangra district of Himachal Pradesh were selected for the studies during 2002-2004. A comprehensive soil sampling for AM spore population and *Azotobacter* count in the rhizosphere was conducted. Ten samples from each orchard were collected. Soil throughout the top 25 cm was taken especially from basin area of the bearing trees. AM spores were isolated from the soil samples by wet sieving and decanting method as suggested by Gerdmann and Nicolson (1963). AM fungal spores were counted with the most probable number (MPN) method, used to enumerate the AM spore count using by 10-fold series of soil dilution (Powell, 1980).

Ten different AM species of the genera *viz.*, *Glomus*, *Gigaspora*, *Acaulospora*, *Scutellospora*, *Entrophospora* and *Sclerocystis* were isolated and characterized. Taxonomic identification of the AM species was done in accordance with the synoptic keys (Schenck and Perez, 1988). Trinocular biological microscope model LEICA DMLB was used to count the spore population and their morphological identification was done with the help of image analysis software system. To determine the extent of root colonization, roots from randomly selected trees were taken. The samples were cleaned and stained fine roots were prepared (Phillips and Hayman, 1970). These samples were assayed for AM fungal colonization using the Gridline Intersect method

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(Giovannetti and Mosse, 1980). The serial dilution technique was employed for the isolation of viable *Azotobacter* count on Jenson's medium. Taxonomic identification of *Azotobacter* isolates was done according to Bergey's Manual of Systematic Bacteriology (Tchan, 1984).

Twenty uniform and healthy shoots all over the tree canopy in all directions were randomly selected. The length of each shoot was measured at the beginning and ends of growing season between the points of initiation of new growth to the extremity of the shoot tip and was expressed in centimeters. For measuring leaf area, 50 leaves were randomly sampled from all over the tree canopy and their accumulative area was recorded with the help of Leaf Area Meter model-3100 and was expressed in square centimeters. Fruit yield in kilogram per tree was recorded at the time of harvest.

Soil samples collected from different mango orchards were analyzed for pH, electrical conductivity (EC), organic carbon (OC) and available nutrient contents by using standard methods of estimation.

Leaf samples were also analyzed for total N by Nitrogen Autoanalyzer- Kjeltech Foss Tecator model-2300, for P by Phosphovanadomolybdate method (Jackson, 1973) and for K and micronutrients (Cu, Zn, Fe and Mn) by Atomic Absorption Spectrophotometer.

A correlation analysis was performed for AM spore population, per cent root colonization and *Azotobacter* count with growth parameters, fruit yield and nutritional status of mango orchards according to Snedecor and Cochran (1980).

Results and discussion

Relationship of AM Fungi and* Azotobacter *with growth and nutrients content

Growth and fruit yield: Under different mango orchards surveyed, AM spore population, per cent root colonization and *Azotobacter* count ranged between 1200 and 3850 kg^{-1} soil, 3.2 and 13.9% and 2.4 x 10^6 and 6.3 x 10^6 CFU, respectively (Table 1). The data on the growth parameters and fruit yield indicated that the shoot extension growth, leaf area and fruit yield varied from 7.0-34.0 cm, 39.5-85.4 cm^2 and 135-410 kg $tree^{-1}$, respectively. The highest average shoot extension growth (26.5cm), leaf area (63.7 cm^2) and fruit yield (340 kg $tree^{-1}$) was exhibited by orchards located in Nihari, whereas, it was minimum in Daad with corresponding values of 9.5 cm, 42.8 cm^2 and 160 kg $tree^{-1}$ (Table 1). Linear correlation analysis revealed that AM spore population exhibited positive and significant correlation with leaf area, shoot extension growth and fruit yield with respective r- values of 0.691, 0.825 and 0.779, respectively. Correlation of *Azotobacter* count with yield was positive and significant (r= 0.303), whereas, with leaf area and shoot extension growth, it was positive but non-significant. However, per cent root colonization was negatively but non-significantly correlated with leaf area, shoot extension growth and yield (Table 4).

The positive relationship of AM spores and *Azotobacter* with growth and yield could be attributed to more dry matter and plant biomass production and enhanced nutrient uptake by roots from the soil. Furthermore, the enhancement in shoot extension growth is also attributed to an increased nutrient uptake particularly, phosphorus apart from an increased uptake of micronutrients (Mathews *et al.,* 2003). This resulted in the improvement of photosynthetic rate and changed microbial plant biomass induced in the host. The positive influence of AM fungi however, might be due to growth promotory effect of AM fungi that had increased phosphorus availability and thereby causing higher protein synthesis resulted in more morphological growth (Singh and Singh, 2004). The results of the present studies were also in accordance with those of Rana and Srivastava (1984), who also reported positive and significant relationship of AM spore

Table 1. AM spore population, per cent root colonization, *Azotobacter* count, growth parameters and fruit yield of mango orchards

Locations	AM Spore number (kg^{-1} soil)	Root colonization (%)	*Azotobacter* count (x 10^6 CFU*)	Shoot extension growth (cm)	Leaf area (cm^2)	Fruit yield (kg $tree^{-1}$)
Dadd	1200	7.6	4.7	7-12 (9.5)	41.3-44.3 (42.8)	135-185 (160.0)
Gehrwin	2300	8.4	3.3	14-19 (16.5)	39.5-54.4 (46.9)	165-210 (187.5)
Kalol	3300	3.2	3.9	18-23 (20.5)	53.5-62.3 (57.9)	290-360 (325.0)
Jukhala	3800	8.9	5.0	25-28 (26.5)	51.6-75.8 (63.7)	310-370 (340.0)
Jarol	2500	6.7	4.7	16-21 (18.5)	40.5-51.8 (46.2)	250-340 (295.0)
Kotlu	2300	12.6	3.8	12-18 (15.0)	40.6-48.4 (44.5)	170-270 (220.0)
Berthin	3600	11.7	4.9	19-25 (22.0)	52.1-66.9 (59.5)	300-350 (325.0)
Bari	3050	13.9	6.3	17-22 (19.5)	40.8-64.4 (52.6)	240-310 (275.0)
Nihari	3850	10.6	4.2	20-34 (27.0)	63.3-85.4 (74.4)	350-410 (380.0)
Bijjar	2100	12.4	3.2	9-16 (12.5)	39.8-50.5 (45.2)	150-180 (165.0)
Railli-Jajjri	2200	11.2	2.9	12-15 (13.5)	40.6-53.4 (47.0)	150-200 (175.0)
Talai	3150	9.3	5.2	16-24 (20.0)	45.7-57.9 (51.8)	280-320 (300.0)
Dashlehra	2800	6.8	3.2	13-20 (16.5)	40.1-59.7 (49.9)	180-240 (210.0)
Railli	2500	4.9	2.4	16-19 (17.5)	43.7-62.1 (52.9)	220-310 (265.0)
Dadhol	3200	5.6	2.7	18-23 (20.5)	47.1-69.9 (58.5)	240-360 (300.0)
Nagrota	2700	11.3	2.9	9-16 (12.5)	43.2-58.5 (50.9)	185-290 (237.5)
Nagni	2900	13.8	5.6	20-25 (22.5)	45.3-67.6 (56.5)	165-250 (207.5)
Utreh	3300	10.8	5.2	17-22 (19.5)	46.9-59.9 (53.4)	145-220 (182.5)
Jachh	3000	8.7	4.9	12-20 (16.0)	45.1-52.6 (48.9)	175-250 (212.5)
Mean	2828.9	9.4	4.2	18.1	50.3	250.7

* Colony forming units, Figures in parentheses are the average values

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Table 2. Soil chemical characteristics of mango orchards

Locations	pH	EC (dSm^{-1})	OC ($g\ kg^{-1}$)	Macronutrients (kg ha^{-1})			Micronutrients (ppm)			
				N	P	K	Cu	Zn	Fe	Mn
Dadd	6.1-6.8 (6.45)	0.33-0.36 (0.33)	4-6 (5.00)	120-149 (134.5)	17-19 (18.0)	170-189 (179.5)	1.5-2.1 (1.80)	2.5-5.8 (4.15)	19-31 (25.0)	11-19 (15.0)
Gehrwin	5.9-6.2 (6.05)	0.32-0.34 (0.33)	2-3 (2.50)	147-166 (156.5)	18-21 (19.5)	165-180 (172.5)	1.9-2.4 (2.15)	3.1-3.8 (3.45)	23-29 (26.0)	13-18 (15.5)
Kalol	6.2-6.8 (6.50)	0.32-0.34 (0.33)	4-5 (4.50)	152-175 (163.5)	11-13 (12.0)	131-146 (138.5)	4.1-5.3 (4.70)	4.9-5.8 (5.35)	26-39 (32.5)	15-23 (19.0)
Jukhala	6.1-6.7 (6.40)	0.30-0.33 (0.31)	7-8 (7.50)	125-134 (129.5)	9-10 (9.5)	126-156 (141.0)	4.1-5.6 (4.85)	5.8-6.6 (6.20)	42-47 (44.5)	19-28 (23.5)
Jarol	6.0-6.5 (6.25)	0.39-0.41 (0.40)	6-8 (7.00)	139-145 (142.0)	13-16 (14.5)	161-174 (167.0)	2.6-3.2 (2.90)	3.5-4.2 (3.85)	31-48 (39.5)	21-29 (25.0)
Kotlu	6.0-6.5 (6.25)	0.31-0.34 (0.32)	4-6 (5.00)	152-180 (166.0)	12-14 (13.0)	158-178 (168.0)	1.8-2.8 (2.30)	3.3-4.5 (3.90)	35-48 (41.5)	18-31 (24.5)
Berthin	6.1-6.8 (6.45)	0.33-0.37 (0.35)	3.5-5 (4.30)	138-160 (149.0)	8-12 (10.0.)	130-146 (138.0)	3.9-5.5 (4.70)	5.5-6.3 (5.90)	23-34 (28.5)	11-19 (15.0)
Bari	6.1-6.5 (6.30)	0.38-0.43 (0.40)	8-10 (9.00)	169-195 (182.0)	13-16 (14.5)	136-155 (145.5)	2.9-4.1 (3.50)	4.3-4.8 (4.55)	29-41 (35.0)	15-26 (20.5)
Nihari	5.5-6.5 (6.00)	0.34-0.38 (0.36)	5-6 (5.50)	146-149 (147.5)	16-18 (17.0)	116-124 (120.0)	4.3-5.8 (5.05)	6.4-6.8 (6.60)	33-52 (42.5)	21-32 (26.5)
Bijjar	6.2-6.7 (6.45)	0.32-0.34 (0.33)	4-5 (4.50)	143-159 (151.0)	12-15 (18.5)	168-192 (180.0)	1.5-2.3 (1.90)	2.5-5.9 (4.20)	36-46 (41.0)	26-35 (30.5)
Raili-Jajjri	6.1-6.8 (6.45)	0.31-0.33 (0.32)	5-6 (5.50)	152-171 (161.5)	9-13 (11.0)	161-186 (173.5)	1.7-2.6 (2.15)	2.8-3.4 (3.10)	42-58 (50.0)	20-28 (24.0)
Talai	6.4-6.8 (6.60)	0.30-0.34 (0.32)	6-7 (6.50)	143-156 (149.5)	10-14 (12.0)	140-155 (147.5)	2.8-3.3 (3.05)	4.9-5.4 (5.15)	46-62 (54.0)	32-42 (37.0)
Dashlehra	5.2-6.0 (5.60)	0.36-0. 38 (0.37)	3-5 (4.00)	152-166 (159.0)	8-10 (9.0)	146-170 (158.0)	2.9-3.8 (3.35)	4.1-5.9 (5.00)	40-52 (46.0)	25-31 (28.0)
Railli	6.3-6.7 (6.50)	0.39-0.41 (0.40)	3-6 (4.50)	139-149 (144.0)	15-19 (17.0)	152-173 (162.5)	2.8-3.9 (3.35)	4.2-5.1 (4.65)	32-43 (37.5)	23-34 (23.5)
Dadhol	5.9-6.2 (6.05)	0.37-0.41 (0.39)	4-6 (5.00)	134-136 (135.0)	20-23 (21.5)	135-144 (139.5)	3.4-4.5 (3.95)	4.7-6.9 (5.80)	28-39 (33.5)	21-30 (25.5)
Nagrota	5.3-5.8 (5.55)	0.34-0.38 (0.36)	3-6 (4.50)	146-165 (155.5)	12-18 (15.0)	128-139 (133.5)	3.1-4.2 (3.65)	4.1-5.2 (5.55)	20-30 (25.5)	35-48 (41.5)
Nagni	5.9-6.5 (6.20)	0.38-0.42 (0.40)	5-7 (6.00)	121-154 (137.5)	16-21 (13.5)	131-138 (134.5)	2.7-3.9 (3.30)	3.7-4.4 (4.05)	26-35 (30.5)	23-31 (27.0)
Utreh	5.7-6.3 (6.00)	0.36-0.40 (0.38)	5-7 (6.00)	135-160 (147.5)	18-23 (20.5)	123-146 (134.5)	2.9-4.2 (3.55)	3.1-4.6 (3.85)	44-56 (50.0)	28-36 (32.0)
Jachh	6.2-6.8 (6.50)	0.39-0.43 (0.41)	6-9 (7.50)	130-155 (142.5)	14-26 (20.0)	132-141 (136.5)	2.7-3.8 (3.25)	3.7-4.5 (4.10)	48-65 (56.5)	17-26 (21.5)
Mean	6.23	0.36	5.49	150.2	15.1	151.1	4.99	4.70	38.9	25.1

Figures in parentheses are the average values

number with growth and yield of litchi orchards. The positive correlation was observed between mycorrhizal spore population in the rhizosphere soil with leaf area and crop yield (Sharma *et al.,* 2005). *Azotobacter* produced growth regulators like IAA and GA besides nitrogen fixation, favoured the availability of N in the soil and its uptake by the crop reflecting on higher fruit yield (Venkateswarlu and Rao, 1983), and hence positively influenced plant growth and fruit yield (Rao and Das, 1989).

Soil nutrient status: Soil analysis (Table 2) showed that pH in different mango orchards ranged from 5.55 (Nagrota) to 6.60 (Talai). The highest average EC (0.41dSm^{-1}) was recorded in soil samples collected from Jachh, whereas, it was minimum (0.31dS m^{-1}) in Jukhala area. Average soil OC content ranged between 2.5 g kg^{-1} (Gehrwin) and 9.00 g kg^{-1} (Bari). All the orchards have shown an intermediate range of soil OC content. Furthermore, all the orchards have been found in medium range with reference

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to the available macro- and micronutrient contents. A perusal of the correlation data indicated that AM spore population had positive and significant correlation with soil Cu (r = 0.809), Zn (r = 0.832) and Mn (r= 0.410), but, it was negative and significant with soil K (r = -0.526). However, the spore population was positively and non-significantly correlated with OC, EC, and available N and Fe content of the orchard soils, while, negatively but non-significantly with soil pH and available P content (Table 5). Negative correlation between AM spores and soil K contents might be due to negative effect of K fertilizers on the development and function of AM fungi.

Correlation between *Azotobacter* count and soil OC content was positive and significant (r = 0.572), whereas, with soil pH, EC, available N, P, K, Cu, Zn, Fe and Mn content of orchard soils was non-significant. This relationship is in agreement with those of

Table 3. Leaf nutrient status of mango orchards

Locations	Macronutrients (%)			Micronutrients (ppm)			
	N	P	K	Cu	Zn	Fe	Mn
Dadd	1.03-1.11 (1.07)	0.07-0.09 (0.08)	1.15-1.29 (1.22)	7-9 (8.0)	13-21 (17.0)	33-44 (38.5)	22-34 (28.0)
Gehrwin	1.08-1.12 (1.10)	0.06-0.10 (0.08)	1.09-1.20 (1.15)	10-14 (12.0)	13-22 (17.5)	38-54 (46.0)	26-35 (30.5)
Kalol	1.20-1.31 (1.26)	0.11-0.15 (0.13)	0.92-1.01 (0.97)	15-20 (17.5)	27-31 (29.0)	45-56 (50.5)	35-44 (39.5)
Jukhala	1.33-1.46 (1.40)	0.13-0.19 (0.16)	0.75-0.88 (0.82)	18-23 (20.5)	25-31 (28.0)	52-63 (57.5)	29-36 (32.5)
Jarol	1.09-1.18 (1.14)	0.09-0.13 (0.11)	1.03-1.13 (1.08)	11-15 (13.0)	18-26 (22.0)	58-74 (66.0)	33-42 (22.5)
Kotlu	1.13-1.38 (1.26)	0.07-0.11 (0.09)	0.99-1.07 (1.03)	10-13 (11.5)	33-40 (36.5)	60-79 (69.5)	31-45 (38.0)
Berthin	1.24-1.40 (1.32)	0.11-0.18 (0.15)	0.88-0.95 (0.92)	17-22 (19.5)	24-29 (26.5)	52-66 (59.0)	28-38 (33.0)
Bari	1.31-1.44 (1.38)	0.10-0.14 (0.12)	1.01-1.12 (1.07)	15-17 (16.0)	21-29 (25.0)	59-74 (66.5)	29-37 (33.0)
Nihari	1.31-1.49 (1.40)	0.14-0.21 (0.17)	0.56-0.65 (0.61)	19-25 (22.0)	29-35 (32.0)	62-82 (72.0)	37-46 (41.5)
Bijjar	1.02-1.19 (1.11)	0.06-0.10 (0.08)	1.09-1.23 (1.16)	8-11 (9.5)	10-17 (13.5)	42-58 (50.0)	39-48 (43.5)
Railli-Jajjri	1.11-1.19 (1.15)	0.08-0.11 (0.10)	1.09-1.20 (1.15)	10-14 (12.0)	15-23 (19.0)	38-56 (47.0)	32-41 (36.5)
Talai	1.18-1.33 (1.26)	0.08-0.14 (0.11)	0.90-1.10 (1.00)	14-17 (15.5)	25-29 (27.0)	44-62 (53.0)	42-54 (48.0)
Dashlehra	1.21-1.36 (1.29)	0.09-0.13 (0.11)	1.03-1.14 (1.09)	12-16 (14.0)	19-27 (23.0)	40-52 (46.0)	34-43 (38.5)
Railli	1.29-1.40 (1.35)	0.11-0.15 (0.13)	1.02-1.18 (1.10)	12-15 (13.5)	20-25 (22.5)	46-59 (52.5)	31-40 (35.5)
Dadhol	1.18-1.31 (1.25)	0.09-0.13 (0.11)	0.90-0.99 (0.95)	16-19 (17.5)	22-25 (23.5)	35-48 (41.5)	33-38 (35.5)
Nagrota	1.14-1.18 (1.16)	0.07-0.13 (0.10)	0.95-1.04 (1.00)	14-18 (16.0)	18-23 (20.5)	31-45 (38.0)	42-56 (49.0)
Nagni	1.19-1.22 (1.21)	0.12-0.15 (0.14)	0.99-1.12 (1.06)	15-21 (18.0)	19-26 (22.5)	38-46 (42.0)	38-46 (42.0)
Utreh	1.12-1.21 (1.17)	0.09-0.13 (0.11)	0.88-0.97 (0.93)	16-19 (17.5)	20-24 (22.0)	45-56 (50.5)	36-47 (41.5)
Jachh	1.16-1.24 (1.20)	0.10-0.14 (0.12)	0.94-1.08 (1.02)	15-20 (17.5)	19-23 (21.0)	49-55 (52.0)	29-38 (33.5)
Mean	1.24	0.12	1.02	15.3	23.6	52.5	39.9

Figures in parentheses are the average values

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Table 4. Correlation (r- values) of AM spore number, per cent root colonization and *Azotobacter* count with growth parameters of mango orchards

Parameters	Shoot extension growth	Leaf area	Fruit yield
AM spore number	0.825**	0.691**	0.779**
Root colonization	-0.102	-0.021	-0.137
Azotobacter count	0.222	0.162	0.303*

*, ** Significant at *P*=0.05 and *P*=0.01, respectively

Tiwary *et al.* (1999), who reported positive relationship between *Azotobacter* population and soil N, Cu and Zn content. Per cent root colonization showed positive and significant relationship with OC (r = 0.306), and available N (r = 0.344), however, this relationship was non-significant with EC, available P, K, Cu, Zn and Mn content of orchard soils. Most of the biological species/strains of mycorrhizal fungi and *Azotobacter* are soil and agro-climatic specific. This limits their widespread and foolproof use with expected performance, which in turn favoured the establishment of arbuscular- mycorrhizae and *Azotobacter* symbiosis.

Leaf nutrient status: The leaf N, P, K, Cu, Zn, Fe and Mn content of mango orchards of Himachal Pradesh varied between 1.07-1.40%, 0.08- 0.17%, 0.61- 1.22%, 8.0- 22.0 ppm, 13.5- 36.5 ppm, 38.5- 72.0 ppm, 22.5- 48.0 ppm per cent, respectively (Table 3). The relationship with soil microflora revealed that the AM spore population had a positive and significant correlation with leaf N, P, Cu and Zn contents with respective r- values of 0.635, 0.651, 0.802 and 0.571, respectively, but negative and significant with leaf K content (r = -0.310) (Table 6). Mycorrhizae can absorb several times more phosphates from soil than the non-infected roots (Gianinazzi *et al.,* 1981). This greater phosphates absorption by AM fungi could be because of its superior efficiency of uptake from liable forms of soil phosphate.

The positive relationship between AM fungi and Cu as well as Zn content of leaf attributed to increased root colonization, which increased the surface area for nutrient absorption. AM fungi enhanced the uptake of slowly immobile nutrients from the soil especially, Cu, Zn, Fe and Mn contents. The application of AM fungi to rhizosphere converted slowly immobile nutrients to the available forms so that these become easily available to plants (Sharma and Bhutani, 2000).

Azotobacter count was positively and significantly correlated with leaf Fe (r= 0.371) and non-significantly related with N, P, Cu and Zn content of leaf, while, negatively but significantly correlated with leaf K (r = -0.314). The positive influence with nitrogen might be due to its enhanced availability in the rhizosphere resulting in better uptake. These results are also in accordance with Rao and Das (1989), who attributed high leaf N to more dry matter production by *Azotobacter chroococcum* in ber and pomegranate. Higher status of N and organic carbon has shown positive relationship with microbial population and root colonization (Sharma *et al.*, 2005). Furthermore, the secretion of IAA and GAs by *Azotobacter* in rhizosphere might have lowered pH of soil and thereby enhanced uptake of nutrients. The relationship between root colonization and N, Zn, Fe, Mn P, K and Cu content of leaf was non-significant.

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Table 5. Correlation (r- values) of AM spore number, per cent root colonization and *Azotobacter* count with soil chemical characteristics of mango orchards

Parameters	pH	OC	EC	N	P	K	Cu	Zn	Fe	Mn
AM spore number	-0.188	0.206	0.037	0.116	-0.237	-0.526**	0.809**	0.832**	0.063	0.410**
Root colonization	0.092	0.306*	-0.224	0.344*	-0.216	-0.047	-0.201	-0.123	0.153	-0.294
Azotobacter count	0.172	0.572**	0.141	0.045	-0.227	-0.136	0.227	0.232	0.027	0.174

*, ** Significant at *P*=0.05 and *P*=0.01, respectively

Table 6. Correlation (r- values) of AM spore number, per cent root colonization and *Azotobacter* count with leaf nutrient contents of mango orchards

Parameters	N	P	K	Cu	Zn	Fe	Mn
AM spore number	0.635**	0.651**	-0.310*	0.802**	0.571**	-0.222	0.099
Root colonization	0.058	-0.041	-0.010	-0.057	0.063	0.291	0.276
Azotobacter count	0.215	0.218	-0.314*	0.194	0.256	0.371*	-0.221

*, ** Significant at *P*=0.05 and *P*=0.01, respectively

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