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EFFECT OF VAM FUNGI AND APPLIED PHOSPHORUS THROUGH STCR PRECISION MODEL ON GROWTH, YIELD AND NUTRIENT DYNAMICS IN MAIZE IN ACID ALFISOL

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ABSTRACT

The inoculation of three VAM cultures viz. local culture *(Glomus mosseae)*, VAM culture from IARI, New Delhi (*Glomus mosseae*) and a culture from The Energy Research Institute (TERI), New Delhi (*Glomus intraradices*) alone or with increasing applied phosphorus levels from 25 to 75% of recommended P_2O_5 based on soil test crop response (STCR) precision model improved the plant height, shoot and root dry matter accumulation, root length and root weight density as well as yield attributes of rainfed maize in an acid alfisol of NW Himalayas. It was revealed that sole application of any of 3 VAM fungi did not have pronounced effect on phenological stages though combined application of VAM cultures with increasing P levels from 25 to 75% of recommended P_2O_5 reduced the days to various phenological stages. It was reported that sole application of these 3 VAM cultures improved the maize grain yield by 17.10 to 25.36 % over control. Increase in P levels from 25 to 75% of recommended P_2O_5 besides VAM inoculation resulted in consistent and significant improvement in grain, stover and biological yield of maize. 75% of recommended P_2O_5 alongwith VAM cultures achieved the goal of targeted yield (40 q ha^{-1}) of maize, thus, saving the applied P to the tune of about 25% without impairing the soil fertility in the present study.

Key words: *Vesicular arbuscular mycorrhizae, phosphorus, maize, growth, targeted yield, nutrient dynamics.*

Maize is one of the major cereal crops in north-western Himalayas particularly wet temperate region of Himachal Pradesh having acidic alfisol (2, 15). The availability of phosphorus in these acidic soils is very less due to fixation of soluble P into insoluble soil phosphate complexes due to high fixation power of these soils as a result of excessive presence of Fe and Al ions (14). Under such conditions, vesicular arbuscular mycorrhizae (VAM) can play a key role in phosphorus mobilization and absorption (4). Most of the hill farmers of Himachal Pradesh are poor and cant afford the use of recommended doses of chemical fertilizers particularly expensive phosphatic fertilizers. The P deficient acidic soils of Himachal Pradesh are best suited to the use of VAM fungi (15). Thus, VAM fungi can play an important role in such low input intensive farming systems of hill farmers which rely less on chemical fertilizers than conventional farming. Maize is an important food crop of the region, thus, it is imperative to generate information on effect of VAM fungi and applied phosphorus on growth, development and productivity of rainfed maize besides nutrient dynamics in acid alfisol of wet temperate NW Himalayas.

MATERIALS AND METHODS

Field studies were conducted on rainfed maize during *Kharif* 2002 in a P deficient silty clay loam acid alfisol at Experimental Farm of CSK HPKV, Palampur (31°6' N 76°3 E, 1291 m above mean sea level) in a randomized block design (RBD) replicated thrice. Treatments were viz. absolute control, farmers' practice (N @ 30 kg ha^{-1}), and three VAM fungi cultures *i.e.*, VAML (Local VAM culture - Glomus mosseae, developed by CSK HPKV, Palampur), VAMT (VAM culture-*Glomus intraradices,* developed by Centre for Mycorrhizal Research, The Energy Research Institute (TERI), New Delhi) and VAMI (VAM culture-*Glomus mosseae,* developed by Indian Agricultural Research Institute (IARI), New Delhi) alone or with 25, 50 and 75% of recommended P_2O_5 dose to rainfed maize based on targeted yield concept following soil test crop response (STCR) precision model (9) as well as one treatment with sole application of 100% of recommended P_2O_5 dose based on STCR precision model. 100% of recommended N and K fertilizers were added in 25, 50, 75 and 100% of recommended P_2O_5 supplied treatments based on STCR model.

N, P and K were supplied through Urea (46% N), Single Super Phosphate (16% P_2O_5) and Muriate of Potash (60% K_2O), respectively. Whole of the P and K were supplied basally at the time of sowing while N was supplied in 3 equal splits i.e. one part at the time of sowing, one part at the time of knee high stage and one part at the silking stage. In case of farmers practice, 30 kg N ha^{-1} was supplied to the crop in 3 splits described above. The fertilizer N, P_2O_5 and K_2O were applied on the basis of STCR model (9) through following fertilizer adjustment equations:

$$FN = 5.67\ T - 0.17\ SN$$

$$FP_2O_5 = 4.38\ T - 5.26\ SP$$

$$FK_2O = 2.29\ T - 0.10\ SK$$

Where, FN, FP_2O_5 and FK_2O are the fertilizer N, P_2O_5 and K_2O in kg ha^{-1}, respectively. T is the targeted yield of maize (40 q ha^{-1}). SN, SP and SK are the soil available N, P and K in kg ha^{-1}, respectively in their elemental form.

Maize crop was sown on June 21, 2002 and harvested on Oct. 14, 2002. The plot size was 9 m^2 and plant spacing was 60 × 20 cm. Maize cv. Early Composite was grown with recommended package of practices. Standard procedures were used for chemical analysis of soil and plant samples (5). Before sowing, the initial organic carbon content in the soil were 14 g per kg soil. The soil pH was 5.6 while available N, P and K were 251, 15 and 250 kg ha^{-1}, respectively. Rainfall received during the crop season was 898 mm.

Data on phenological stages was taken at 50% expression of each stage in the concerned treatments and the plant height was also taken at these stages on marked 10 plants in each net plot. Shoot, root and total dry matter production was also taken at flowering stage in maize besides root length and root weight density from the sampling row comprising of 2 sampled plants from each plot. Statistical analysis was done by the standard procedures (3).

VAM Inoculation

Soil mixed VAM cultures having VAM spores and fungal hyphae were used in the study. In all the 3 VAM cultures viz. Local, TERI and IARI cultures, the spore count was 110, 500 and 400 per 250 g air dry soil, respectively. The VAM cultures were used @ 12 kg ha^{-1}. These VAM cultures were used on spore equivalent basis taking TERI VAM culture into consideration while using the VAM cultures. Local VAM culture was prepared by the investigating scientists (authors) themselves by raising the target crop (maize) till maturity in pots containing 7 kg sterilized soil + 2 kg FYM and 1 kg mother culture. After harvest, rhizosphere soil of pot as well as root biomass constituted the local VAM culture. The actual inoculation of maize seeds with above cultures was performed by preparing soil slurry of cultures and dipping the seeds into it for half hour followed by shade drying for making seed pallets and then sowing in the field.

RESULTS AND DISCUSSION

Growth and development

Data in Table 1 reveals that increase in phosphorus levels from 25 to 75% of recommended P_2O_5 dose based on STCR model alongwith either of the 3 VAM cultures resulted in reduction in days to knee high stage, tasseling, silking as well as physiological maturity though the results were not statistically so contracting. Similarly, all the 3 VAM cultures remained statistically at par in phenological stage expression without or with inorganic P fertilization. Plant height on the other hand was significantly improved with the application of either of the 3 VAM cultures over control and farmers' practice at all the phenological stages under study (Table 1), thereby, indicating the positive effect of VA-mycorrhizae on growth and development of rainfed maize (1, 6). Similarly, increase in P levels from 25 to 75 % alongwith either of 3 VAM cultures resulted in consistent and significant improvement in maize plant height. It was also observed that plant height of maize with the application of 50 to 75% of recommended P_2O_5 dose alongwith either of 3 VAM cultures remained statistically at par with sole application of 100% of recommended P_2O_5 dose in maize which again indicate that VAM fungi has positive bearing on plant growth beside inorganic P fertilizer economization. Similar results have also been reported by (6, 16).

Data presented in Table 2 on dry matter production and root studies at silking stage reveal that shoot, root and total dry matter, root length and root weight density of rainfed maize was significantly higher with the use of either of the 3 VAM cultures (12) without NPK fertilization over control and quite comparable with farmers' practice, thus, indicating positive effect of mycorrhizal biofertilizer on root and shoot growth parameters (1, 7). Increase in phosphorus levels from 25 to 75% of recommended

P_2O_5 does with either of the 3 VAM cultures were almost comparable to sole use of 100% of recommended P_2O_5 dose particularly with use of TERI VAM culture which was proved to be superiormost than other 2 VAM cultures with or without P application; though the differences among the 3 VAM cultures were non-significant at each level of P fertilization in the present study. These results reveal that VAM fungi improved the plant growth in terms of biomass production as well as root length and root weight density (7, 12).

Yield Attributes and Yield

Yield attributes in table 3 reveals that cob length, number of grain rows per cob, grains per cob row, grains per cob as well as 1000-grain weight in maize with either of the 3 VAM cultures alone were higher over control and farmersÆ practice (N_{30}). Either of the 3 VAM cultures with increase in P levels from 25 to 75% of recommended P_2O_5 dose resulted in consistent improvement in these yield attributing characters (16), though the differences were not statistically contrasting with each incremental increase in P levels alongwith mycorrhizal biofertilizers. The application of 75% of recommended P_2O_5 in combination with either of the 3 VAM cultures exhibited statistically similar magnitude of yield attributes compared to sole application of 100% of recommended P_2O_5 dose. The TERI VAM culture remained superior in yield attributes over other 2 cultures though the differences were non-significant among themselves alone or with each P level (15, 16).

Grain, stover and biological yields of maize (Table 3) followed the similar trend as that of yield attributing characters. It was observed that the grain and stover yield as well as biological yield of maize (Table 3) with the application of either of the 3 VAM cultures was higher over control and farmers' practice. Data also revealed that sole use of either of these 3 VAM cultures resulted in 17.10 to 25.36% increase in grain yield of maize over control thereby suggesting its positive bearing on yield expression (4, 12). These 3 VAM cultures alongwith 25 to 75% of recommended P2O5 dose resulted in consistent and significant improvement in maize grain, stover and biological yields of maize. These VAM cultures alongwith 75% P_2O_5 level produced statistically equal yields as produced by sole use of 100% P_2O_5 dose and TERI culture alongwith 75% P_2O_5 dose even outyielded the sole use of 100% P_2O_5 dose in terms of stover and biological yields. It is also reported that either of these 3 VAM cultures alongwith 75% of recommended P_2O_5 on targeted yield concept basis achieved the goal of target yield of 40 q ha^{-1} thereby saving 25% phosphatic fertilizers. Thus, it can be inferred that we can economize the use of inorganic P fertilizers by 25% with application of mycorrhizal biofertilizers without affecting our yield targets (4, 15). The treatment effects on harvest index in the present study were non-significant. Overall, it was observed that use of mycorrhizal cultures resulted in significant improvement in the yield attributes and yield of maize crop (4, 12). These results are also supported by the findings of (6 and 13).

Nutrient Dynamics

Data presented on soil available NPK after harvest of maize (Table 4) reveals that either of the 3 VAM cultures *i.e.*, VAML, VAMT and VAM_I alone or in combination with 25 to 75% of recommended P_2O_5 dose based on targeted yield concept (STCR) resulted in consistent and significant improvement in soil available P and K. There was slight increase in soil available N with the application of 25% P_2O_5 dose with VAM cultures over VAM cultures alone but further increase in P fertilization resulted in decrease in soil available N upto 75% P_2O_5 dose though the differences were non-significant. Similarly, P and K content in soil were lower with either of the 3 VAM cultures alone over control except soil N. On the other hand, available N content in soil at 50 and 75% P_2O_5 dose, and available K content at 75% P_2O_5 dose were at par with sole application of 100% of recommended P_2O_5 dose. These results show that VA-mycorrhization resulted in increased uptake of P and K from the soil at lower soil P levels while at high P fertilization rates N and K content were improved in the soil (4), thereby, suggesting that VAM might have mobilized the non-available complex native N and K pool thus improving the soil available N and K pool which indicates that VAM have some role in nutrient dynamics in soil plant system (8). These observations are also supported by (10, 11). Results of the above experiment, overall, suggest that VA-mycorrhizal fungi has positive effect on growth, development, yield attributes and yield of maize as well as soil fertility status. Besides, it is possible to economize chemical fertilizer use to the tune of at least by 25 % by resorting to VAM inoculation in rainfed maize *vis-vis* yield target of 40 q ha^{-1}. It is notable that above technology leads to improvement in the soil fertility.

Table 1 : Effect of VAM cultures and applied P on phenological stages and plant height at various phenological stages of maize.

Treatments	Days taken to various phonological stages				Plant height (cm) at various phological stages			
	knee high stage	tasseling stage	siking stage	physiological maturity	knee high stage	tasseling stage	siking stage	physiological maturity
Control	38	64	74	111	47.4	231.5	240.6	240.7
Farmers' practice	38	53	74	111	47.5	232.2	241.2	241.4
VAM_L alone	38	63	73	111	48.0	236.4	243.7	244.0
VAM_T alone	38	63	73	111	50.1	235.4	243.8	244.2
VAM_I alone	38	62	72	111	50.3	235.2	244.0	244.4
VAM_L + 25% P_2O_5 based on STCR Model	36	61	72	110	51.8	236.4	246.7	247.0
VAM_T + 25% P_2O_5 based on STCR Model	36	61	72	111	51.9	236.7	246.4	246.6
VAM_I + 25% P_2O_5 based on STCR Model	36	61	71	111	51.9	236.4	246.3	246.6
VAM_L + 50% P_2O_5 based on STCR Model	34	59	70	110	56.5	238.1	249.3	249.8
VAM_T + 50% P_2O_5 based on STCR Model	34	59	71	110	56.5	238.1	250.9	251.4
VAM_I + 50% P_2O_5 based on STCR Model	33	59	68	110	56.4	238.1	249.3	249.7
VAM_L + 75% P_2O_5 based on STCR Model	34	57	71	109	58.6	240.1	250.4	251.0
VAM_T + 75% P_2O_5 based on STCR Model	34	58	69	109	58.6	239.7	251.1	251.7
VAM_I + 75% P_2O_5 based on STCR Model	34	58	70	109	58.7	239.7	250.7	251.3
100% P_2O_5 based on STCR Model	34	59	70	109	58.4	241.3	250.6	251.2
LSD (P=0.05)	**2.0**	**3.3**	**3.5**	**1.3**	**2.5**	**4.7**	**4.1**	**4.1**

Table 2 : Effect of VAM cultures and applied P on dry matter accumulation and root parameters of maize at silking stage.

Treatments		Root dry matter accumulation (g/plant)	Total dry matter accumulation (g/plant)	Root length (cm)	Root weight density (g/cm^3)
Control	98.4	10.7	109.8	64.3	0.0081
Farmers' practice	107.7	11.4	119.1	69.8	0.0086
VAM_L alone	103.2	11.1	116.9	69	0.0084
VAM_T alone	104.9	11.0	115.9	70.7	0.0083
VAM_I alone	103.3	11.0	114.3	69.0	0.0083
VAM_L + 25% P_2O_5 based on STCR Model	122.8	14.5	137.3	78.9	0.0110
VAM_T + 25% P_2O_5 based on STCR Model	129.6	15.3	144.9	78.4	0.0116
VAM_I + 25% P_2O_5 based on STCR Model	127.7	14.9	142.6	79.1	0.0113
VAM_L + 50% P_2O_5 based on STCR Model	135.6	17.4	153.0	92.2	0.0132
VAM_T + 50% P_2O_5 based on STCR Model	140.7	18.0	158.7	95.0	0.0137
VAM_I + 50% P_2O_5 based on STCR Model	137.5	17.8	155.3	93.0	0.0135
VAM_L + 75% P_2O_5 based on STCR Model	148.9	19.1	168.1	95.0	0.0145
VAM_T + 75% P_2O_5 based on STCR Model	152.8	19.8	172.6	96.7	0.0149
VAM_I + 75% P_2O_5 based on STCR Model	150.9	18.7	169.6	97.0	0.0141
100% P_2O_5 based on STCR Model	157.3	20.7	181.3	101.3	0.0156
LSD (P=0.05)	**3.43**	**1.66**	4.31	**4.50**	**0.0013**

Table 3 : Effect of VAM cultures and applied P on yield attributes, yield and harvest index of maize.

Treatments	Cob length (cm)	Cobs/ plant	Number of grain rows/cob	Number of grains/row	Number of grains/cob	1000-grain weight (g)	Grain yield (q ha^{-1})	Stover yield (q ha^{-1})	Biological yield (q ha^{-1})	Harvest index (%)
Control	10.2	1.0	10.0	18.3	185.0	190.44	18.65	40.10	58.75	0.32
Farmers' practice	10.5	1.0	11.3	26.3	303.3	191.06	23.48	49.94	73.42	0.32
VAM_L alone	11.0	1.0	12.7	25.3	320.0	188.40	21.84	44.58	66.42	0.33
VAM_T alone	12.2	1.0	12.7	31.7	393.3	190.10	23.38	45.96	69.32	0.34
VAM_I alone	12.3	1.0	12.7	32.3	401.7	190.72	21.97	43.82	65.78	0.33
VAM_L + 25% P_2O_5 based on STCR Model	13.0	1.0	12.7	31.0	396.7	195.50	30.80	59.33	90.13	0.34
VAM_T + 25% P_2O_5 based on STCR Model	15.7	1.0	14.0	34.3	467.3	195.51	34.82	67.10	101.92	0.34
VAM_I + 25% P_2O_5 based on STCR Model	14.0	1.0	14.0	32.0	438.3	191.52	35.72	71.76	107.47	0.33
VAM_L + 50% P_2O_5 based on STCR Model	14.7	1.0	14.0	31.0	426.7	192.98	44.42	87.51	131.92	0.34
VAM_T + 50% P_2O_5 based on STCR Model	15.2	1.0	14.0	35.3	483.7	196.02	44.13	76.23	120.36	0.37
VAM_I + 50% P_2O_5 based on STCR Model	14.0	1.0	13.3	34.0	456.7	194.86	43.09	73.48	116.59	0.37
VAM_L + 75% P_2O_5 based on STCR Model	16.0	1.0	13.3	37.0	485.0	194.46	49.66	89.73	139.38	0.36
VAM_T + 75% P_2O_5 based on STCR Model	16.3	1.3	14.0	39.0	531.7	199.46	53.75	99.91	153.66	0.37
VAM_I + 75% P_2O_5 based on STCR Model	16.3	1.0	14.0	37.7	525.0	196.9	49.84	86.05	135.89	0.38
100% P_2O_5 based on STCR Model	17.8	1.3	14.7	40.0	570.0	199.50	58.51	93.05	151.56	0.9
LSD (P=0.05)	**4.2**	**NS**	**2.3**	**5.4**	**84.8**	**6.4**	**6.54**	**16.02**	**20.69**	**NS**

Table 4 : Effect of VAM cultures and applied P on plant nutrient content and nutrient uptake after harvest of maize.

Treatments	N content (%)		N uptake (kg ha^{-1})	P content (%)		N uptake (kg ha^{-1})	K content (%)		K uptake (kg ha^{-1})
	Grain	Straw		Grain	Straw		Grain	Straw	
Control	1.45	0.47	46.1	0.22	0.067	6.8	0.29	0.55	27.3
Farmers' practice	1.48	0.47	57.5	0.22	0.068	8.5	0.30	0.55	34.5
VAM_L alone	1.49	0.48	53.9	0.22	0.070	7.9	0.31	0.56	31.5
VAM_T alone	1.48	0.49	57.1	0.22	0.071	8.5	0.31	0.56	33.2
VAM_I alone	1.47	0.49	53.8	0.22	0.070	8.0	0.31	0.56	31.4
VAM_L + 25% P_2O_5 based on STCR Model	1.49	0.49	76.2	0.23	0.074	11.4	0.34	0.61	46.8
VAM_T + 25% P_2O_5 based on STCR Model	1.51	0.51	86.4	0.23	0.073	12.9	0.35	0.64	55.3
VAM_I + 25% P_2O_5 based on STCR Model	1.48	0.51	88.7	0.23	0.074	13.4	0.34	0.64	58.4
VAM_L + 50% P_2O_5 based on STCR Model	1.50	0.50	111.5	0.23	0.077	17.0	0.37	0.63	71.6
VAM_T + 50% P_2O_5 based on STCR Model	1.50	0.51	105.9	0.23	0.078	16.2	0.37	0.65	65.7
VAM_I + 50% P_2O_5 based on STCR Model	1.50	0.52	102.6	0.23	0.077	15.6	0.37	0.63	62.0
VAM_L + 75% P_2O_5 based on STCR Model	1.51	0.51	121.0	0.24	0.084	19.3	0.37	0.64	75.7
VAM_T + 75% P_2O_5 based on STCR Model	1.52	0.53	134.1	0.24	0.086	21.3	0.39	0.66	86.3
VAM_I + 75% P_2O_5 based on STCR Model	1.51	0.53	121.0	0.24	0.085	19.2	0.38	0.65	74.6
100% P_2O_5 based on STCR Model	1.53	0.55	140.3	0.24	0.089	22.6	0.39	0.66	84.5
LSD (P=0.05)	**0.04**	**0.03**	**16.43**	**0.01**	**0.006**	**2.42**	**0.03**	**0.04**	**12.24**

Table 5 : Effect of VAM cultures and applied P on available nutrient status (kg ha^{-1}) after harvest of maize.

Treatments	Available N	Available P	Available K
Control	226.7	12.7	240.4
Farmers' practice	234.7	13.0	243.1
VAM_L alone	261.8	12.6	238.3
VAM_T alone	227.9	12.5	236.7
VAM_I alone	229.4	12.6	237.0
VAM_L + 25% P_2O_5 based on STCR Model	262.3	16.3	246.3
VAM_T + 25% P_2O_5 based on STCR Model	262.2	16.2	245.8
VAM_I + 25% P_2O_5 based on STCR Model	259.9	16.2	246.2
VAM_L + 50% P_2O_5 based on STCR Model	258.9	22.1	250.4
VAM_T + 50% P_2O_5 based on STCR Model	260.5	21.7	247.8
VAM_I + 50% P_2O_5 based on STCR Model	259.3	21.9	249.5
VAM_L + 75% P_2O_5 based on STCR Model	256.5	25.5	253.5
VAM_T + 75% P_2O_5 based on STCR Model	252.5	25.4	253.2
VAM_I + 75% P_2O_5 based on STCR Model	254.4	25.7	253.4
100% P_2O_5 based on STCR Model	253.3	32.0	253.6
LSD (P=0.05)	**25.93**	**0.97**	**3.45**
Initial status	**251.4**	**14.6**	**250.9**

REFERENCES

1. Aguilera, G.L., Davies, F.T., Olalde, V. and Duray, S.A. 1999. Influence of phosphorus and endomycorrhiza on gas exchange and plant growth of Chile ancho pepper. *Photosynthetica*, **36**:441-449.
2. Anonymous 1997. Soils of Himachal Pradesh for optimizing land use. National Bureau of Soil Survey and Land Use Planning (ICAR), Nagpur and Department of Agriculture, Govt. of H.P., Shimla.
3. Gomez, K.A. and Gomez, A.A. 1984. *Statistical Procedures for Agricultural Research.* A Wiley-Interscience Publication, John Wiley and Sons Inc., New York, USA.
4. Harrier, L.A. and Watson, C.A. 2003. The role of arbuscular mycorrhizal fungi in sustainable cropping systems. *Advances in Agronomy*, **79**:185-225.
5. Jackson, M.L. 1967. *Soil Chemical Analysis.* Prentice Hall of India Pvt. Ltd., New Delhi, pp. 331-334.
6. Mukherjee, P.K. and Rai, R.K. 2000. Effect of VAM and PSB on growth, yield and phosphorus uptake by wheat (*Triticum aestivum*) and chickpea (*Cicer arientium*). *Indian Joumal of Agronomy,* **45**:602-607.
7. Nadian, H., Hashemi, M. and Herbert, S.J. 2009. Soil aggregate size and mycorrhizal colonization effect on root growth and phosphorus accumulation by berseem clover. *Communications in soil Science and Plant Analysis,* **40**:2413-2425.
8. Narsian, V.T. and Patel, H.H. 2009. Relationship of physicochemical properties of rhizosphere soils with native population of mineral phosphate solubilizing fungi. *Indian Journal of Microbiology,* **49**:60-67.
9. Ramamoorthy, B., Narasimham, R.L. and Dinesh, R.S. 1967. Fertilizer recommendations based on fertilizer application for specific yield target of Sonora-64. *Indian Farming,* **17**:443-451.
10. Shirani Rad, A.H. and Alizadeh, A. 2000. Study on the effects of VAM-fungi, *Bradyrhizobium japonicum* and phosphorus on nutrient uptake efficiency in soybean. *Seed and Plant,* **16**(2):172-191.
11. Shirani Rad, A.H., Alizadeh, A. and Hashemi, D.A. 2000. The study of VAM fungi, phosphorus and drought stress effect or nutrient uptake efficiency in wheat. *Seed and Plant,* **16**(3):327-349.
12. Singh, S.K. and Srivastava, J.S. 2007. Response of pea cultivars to rhizobia and mycorrhizal fungi. *Journal of Food Legumes,* **20**(1):87-89.
13. Singh, S. and Kapoor, K.K. 1999. Inoculation with phosphate solubilizing microorganisms and a VAM fungus improves dry matter yield and nutrient uptake by wheat grown in a sandy soil. *Biology and Fertility of Soils,* **28**:139-144.
14. Sharma, P.K., Verma, S.P. and Bhumbla, D.R. 1980. Transformation of added phosphorus into inorganic phosphorus fractions in some acid soils of Himachal Pradesh. *Journal of Indian Society of Soil Science,* **28**:450.
15. Suri, V.K., Choudhary, A.K., Chander, G. and Verma, T.S. 2006. Studies on VAM fungi as a potential biofertilizer in an acid alfisol of NW Himalayas. In: 18th World Congress of Soil Science, Philadelphia, Pennsylvania, USA. 18th WCSS Congress Abstracts p 515.
16. Suri, V.K., Chander, G., Choudhary, A.K. and Verma T.S. 2006. Co-inoculation of VAM and phosphate solubilizing bacteria in enhancing phosphorus supply to wheat in Typic Hapludalf. *Crop Research* **31**(3):357-361.