Indian Journal of Agronomy **60** (1): 163–167 (March 2015)

Research Communication

Influence of AM fungi and inorganic phosphorus levels on growth, green pod yield and profitability of pea (*Pisum sativum*) in Himalayan acid Alfisol

ARTI YADAV[1], V.K. SURI[2], ANIL KUMAR[3] AND ANIL K. CHOUDHARY[4]

Chaudhary Sarwan Kumar Himachal Pradesh Agricultural University, Palampur, Himachal Pradesh 176 062

Received : February 2014; Revised accepted : March 2015

ABSTRACT

Present investigation was carried out during winter season of 2010–11 at Palampur, Himachal Pradesh in garden pea (*Pisum sativum* L.) with the broad aim of assessing its productivity and profitability following integrated use of AM fungi (AMF) and inorganic P at varying irrigation regimes in Himalayan acid Alfisol. At 120 DAS, AMF imbedded treatments exhibited an increase in plant height and LAI to the tune of 7.4 and 2.3%, respectively over non–AMF treatments. Green pod yield, net returns, benefit: cost ratio got enhanced by 6.5, 12.7, 9.2%, while production and monetary efficiencies increased by 3.1 and 10.8% following AMF inoculation over non–AMF treatments respectively. Increase in inorganic P levels from 50 to 100% at both irrigation regimes with or without AMF, led to increase in plant height, LAI, green pod yield, net returns and B: C ratio in pea; however, irrigation regime of $IW/CPE_{1.0}$ showed its superiority over $IW/CPE_{0.6}$. AMF + 75% P at both irrigation regimes produced pod yield and net returns statistically similar to 100% generalized recommended P dose (GRD), thus, indicating a net saving of about 25% in fertilizer P. Overall, integrated use of AM fungi and 75% soil–test based P dose at both irrigation regimes led to enhanced productivity and profitability besides economizing fertilizer P dose by about 25% in acid Alfisol conditions.

Key words **:** Acid Alfisol, Arbuscular mycorrhizal fungi, Inorganic P, Pea, Productivity

Garden pea is an important vegetable crop in wet–temperate north–western (NW) Himalayas because of well suited agro–climatic conditions. Presently, this crop is fetching high premium in markets due to which area under pea is increasing rapidly under mid–hill and high–hill zones of NW Himalayas. However, despite favourable conditions, yield potential of above crop is less especially due to acidic nature of soils with low water retentivity. In acid soils, much of applied P react with iron (Fe) and aluminium (Al) ions, thereby getting precipitated/fixed as Fe and Al hydroxyl phosphates unavailable for plant use (Kumar *et al.,* 2014). Erratic and ill– distributed rainfall pattern especially in winter (*Rabi*) season further act as barrier to harness higher yields in the region (Paul *et al.,* 2011).

In above scenario, utilization of arbuscular mycorrhizal fungi (AMF) in crop production has huge potential to enhance P and water availability to crops, as it is well suited to acid soils. AMF carry out its functions by developing an extensive extra–radical hyphal network that grows away from the root, thereby, increasing roots exploratory area for harnessing various nutrients including P and water (Harrier and Watson, 2003). Beside, AM fungi also release certain organic acids (*oxalic, mallic acids, etc.*) and enzymes (*chitinase, peroxidase, cellulase, protease, phosphatase, etc.*), which solubilize insoluble nutrients including P and convert complex organic compounds into simple ones (Zou *et al.,* 1995; Nahas, 1996) followed by their absorption by fungi or host plants (Chen *et al.*, 2007). As, limited information is available on the performance of AMF at graded P and irrigation levels under Himalayan acid Alfisol, thus, an attempt was made to evaluate the potential of AMF in influencing the productivity and profitability of garden pea so as to develop necessary package for hill farmers to increase their income levels through cultivation of garden pea.

Based on a part of M.Sc. Thesis of the first author submitted to CSKHPAU, Palampur, Himachal Pradesh (Unpublished)

[1]**Corresponding author Email**: ambikarti@gmail.com; anilkumarhpkv@gmail.com

[1]Research Associate ICAR–Indian Institute of Pulse Research, Kanpur, Uttar Pradesh; [2]Chief Scientist, CSK Himachal Pradesh Agricultural University, Palampur, Himachal Pradesh; [3]Assistant Professor, Farm Science Centre, GAD Veterinary and Animal Sciences University, Tarn Taran, Punjab; [4]Senior Scientist, Division of Agronomy, ICAR–Indian Agricultural Research Institute, New Delhi 110 012

A study on garden pea (*Pisum sativum* L.) was conducted during winter season of 2010–11 at CSK Himachal Pradesh Agricultural University, Palampur (32º 6' N latitude; 76º3' E longitude; 1250 m altitude) on soil with acidic soil reaction, silty–clay loam texture and 7.4 g/kg organic carbon. The available N, P_2O_5 and K_2O status was 264, 43 and 134 kg/ha, respectively. Experimentation was replicated thrice in a randomized block design comprising 14 treatments with 12 treatment combinations of 2 arbuscular mycorrhizal fungi (AMF) levels [0 and 12 kg/ha], 3 phosphorus levels [50, 75 and 100% of recommended soil–test based P dose] and 2 irrigation regimes ($IW/CPE_{0.6}$ and $IW/CPE_{1.0}$); besides, one treatment with 'generalized recommended NPK dose with generalized recommended irrigations (GRD)' as well as one treatment based on 'farmers' practice of plant nutrition and irrigation management in NW Himalayas (Table 1). The various inputs including FYM were applied as per treatments.

Inoculation of pea seeds 'Palam Priya' with AMF culture (*Glomus mosseae*; spore count 29–31 per 10 g culture) was done by preparing soil slurry using AMF culture @ 12 kg/ha followed by dipping of seeds into it for half an hour. Inoculated seeds were then dried in shade and subsequently sown in the field (Kumar *et al.*, 2014). For irrigation scheduling, 'Climatological approach' was followed, which involved estimation of atmospheric evaporative demand by taking ratio between 'amount of irrigation water applied (mm)' to the 'cumulative pan evaporation (CPE) (mm)'. The present experiment involved irrigations at IW/CPE ratios of 1.0 and 0.6. Upon the arrival of pre–determined CPE, irrigation (5 cm depth) was applied in respective plots. The economic analysis of the experimentation was carried out by taking into consideration the prevailing market prices (₹/kg) of inputs used and economic produce, which were ₹0.40, 10.06, 23.7, 7.42, 20 and 10 for FYM, N, P_2O_5, K_2O, AMF culture and pea green pod, respectively.

Production efficiency (PE) of pea (kg/ha/day) was computed by dividing the economic yield of pea (kg/ha) with number of days between sowing to final picking, while monetary efficiency (ME) (₹/ha/day) was calculated by dividing the net returns of pea (₹/ha) with number of days between sowing to final picking.

The pea crop was sown on 'October 28, 2010', whereas final harvest was carried out on 'April 18, 2011', therefore '173 days' were taken into consideration for the computation of production and monetary efficiencies. Statistically analysis was carried out following standard procedure.

At 60 DAS, an irregular trend was reported in plant height of pea with maximum magnitude in $V_0P_{75\%}IW/CPE_{0.6}$ followed by $V_0P_{50\%}IW/CPE_{0.6}$ and $V_{12}P_{50\%}IW/CPE_0$, respectively (Fig. 1). However, at 90 DAS, maximum plant height was obtained in $V_{12}P_{50\%}IW/CPE_{0.6}$. The AMF imbedded treatments, viz. $V_{12}P_{75\%}IW/CPE_{1.0}$ and $V_{12}P_{50\%}IW/CPE_{1.0}$ gave higher plant height by 14.3 and 12.9%, respectively over their non–AMF counterpart treatments, viz. $V_0P_{75\%}IW/CPE_{1.0}$ and $V_0P_{50\%}IW/CPE_{1.0}$. At 60 DAS, the plant height in AMF imbedded treatments was not influenced significantly probably due to just initiation of root infection by AMF, whereas at 120 DAS, AMF root infec-

Table 1. Details of experimental treatments evaluated in garden pea

Treatment	Treatment details	Treatment code
T_1	No AMF + $N_{25\%}P_0K_0$ + irrigations now and then depending on water availability (Farmers' practice)	$V_0N_{25\%}P_0K_0FYM_{3t}I_{WA}$(FP)
T_2	No AMF + 100%NPK + irrigations as per need and soil moisture content [Generalized nutrient recommended dose and generalized irrigations (GRD)]	V_0+$NPK_{100\%}$+$FYM_{12.8t}I_{AR}$(GRD)
T_3	No AMF + 30 kg P_2O_5/ha + irrigation at $IW/CPE_{0.6}$	$V_0P_{50\%}IW/CPE_{0.6}$
T_4	No AMF + 45 kg P_2O_5/ha + irrigation at $IW/CPE_{0.6}$	$V_0P_{75\%}IW/CPE_{0.6}$
T_5	No AMF + 60 kg P_2O_5/ha + irrigation at $IW/CPE_{0.6}$	$V_0P_{100\%}IW/CPE_{0.6}$
T_6	12 kg AMF/ha + 30 kg P_2O_5/ha + irrigation at $IW/CPE_{0.6}$	$V_{12}P_{50\%}IW/CPE_{0.6}$
T_7	12 kg AMF/ha + 45 kg P_2O_5/ha + irrigation at $IW/CPE_{0.6}$	$V_{12}P_{75\%}IW/CPE_{0.6}$
T_8	12 kg AMF/ha + 60 kg P_2O_5/ha + irrigation at $IW/CPE_{0.6}$	$V_{12}P_{100\%}IW/CPE_{0.6}$
T_9	No AMF + 30 kg P_2O_5/ha + irrigation at $IW/CPE_{1.0}$	$V_0P_{50\%}IW/CPE_{1.0}$
T_{10}	No AMF + 45 kg P_2O_5/ha + irrigation at $IW/CPE_{1.0}$	$V_0P_{75\%}IW/CPE_{1.0}$
T_{11}	No AMF + 60 kg P_2O_5/ha + irrigation at $IW/CPE_{1.0}$	$V_0P_{100\%}IW/CPE_{1.0}$
T_{12}	12 kg AMF/ha + 30 kg P_2O_5/ha + irrigation at $IW/CPE_{1.0}$	$V_{12}P_{50\%}IW/CPE_{1.0}$
T_{13}	12 kg AMF/ha + 45 kg P_2O_5/ha + irrigation at $IW/CPE_{1.0}$	$V_{12}P_{75\%}IW/CPE_{1.0}$
T_{14}	12 kg AMF/ha + 60 kg P_2O_5/ha + irrigation at $IW/CPE_{1.0}$	$V_{12}P_{100\%}IW/CPE_{1.0}$

IW, Irrigation water (mm); CPE, cumulative pan evaporation (mm); AR, as per requirement; WA, as per water availability. FYM application at 3 t/ha on dry weight basis, i.e. 5 t/ha on fresh weight basis was applied in 13 treatments (T_2–T_{14}), whereas in T_1 FYM was applied at 12.8 t/ha on a dry–weight basis or 20 t/ha on a fresh–weight basis. Recommended NPK dose for pea is 50:60:60 kg/ha.

tion and fungal network developed substantially, thereby, resulting into a significant improvement in plant height in AMF imbedded treatments. Further, AMF explore larger soil volume through its ramifying hyphae enabling the crop to absorb additional nutrients and water, eventually resulting into increased plant height (Kumar *et al.*, 2014).

At 60 DAS, AMF imbedded treatments, viz. $V_{12}P_{100\%}IW/CPE_{1.0}$, $V_{12}P_{75\%}IW/CPE_{1.0}$ and $V_{12}P_{50\%}IW/CPE_{1.0}$ gave higher LAI over their non–AMF counterparts ($V_0P_{100\%}IW/CPE_{1.0}$, $V_0P_{75\%}IW/CPE_{1.0}$ and $V_0P_{50\%}IW/CPE_{1.0}$) by 1.4, 1.9 and 2.4%, respectively. The magnitude of increase in LAI following $V_{12}P_{75\%}IW/CPE_{0.6}$, $V_{12}P_{75\%}IW/CPE_{0.6}$ and $V_{12}P_{50\%}IW/CPE_{0.6}$ was 2% in each case over their non–AMF counterparts (Fig. 1). Similarly, at 120 DAS, $V_{12}P_{100\%}IW/CPE_{1.0}$, $V_{12}P_{75\%}IW/CPE_{1.0}$ and $V_{12}P_{50\%}IW/CPE_{1.0}$ gave higher LAI by 2.9, 2.9 and 1.3 %, respectively over non–AMF counterparts. A similar trend in LAI was found in treatments irrigated at $IW/CPE_{0.6}$ with and without AMF at varying P levels (Fig. 1). The increase in LAI following AMF inoculation is attributable to enhanced activity of cytokinin, which is an important growth promoter and contains P as one of the major constituents. It seems to promote leaf growth through its effect on cell division and cell expansion (Allen *et al*., 1981). The results of current study are in accordance with the findings of Edathil *et al*. (1996), who registered higher (61%) leaf area in tomato due to integrated use of AMF with applied P in a P deficient soil under humid conditions.

The highest green pod yield was registered in $V_{12}P_{100\%}IW/CPE_{1.0}$ followed by $V_{12}P_{100\%}IW/CPE_{0.6}$ and GRD, all of which remained statistically at par (Table 2). However, $V_{12}P_{100\%}IW/CPE_{1.0}$, $V_{12}P_{75\%}IW/CPE_{1.0}$ and $V_{12}P_{50\%}IW/CPE_{1.0}$ gave significantly higher pod yield than $V_0P_{100\%}IW/CPE_{1.0}$, $V_0P_{75\%}IW/CPE_{1.0}$ and $V_0P_{50\%}IW/CPE_{1.0}$ by 6.3, 8.1 and 7.0%, respectively. The magnitude of increase in above parameter in $V_{12}P_{75\%}IW/CPE_{0.6}$ and $V_{12}P_{50\%}IW/CPE_{0.6}$ was to the tune of 7.2 and 4.4%, respectively over their non–AMF counterparts. The AMF + 75% soil–test based P dose at either of two irrigation regimes and GRD as well as AMF + 100% soil–test based P dose at either of two irrigation regimes gave statistically similar pea pod yields, thus, suggesting an economy of about 25% soil–test based P dose in Himalayan acid Alfisol. The AMF application enhanced the pea yield attributes (pod length, pod girth, and average pod weight), which consequently resulted in greater pod yield. In acid soils, AMF have the ability to utilize greater amount of P as a result of efficient solubilization and mobilization by releasing various enzymes and acids (Nahas, 1996). Thus, AMF application enhanced the pea pod yield in a Himalayan acidic Alfisol. The present results are in conformity with the findings of Suri and Choudhary (2012), who reported increased productivity and fertilizer P economy in wheat and maize using AMF culture.

Maximum net returns in pea were registered with $V_{12}P_{100\%}IW/CPE_{1.0}$ followed by $V_{12}P_{100\%}IW/CPE_{0.6}$, which

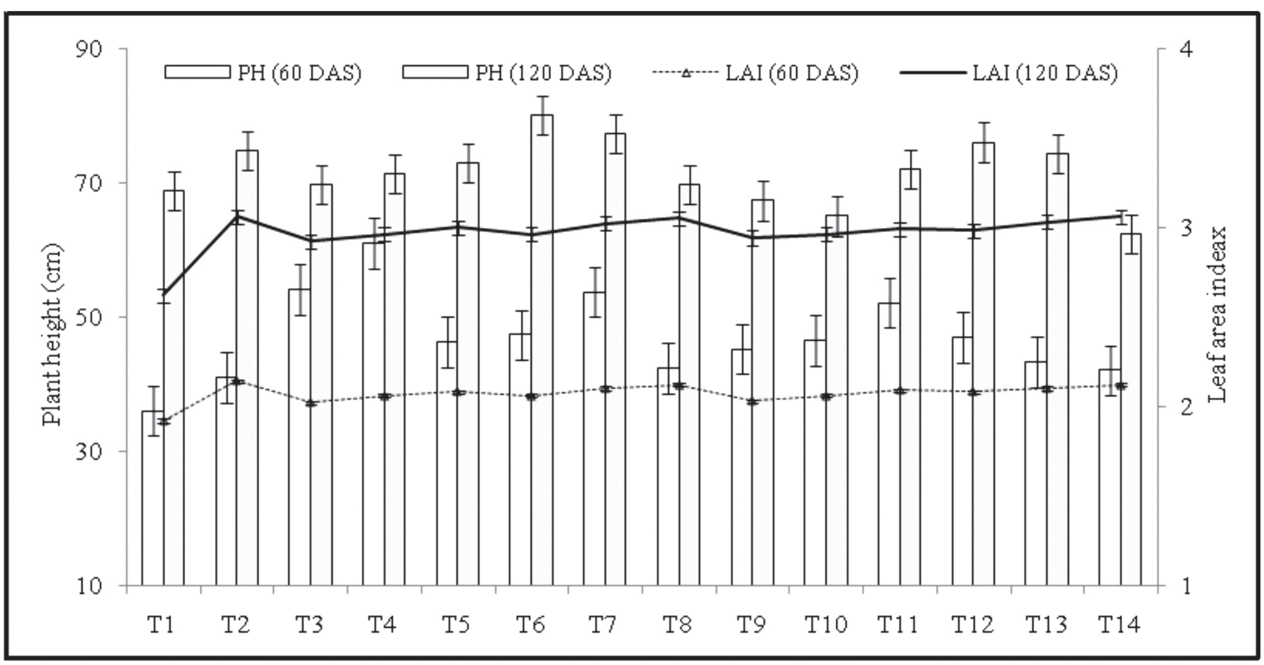

Fig. 1. Effect of integrated application of AM–fungi, inorganic P and irrigation regimes on plant height (cm) and leaf area index of pea at different growth stages (Bars represent CD values at P=0.05 to determine the significance differences among treatment means)

were higher by 17.1 and 15.8% over GRD (Table 2). Likewise, $V_{12}P_{100,\%}IW/CPE_{1.0}$, $V_{12}P_{75\%}IW/CPE_{1.0}$ and $V_{12}P_{50\%}IW/CPE_{1.0}$ exhibited significant respective increases of 8, 11.9 and 9.7%, respectively in net returns over their non–AMF counterparts. Following the above trend, the benefit: cost ratio under $V_{12}P_{100\%}IW/CPE_{1.0}$, $V_{12}P_{75\%}IW/CPE_{1.0}$ and $V_{12}P_{50\%}IW/CPE_{1.0}$ was respectively higher by 8.1, 10.8 and 8.7% over $V_0P_{100\%}IW/CPE_{1.0}$, $V_0P_{75\%}IW/CPE_{1.0}$ and $V_0P_{50\%}IW/CPE_{1.0}$. A similar trend with respect to above parameters was found in treatments irrigated at $IW/CPE_{0.6}$ with and without AMF at varying P levels. It is attributable to the fact that AMF leads to better solubilization and mobilization of native and applied P (Harrier and Watson, 2003; Suri *et al*., 2013), which in turn led to higher productivity and profitability in AMF inoculated plots. Treatments involving AMF inoculation at 75% soil–test based P dose at either of the two irrigation regimes have given statistically similar values of above parameters as that obtained in plots receiving 100% soil–test based P dose alone, thus, indicating a net saving of about 25% in fertilizer P, which ultimately got reflected in enhanced pea profitability. The results of present investigation are in accordance with the findings of Kumar *et al.* (2014), who has also reported higher net returns and benefit: cost ratio of pea following integrated use of AMF with applied P in an acid Alfisol.

The production efficiency of pea was enhanced marginally by 1.02, 1.6 and 1.0% in $V_{12}P_{100\%}IW/CPE_{0.6}$, $V_{12}P_{75\%}IW/CPE_{0.6}$ and $V_{12}P_{50\%}IW/CPE_{0.6}$, respectively over their non–AMF counterparts *viz.* $V_0P_{100\%}IW/CPE_{0.6}$, $V_0P_{75\%}IW/CPE_{0.6}$ and $V_0P_{50\%}IW/CPE_{0.6}$ owing to better crop yields governed by higher nutrient and water acquisition by mycorrhizal plants (Harrier and Watson, 2003; Auge, 2006; Suri *et al.*, 2013). As regarding monetary efficiency, highest value was obtained in $V_{12}P_{100\%}IW/CPE_{1.0}$ followed by $V_{12}P_{100\%}IW/CPE_{0.6}$ with respective increases of 17.2 and 15.7% over GRD (Fig. 2). Likewise, $V_{12}P_{75\%}IW/CPE_{1.0}$ and $V_{12}P_{75\%}IW/CPE_{0.6}$ exhibited significant respective increases of 10.3 and 6.8% over GRD. The $V_{12}P_{100\%}IW/CPE_{1.0}$, $V_{12}P_{75\%}IW/CPE_{1.0}$ and $V_{12}P_{50\%}IW/CPE_{1.0}$ gave higher monetary efficiency by 8.8, 11.7 and 9.7%, respectively over $V_0P_{100\%}IW/CPE_{1.0}$, $V_0P_{75\%}IW/CPE_{1.0}$ and $V_0P_{50\%}IW/CPE_{1.0}$. Similarly, magnitude of increase in above parameter in $V_{12}P_{100\%}IW/CPE_{0.6}$, $V_{12}P_{75\%}IW/CPE_{0.6}$ and $V_{12}P_{50\%}IW/CPE_{0.6}$ was to the tune of 8.0, 10.7 and 9.8%, respectively over $V_0P_{100\%}IW/CPE_{0.6}$, $V_0P_{75\%}IW/CPE_{0.6}$ and $V_0P_{50\%}IW/CPE_{0.6}$. Better crop yields owing to higher nutrient and water acquisition by mycorrhizal plants may be the possible reason for enhanced production and monetary efficiency in current study (Harrier and Watson, 2003; Auge, 2006; Suri *et al.,* 2013). In current study, all the parameters under study gave statistically similar values under both the irrigation regimes ($IW/CPE_{1.0}$ and $IW/CPE_{0.6}$) at varying AMF and P levels due to rains at regular interval. Thus, the effects due to irrigation regimes were observed statistically non–significant. Hence, while discussing results, effects due to irrigation regimes are omitted. In all the parameters discussed above, the farmers' practice was the tailing treatment due to the reason that the farmers in NW Himalayas apply only one fourths of recommended N and the use of phosphatic and potassic fertilizers by the farmers is almost nil, which re-

Table 2. Effect of integrated application of AM fungi, inorganic phosphorus and irrigation regimes on productivity and profitability of pea

Treatment		Pod yield (t/ha)	Cost of cultivation (×10³ ₹/ha)	Net returns (×10³ ₹/ha)	Benefit: cost ratio
T_1	$V_0 N_{25\%}P_0K_0 FYM_{3t} I_{WA}$ (FP)	5.35	29.2	24.4	–
T_2	$V_0 + NPK_{100\%} + FYM_{12.8t} I_{AR}$ (GRD)	9.71	38.7	58.3	1.50
T_3	$V_0P_{50\ \%}IW/CPE_{0.6}$	8.09	30.0	50.9	1.70
T_4	$V_0P_{75\%}IW/CPE_{0.6}$	8.66	30.4	56.2	1.85
T_5	$V_0P_{100\%}IW/CPE_{0.6}$	9.32	30.8	62.4	2.02
T_6	$V_{12}P_{50\%}IW/CPE_{0.6}$	8.45	30.3	54.2	1.79
T_7	$V_{12}P_{75\%}IW/CPE_{0.6}$	9.29	30.6	62.3	2.03
T_8	$V_{12}P_{100\%}IW/CPE_{0.6}$	9.86	31.1	67.5	2.17
T_9	$V_0P_{50\%}IW/CPE_{1.0}$	8.27	29.4	53.4	1.82
T_{10}	$V_0P_{75\%}IW/CPE_{1.0}$	8.74	29.8	57.6	1.93
T_{11}	$V_0P_{100\%}IW/CPE_{1.0}$	9.29	30.1	62.8	2.08
T_{12}	$V_{12}P_{50\%}IW/CPE_{1.0}$	8.82	29.6	58.6	1.98
T_{13}	$V_{12}P_{75\%}IW/CPE_{1.0}$	9.45	30.1	64.4	2.14
T_{14}	$V_{12}P_{100\%}IW/CPE_{1.0}$	9.87	30.4	68.3	2.25
SEm±		0.20	–	2.28	0.07
CD (P=0.05)		0.58	–	6.67	0.20

pH, Plant height; LAI, leaf area index

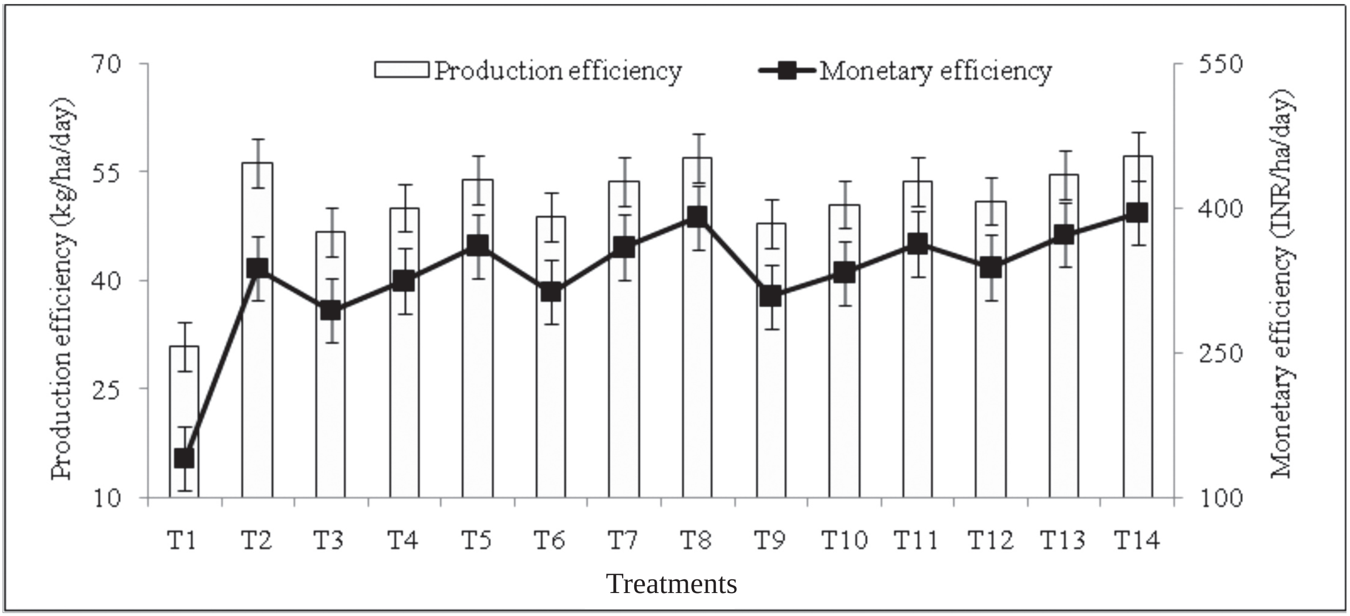

Fig. 2. Effect of integrated application of AM–fungi, inorganic P and irrigation regimes on production efficiency (kg/ha/day) and monetary efficiency (₹/ha/day) of pea. (Bars represent CD values at P=0.05 to determine the significance differences among treatment means)

flects a great technology gap w.r.t. plant nutrition in above region. Therefore, integrated use of AMF and inorganic P has tremendous potential in raising the pea productivity and profitability in Himalayan acid Alfisol.

Overall, it was revealed that AMF inoculation led to 7.4 and 2.3% increase in plant height and LAI over non–AMF counterparts. Further, pea pod yield was enhanced by 6.5% following AMF inoculation over non–AMF counterparts. AMF inoculation also improved the gross and net returns as well as benefit: cost ratio in pea. Further, production and monetary efficiencies increased by 3.1 and 10.7% by AMF inoculation, respectively over non–AMF counterparts. It was also inferred that integrated use of AM fungi and 75% soil–test based P dose led to an economy of about 25% soil–test P dose without impairing pea pod yield in a Himalayan acid Alfisol.

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