

Chapter 7

Effect of Phosphate solubilizing microorganisms at multilocational sites

7.1 Phosphate-solubilizing bacteria as bio-inoculants at multilocal sites

For multilocal study, field trials were conducted at three different sites. These sites come under different agroclimatic regions that have different climatic conditions and soil fertility levels (Table 7.1). The effects of selected PSBs isolates on improvement of crop yield and soil fertility in these different regions were tested. The survival, effect on crop yield and soil fertility in these different agroclimatic regions will provide us the consistent performance of these isolates in different agroclimatic regions.

7.1.1 Maize experiment at multilocal sites with bacterial inoculants

During the first year of field study, maize experiment was conducted at all three different sites. Significant improvement in plant shoot height, shoot and root dry weight was observed in all three sites with bacterial inoculation alone or along with RP fertilization. The improvement was significant in inoculation treatments along with RP fertilization compared to individual inoculation and DAP treatments (Table 7.2). A significant increase in maize yield (Fig. 7.1) up to 21 % was observed at all three sites in inoculated and RP fertilized soil, it was increased up to 18 % with inoculation alone, 16 % with RP fertilization alone and 9.0 to 13 % with DAP fertilization compared to un-inoculated control soil. A significant improvement in P uptake in seeds, shoots and roots of maize crop was observed by *P. cyripedii* and *P. plecoglossicida* compared to control treatments (Table 7.3). Stimulatory effects of inoculation treatments along with RP fertilization on P uptake were found to be more pronounced compared to inoculation alone, RP fertilization alone and DAP fertilization. Enhancement in yield and P uptake in maize was more pronounced and significantly higher at the sub mountain undulating region compared to the central plain region and sub mountain undulating central region.

Physiochemical properties of maize rhizospheric soils were significantly improved in all treatments and the effects were more pronounced when inoculation was done along with RP fertilization. Bacterial inoculation slightly decreased the soil pH in all treatments compared to un-inoculated control in all field trials (Table 7.4). Organic carbon and organic matter was significantly improved due to inoculation and RP fertilization treatments compared to DAP and un-inoculated control treatments (Fig 7.2 and 7.3). During first year in maize crop field experiment, inoculation along with RP fertilization increased the soil organic carbon content 43 %, 39 % and 47 % and DAP treatments increased the soil organic carbon content 3.2 %, 18 % and 20 % at central plain region, sub mountain undulating central region and at sub mountain undulating region, respectively compared to control treatments. Available P significantly increased at central plain region (52 %), sub mountain undulating central region (52 %) and at sub mountain undulating region (42 %) due to inoculation but the effect was more pronounced (113 %, 110 % and 113 %) when RP was supplemented along with inoculation. Significant improvement in total P was observed in RP fertilization and DAP treatments, but available P was significantly improve only in RP fertilization along with inoculation treatments compared to inoculation, RP fertilization and DAP treatment (Table 7.5). Acid phosphatase, alkaline phosphatase, phytase and dehydrogenase enzyme activities were significantly increased in all the treatments compared to control but the results were more pronounced with inoculation treatments along with RP fertilization at all sites (Figure 7.4, 7.5, 7.6 and 7.7). In all the field trials at different sites phytase enzyme activity was higher than acid phosphatase and alkaline phosphatase.

After harvesting of the maize crop, rhizospheric soil was examined for phosphate-solubilizing bacterial population density. Maximum population density of PSBs was observed in inoculation treatments along with RP fertilization compared to other treatments in all field trials. Phosphate-solubilizing bacterial population density at central plain region, sub

mountain undulating central region and sub mountain undulating region was 0.3×10^5 cfu g⁻¹, 0×10^5 cfu g⁻¹ and 1.8×10^6 cfu g⁻¹ in un-inoculated control seed treatment, $5.3-6.7 \times 10^7$ cfu g⁻¹, $3.6-5.7 \times 10^7$ cfu g⁻¹ and $1.0-1.1 \times 10^8$ cfu g⁻¹ in inoculation treatments, 1.7×10^5 cfu g⁻¹, 0.7×10^5 cfu g⁻¹ and 3.5×10^6 cfu g⁻¹ in single RP fertilization treatments, $8.9-9.3 \times 10^7$ cfu g⁻¹, $6.7-7.6 \times 10^7$ cfu g⁻¹ and $2.3-2.5 \times 10^8$ cfu g⁻¹ in inoculation along with RP fertilization and 1.7×10^5 cfu g⁻¹, 1.3×10^5 cfu g⁻¹ and 2.1×10^6 cfu g⁻¹ in DAP treatments. RP fertilization treatments along with bacterial inoculation increased the yield and soil fertility in context to organic carbon, total P, available P, soil enzyme activities and PSBs population significantly, compared to inoculation treatments alone, RP fertilization treatments alone and DAP treatment.

Table 7.1 Some climatic and soil physiochemical properties of experimental sites.

Sites	Agrocilmatic regions	Soil type	Location	Climate	pH	Organic carbon (%)	Available P (mg kg ⁻¹)	Total P (mg kg ⁻¹)	Organic P (mg kg ⁻¹)	Total nitrogen (%)
Patiala	Central plain region	Sandy loam (Typic Ustifluvents)	30.30° N 76.38° E	tropical hot and dry	8.27 ± 0.05	0.33 ± 0.05	3.9 ± 0.17	251 ± 14	138 ± 42	0.020 ± 0.013
Balachaur	Sub mountain undulating central region	Sandy loam (Typic Ustifluvents)	31.07° N 76.32° E	dry sub humid	8.18 ± 0.02	0.31 ± 0.09	3.6 ± 0.16	237 ± 15	124 ± 24	0.019 ± 0.007
Pojewal	Sub mountain undulating region	Loamy sand (Typic Ustorthents)	31.65° N 76.26° E	dry sub humid	8.37 ± 0.02	0.42 ± 0.08	4.3 ± 0.09	245 ± 8.33	207 ± 24	0.035 ± 0.008

Values are Mean ± SD (*n* =3).

Table 7.2 Effect of *Pantoea cyripedii* (Pc) and *Pseudomonas plecoglossicida* (Pp) alone or along with RP fertilization and chemical fertilizer (DAP) on the growth parameters of maize plants grown in Central plain region (Thapar university, Patiala, Punjab), Sub mountain undulating central region (Balachaur, Punjab) and Sub mountain undulating region (Pojewal, Punjab).

Treatments	Shoot length (cm)	Shoot dry weight (g)	Root dry weight (g)
Central plain region			
Soil	216 ± 5.3gh	34 ± 1.4gh	9.5 ± 0.30gh
Soil + Pc	231 ± 2.5defgh	42 ± 1.5efgh	11.1 ± 0.40cdefgh
Soil + Pp	234 ± 2.5defg	44 ± 1.8defgh	11.0 ± 0.42defgh
Soil + BC	235 ± 1.5def	46 ± 1.0defgh	11.2 ± 0.34cdefgh
Soil + RP	233 ± 3.9defg	51 ± 5.3bcdef	9.95 ± 0.67gh
Soil + RP + Pc	247 ± 1.5abcd	59 ± 3.5abcd	12.6 ± 1.56bcdef
Soil + RP + Pp	248 ± 6.4abcd	62 ± 7.5abc	12.8 ± 0.98abcde
Soil + RP + BC	249 ± 9.2abcd	63 ± 4.4ab	13.0 ± 0.52abcd
DAP	233 ± 6.4defg	39 ± 1.0fgh	11.1 ± 0.08defgh
Sub mountain undulating central region			
Soil	214 ± 6.3h	32 ± 1.7h	8.71 ± 0.10h
Soil + Pc	228 ± 4.7efgh	41 ± 2.7fgh	9.61 ± 0.34gh
Soil + Pp	229 ± 11efgh	41 ± 3.9fgh	9.86 ± 0.10fgh
Soil + BC	226 ± 6.0fgh	42 ± 3.6efgh	10.2 ± 0.09fgh
Soil + RP	232 ± 6.1defgh	39 ± 2.1fgh	9.80 ± 0.27fgh
Soil + RP + Pc	239 ± 7.0def	49 ± 6.3bcdefg	11.4 ± 0.57cdefgh
Soil + RP + Pp	244 ± 3.0bcde	57 ± 2.5abcde	11.6 ± 1.35cdefg
Soil + RP + BC	246 ± 4.7bcde	58 ± 10abcd	12.1 ± 1.3bcdef
DAP	231 ± 4.7defgh	42 ± 9.4fgh	9.53 ± 0.31gh
Sub mountain undulating region			
Soil	225 ± 3.3fgh	36 ± 1.9fgh	9.70 ± 1.0gh
Soil + Pc	236 ± 4.7def	47 ± 1.3cdefg	11.3 ± 0.3cdefgh
Soil + Pp	238 ± 3.1def	47 ± 10cdefg	11.3 ± 0.3cdefgh
Soil + BC	239 ± 3.5cdef	51 ± 2.6bcdef	11.6 ± 0.9cdefg
Soil + RP	237 ± 3.0def	51 ± 5.1bcdef	10.0 ± 0.5gh
Soil + RP + Pc	257 ± 4.7abc	63 ± 6.6ab	13.7 ± 1.0abc
Soil + RP + Pp	265 ± 6.1a	69 ± 2.1a	14.2 ± 0.7ab
Soil + RP + BC	260 ± 4.7ab	70 ± 2.5a	15.0 ± 0.81a
DAP	239 ± 6.3cdef	49 ± 1.5bcdefg	10.6 ± 0.8efgh
LSD (P<0.05)	9.33	7.80	1.31

Values are Mean ± SD (*n* =10). Means sharing a common letter within the column are not significantly different at *P*<0.05. Pronounced results are represented in bold.

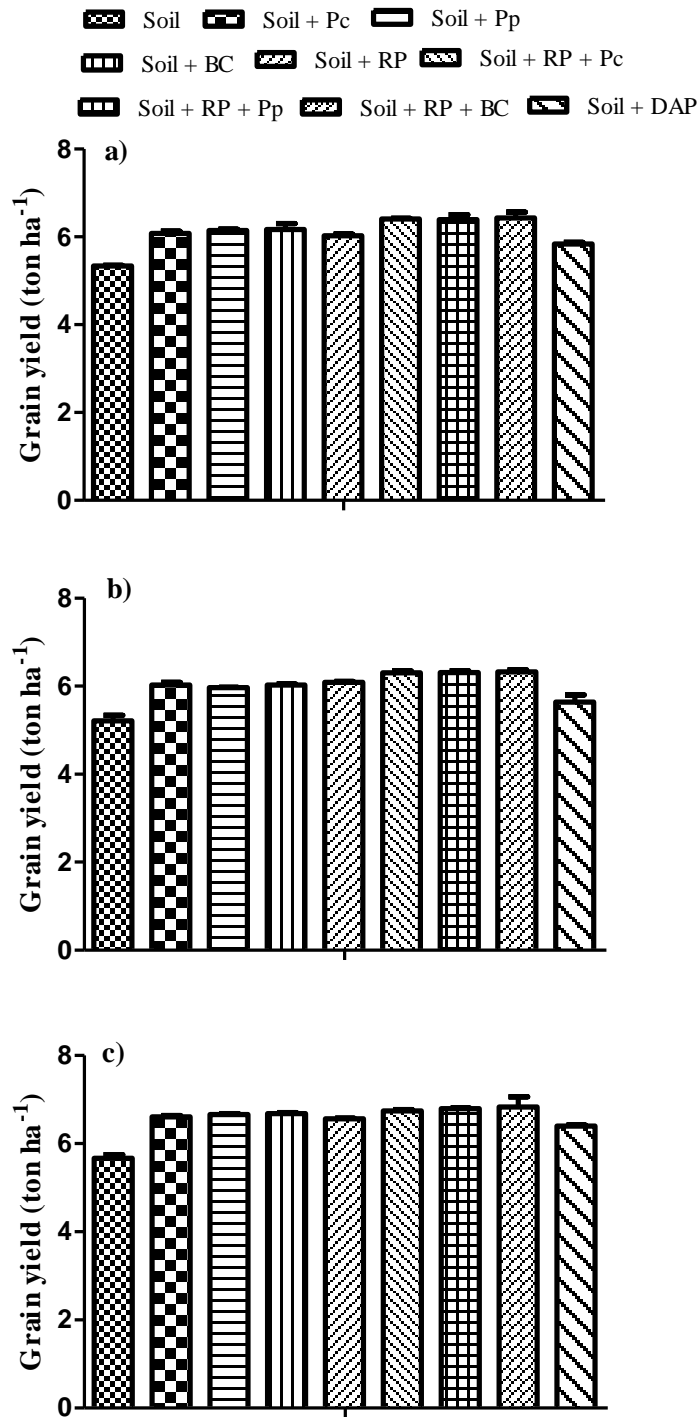


Fig. 7.1 Effect of *Pantoea cyripedii* (Pc) and *Pseudomonas plecoglossicida* (Pp) alone or along with RP fertilization and chemical fertilizer (DAP) on grain yield of maize plants grown in a) Central plain region (Thapar university, Patiala, Punjab), b) Sub mountain undulating central region (Balachaur, Punjab) and c) Sub mountain undulating region (Pojewal, Punjab).

Table 7.3 Effect of *Pantoea cypripedii* (Pc) and *Pseudomonas plecoglossicida* (Pp) alone or along with RP fertilization and chemical fertilizer (DAP) on P uptake of maize plants grown in Central plain region (Thapar university, Patiala, Punjab), Sub mountain undulating central region (Balachaur, Punjab) and Sub mountain undulating region (Pojewal, Punjab).

Treatments	Grains (mg kg ⁻¹)	Shoot (mg kg ⁻¹)	Root (mg kg ⁻¹)
Central plain region			
Soil	136 ± 8.7jk	129 ± 4jk	123 ± 5ij
Soil + Pc	169 ± 6.4efghi	155 ± 15cdefghij	166 ± 4defgh
Soil + Pp	166 ± 4.2fghij	156 ± 6cdefghij	168 ± 13defgh
Soil + BC	170 ± 4.2efghi	158 ± 4bcdefghi	170 ± 4defg
Soil + RP	169 ± 6.4efghi	152 ± 13defghijk	133 ± 11ghij
Soil + RP + Pc	204 ± 8.3abcd	175 ± 7abcdef	213 ± 6abc
Soil + RP + Pp	209 ± 6.4abc	177 ± 2abcde	216 ± 11abc
Soil + RP + BC	206 ± 13abcd	179 ± 8abcd	218 ± 6abc
DAP	161 ± 9ghij	145 ± 8ghijk	159 ± 6efghij
Sub mountain undulating central region			
Soil	129 ± 13k	125 ± 11k	120 ± 4j
Soil + Pc	161 ± 9ghij	150 ± 13efghijk	151 ± 17efghij
Soil + Pp	159 ± 9hijk	147 ± 10fghijk	156 ± 15efghij
Soil + BC	162 ± 8ghij	143 ± 13ghijk	155 ± 6efghij
Soil + RP	163 ± 6ghij	145 ± 15ghijk	150 ± 4efghij
Soil + RP + Pc	198 ± 6abcde	163 ± 9abcdeghi	204 ± 8abcd
Soil + RP + Pp	195 ± 8bcdef	168 ± 10abcdeffg	206 ± 6abcd
Soil + RP + BC	191 ± 4cdefg	169 ± 6abcdeffg	194 ± 6ab
DAP	156 ± 6hijk	137 ± 8hijk	141 ± 11fghij
Sub mountain undulating region			
Soil	143 ± 10ijk	136 ± 9ijk	127 ± 10hij
Soil + Pc	177 ± 9defgh	162 ± 4abcdeffghi	165 ± 10defghi
Soil + Pp	180 ± 17cdefgh	165 ± 10abcdeffgh	180 ± 13cdef
Soil + BC	183 ± 17cdefgh	166 ± 4abcdeffg	186 ± 9bcde
Soil + RP	179 ± 13cdefgh	170 ± 11abcdeffg	148 ± 6efghij
Soil + RP + Pc	198 ± 13abcde	186 ± 6ab	220 ± 7abc
Soil + RP + Pp	223 ± 13ab	183 ± 4abc	226 ± 10ab
Soil + RP + BC	227 ± 6a	188 ± 2a	230 ± 6a
DAP	155 ± 13hijk	150 ± 11efghijk	138 ± 6fghij
LSD (P<0.05)	16	15	22

Values are Mean ± SD (n =10). Means sharing a common letter within the column are not significantly different at P<0.05. Pronounced results are represented in bold.

Table 7.4 Effect of *Pantoea cyripedii* (Pc) and *Pseudomonas plecoglossicida* (Pp) alone or along with RP fertilization and chemical fertilizer (DAP) on rhizosphere soil characteristics of maize plants grown in Central plain region (Thapar university, Patiala, Punjab), Sub mountain undulating central region (Balachaur, Punjab) and Sub mountain undulating region (Pojewal, Punjab).

Treatments	pH	EC (mScm ⁻¹)	TDS (ppm)
Central plain region			
Soil	8.24 ± 0.03b	0.16 ± 0.02fg	0.11 ± 0.010de
Soil + Pc	8.11 ± 0.02cd	0.21 ± 0.02abcdef	0.14 ± 0.013abcd
Soil + Pp	8.03 ± 0.02de	0.22 ± 0.025abcdef	0.15 ± 0.017abcd
Soil + BC	8.02 ± 0.03ef	0.23 ± 0.03abcdef	0.15 ± 0.017abcd
Soil + RP	7.80 ± 0.02hijkl	0.21 ± 0.02abcdef	0.14 ± 0.013abcd
Soil + RP + Pc	7.73 ± 0.02lmn	0.24 ± 0.03abcde	0.16 ± 0.020abc
Soil + RP + Pp	7.74 ± 0.01klmn	0.23 ± 0.02abcde	0.16 ± 0.010abcd
Soil + RP + BC	7.75 ± 0.05jklmn	0.22 ± 0.02abcdef	0.15 ± 0.014abcd
DAP	8.15 ± 0.06bc	0.23 ± 0.03abcdef	0.15 ± 0.018abcd
Sub mountain undulating central region			
Soil	8.19 ± 0.02bc	0.13 ± 0.02g	0.09 ± 0.010e
Soil + Pc	7.87 ± 0.02gh	0.19 ± 0.02bcdefg	0.13 ± 0.010bcde
Soil + Pp	7.85 ± 0.01hi	0.18 ± 0.02defg	0.12 ± 0.010cde
Soil + BC	7.85 ± 0.01hi	0.19 ± 0.01cdefg	0.13 ± 0.007bcde
Soil + RP	7.82 ± 0.02hijk	0.19 ± 0.03defg	0.13 ± 0.017bcde
Soil + RP + Pc	7.72 ± 0.01lmn	0.22 ± 0.01abcdef	0.15 ± 0.007abcd
Soil + RP + Pp	7.70 ± 0.01mn	0.21 ± 0.02abcdef	0.14 ± 0.010abcd
Soil + RP + BC	7.69 ± 0.05n	0.23 ± 0.02abcdef	0.15 ± 0.014abcd
DAP	7.98 ± 0.03ef	0.20 ± 0.02bcdef	0.13 ± 0.014abcd
Sub mountain undulating region			
Soil	8.33 ± 0.03a	0.18 ± 0.02efg	0.12 ± 0.02cde
Soil + Pc	7.84 ± 0.02hij	0.26 ± 0.03abc	0.17 ± 0.02ab
Soil + Pp	7.85 ± 0.01hi	0.24 ± 0.03abcde	0.16 ± 0.02abcd
Soil + BC	7.81 ± 0.06hijk	0.27 ± 0.02abc	0.17 ± 0.01ab
Soil + RP	7.94 ± 0.02fg	0.19 ± 0.02bcdefg	0.13 ± 0.01bcde
Soil + RP + Pc	7.78 ± 0.02ijklm	0.27 ± 0.03a	0.18 ± 0.02a
Soil + RP + Pp	7.76 ± 0.01jklmn	0.26 ± 0.03ab	0.17 ± 0.02ab
Soil + RP + BC	7.75 ± 0.03klmn	0.26 ± 0.01ab	0.17 ± 0.01ab
DAP	8.01 ± 0.04ef	0.25 ± 0.02abcd	0.17 ± 0.01abc
LSD (P<0.05)	0.044	0.035	0.024

Values are Mean ± SD (*n* =10). Means sharing a common letter within the column are not significantly different at *P*<0.05. Pronounced results are represented in bold.

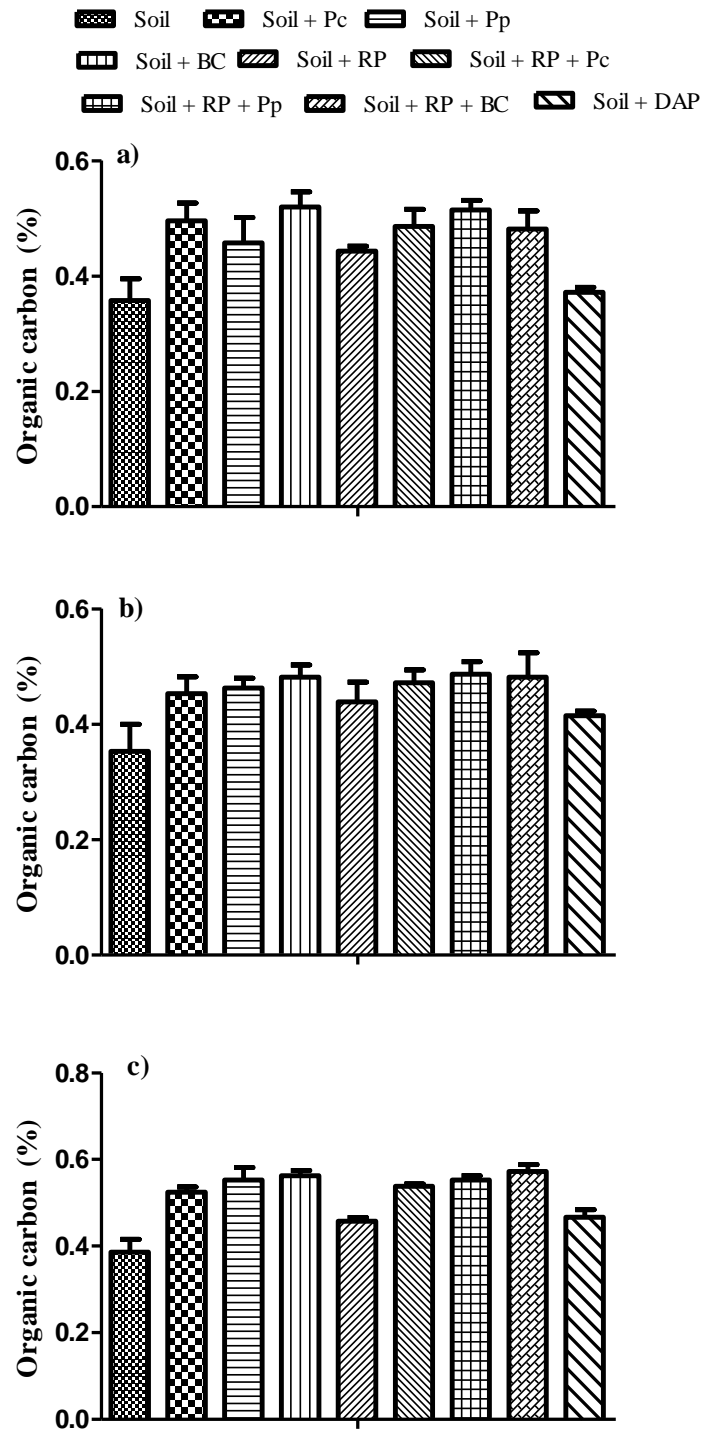


Fig. 7.2 Effect of *Pantoea cyripedii* (Pc) and *Pseudomonas plecoglossicida* (Pp) alone or along with RP fertilization and chemical fertilizer (DAP) on organic carbon of rhizosphere soil of maize plants grown in a) Central plain region (Thapar university, Patiala, Punjab), b) Sub mountain undulating central region (Balachaur, Punjab) and c) Sub mountain undulating region (Pojewal, Punjab).

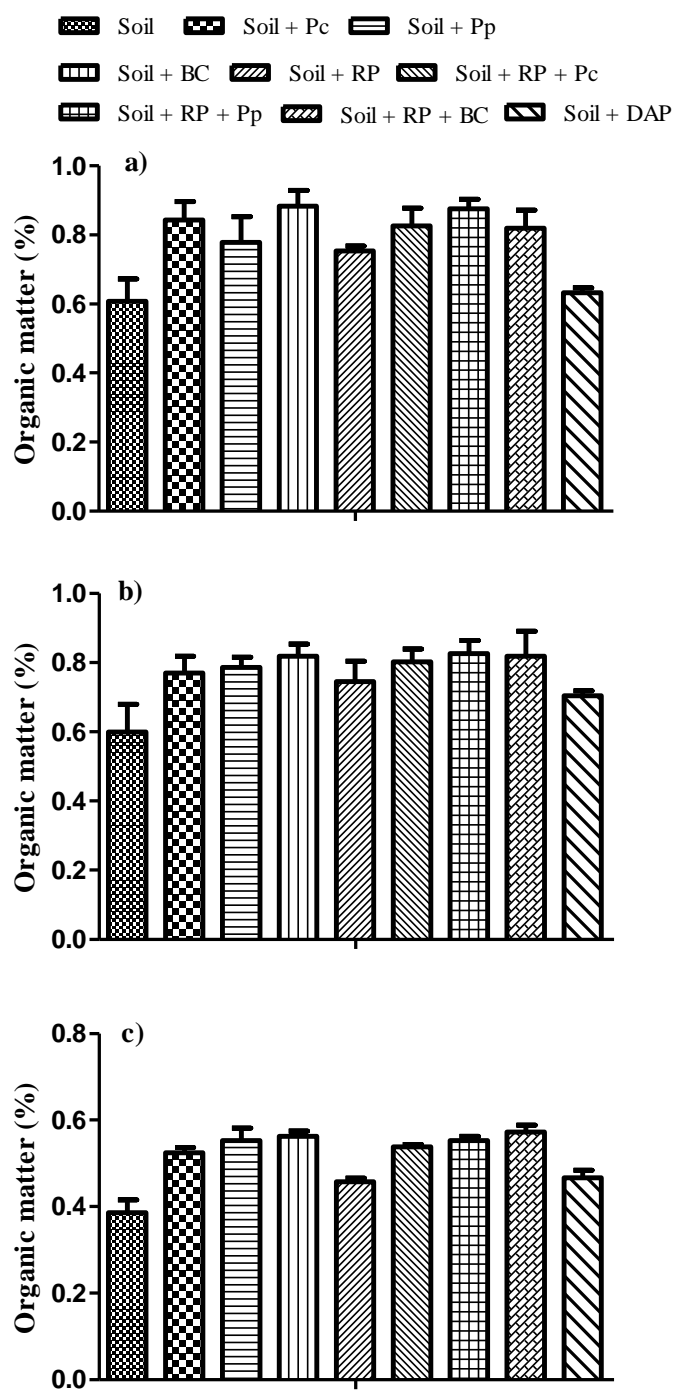


Fig. 7.3 Effect of *Pantoea cyripedii* (Pc) and *Pseudomonas plecoglossicida* (Pp) alone or along with RP fertilization and chemical fertilizer (DAP) on organic matter of rhizosphere soil of maize plants grown in a) Central plain region (Thapar university, Patiala, Punjab), b) (Sub mountain undulating central region (Balachaur, Punjab) and c) Sub mountain undulating region (Pojewal, Punjab).

Table 7.5 Effect of *Pantoea cypripedii* (Pc) and *Pseudomonas plecoglossicida* (Pp) alone or along with RP fertilization and chemical fertilizer (DAP) on rhizosphere soil characteristics of maize plants grown in Central plain region (Thapar university, Patiala, Punjab), Sub mountain undulating central region (Balachaur, Punjab) and Sub mountain undulating region (Pojewal, Punjab).

Treatments	Total P (mg kg ⁻¹)	Available P (mg kg ⁻¹)	Total nitrogen (%)
Central plain region			
Soil	251 ± 15e	3.37 ± 0.19jk	0.031 ± 0.005a
Soil + Pc	256 ± 6e	4.74 ± 0.12efgh	0.034 ± 0.008a
Soil + Pp	260 ± 9e	4.64 ± 0.13efghi	0.036 ± 0.010a
Soil + BC	251 ± 2e	4.84 ± 0.13defgh	0.037 ± 0.004a
Soil + RP	483 ± 8abc	5.11 ± 0.13cdef	0.035 ± 0.010a
Soil + RP + Pc	494 ± 17a	7.09 ± 0.31b	0.036 ± 0.013a
Soil + RP + Pp	493 ± 10a	7.16 ± 0.14b	0.031 ± 0.010a
Soil + RP + BC	490 ± 21ab	7.26 ± 0.90b	0.031 ± 0.010a
DAP	494 ± 6a	4.11 ± 0.07ghij	0.036 ± 0.005a
Sub mountain undulating central region			
Soil	227 ± 15e	3.22 ± 0.17k	0.028 ± 0.005a
Soil + Pc	240 ± 10e	4.33 ± 0.15fghi	0.034 ± 0.008a
Soil + Pp	244 ± 6e	4.41 ± 0.18fghi	0.031 ± 0.005a
Soil + BC	250 ± 7e	4.40 ± 0.09fghi	0.031 ± 0.013a
Soil + RP	447 ± 21bcd	4.89 ± 0.09cdefg	0.036 ± 0.005a
Soil + RP + Pc	436 ± 15d	6.57 ± 0.18b	0.028 ± 0.013a
Soil + RP + Pp	447 ± 15cd	6.75 ± 0.24b	0.034 ± 0.008a
Soil + RP + BC	445 ± 21cd	6.85 ± 0.26b	0.036 ± 0.005a
DAP	504 ± 13a	3.87 ± 0.22ijk	0.031 ± 0.005a
Sub mountain undulating region			
Soil	237 ± 8e	4.01 ± 0.17hijk	0.034 ± 0.002a
Soil + Pc	241 ± 4e	5.62 ± 0.16cde	0.039 ± 0.004a
Soil + Pp	256 ± 2e	5.63 ± 0.05cd	0.040 ± 0.001a
Soil + BC	261 ± 6e	5.66 ± 0.10c	0.039 ± 0.013a
Soil + RP	465 ± 9abcd	5.29 ± 0.07cde	0.042 ± 0.017a
Soil + RP + Pc	480 ± 35abc	8.07 ± 0.22a	0.039 ± 0.009a
Soil + RP + Pp	504 ± 17a	8.48 ± 0.33a	0.048 ± 0.010a
Soil + RP + BC	497 ± 6a	8.53 ± 0.10a	0.041 ± 0.002a
DAP	487 ± 8abc	4.94 ± 0.09cdefg	0.039 ± 0.005a
LSD (P<0.05)	22	0.43	0.01

Values are Mean ± SD (n =10). Means sharing a common letter within the column are not significantly different at P<0.05. Pronounced results are represented in bold.

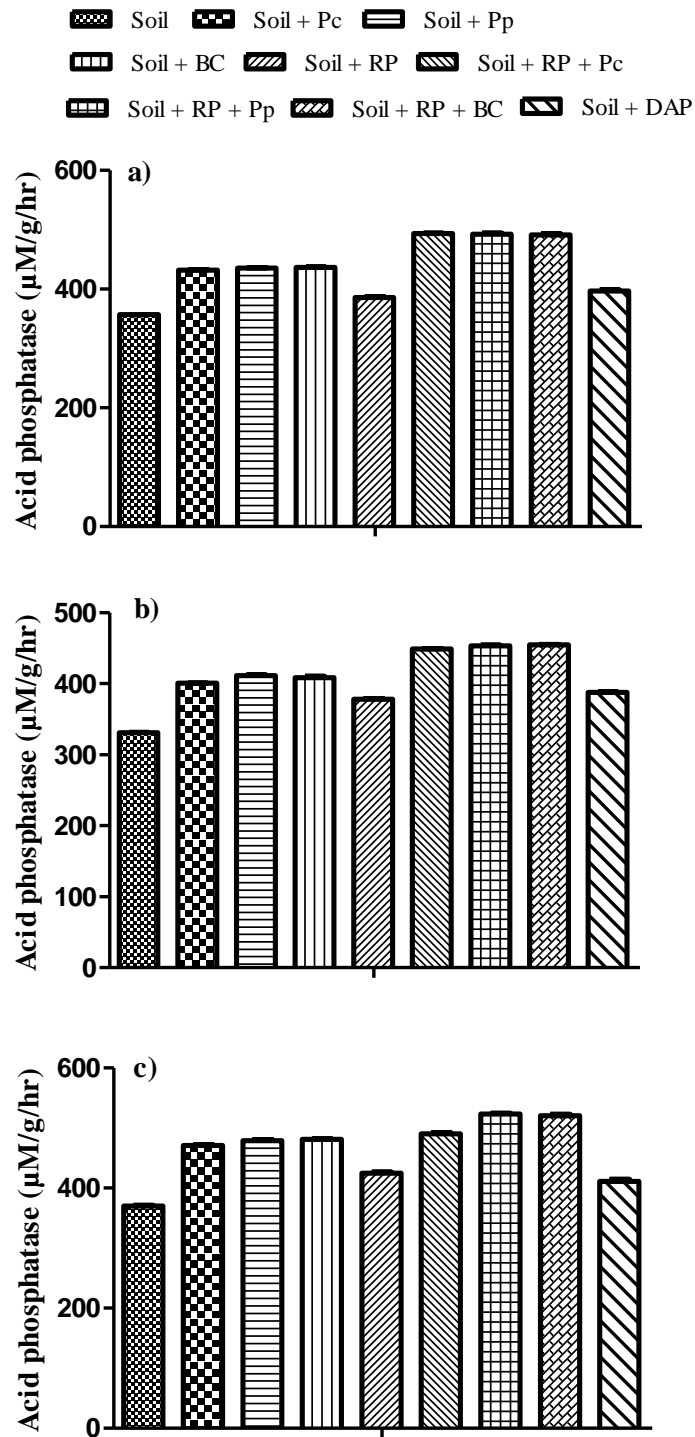


Fig. 7.4 Effect of *Pantoea cyripedii* (Pc) and *Pseudomonas plecoglossicida* (Pp) alone or along with RP fertilization and chemical fertilizer (DAP) on acid phosphatase enzyme activities of rhizosphere soil of maize plants grown in a) Central plain region (Thapar university, Patiala, Punjab), b) Sub mountain undulating central region (Balachaur, Punjab) and c) Sub mountain undulating region (Pojewal, Punjab).

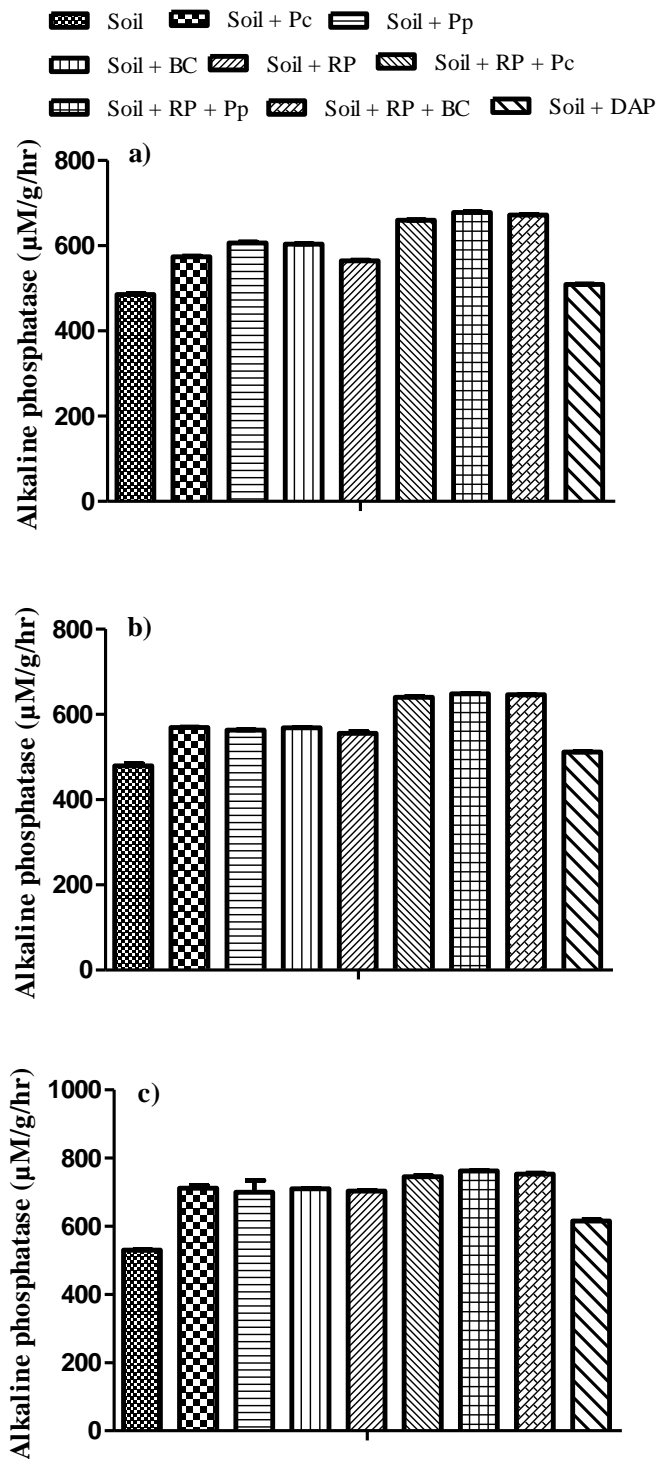


Fig. 7.5 Effect of *Pantoea cyripedii* (Pc) and *Pseudomonas plecoglossicida* (Pp) alone or along with RP fertilization and chemical fertilizer (DAP) on alkaline phosphatase enzyme activities of rhizosphere soil of maize plants grown in a) Central plain region (Thapar university, Patiala, Punjab), b) Sub mountain undulating central region (Balachaur, Punjab) and c) Sub mountain undulating region (Pojewal, Punjab).

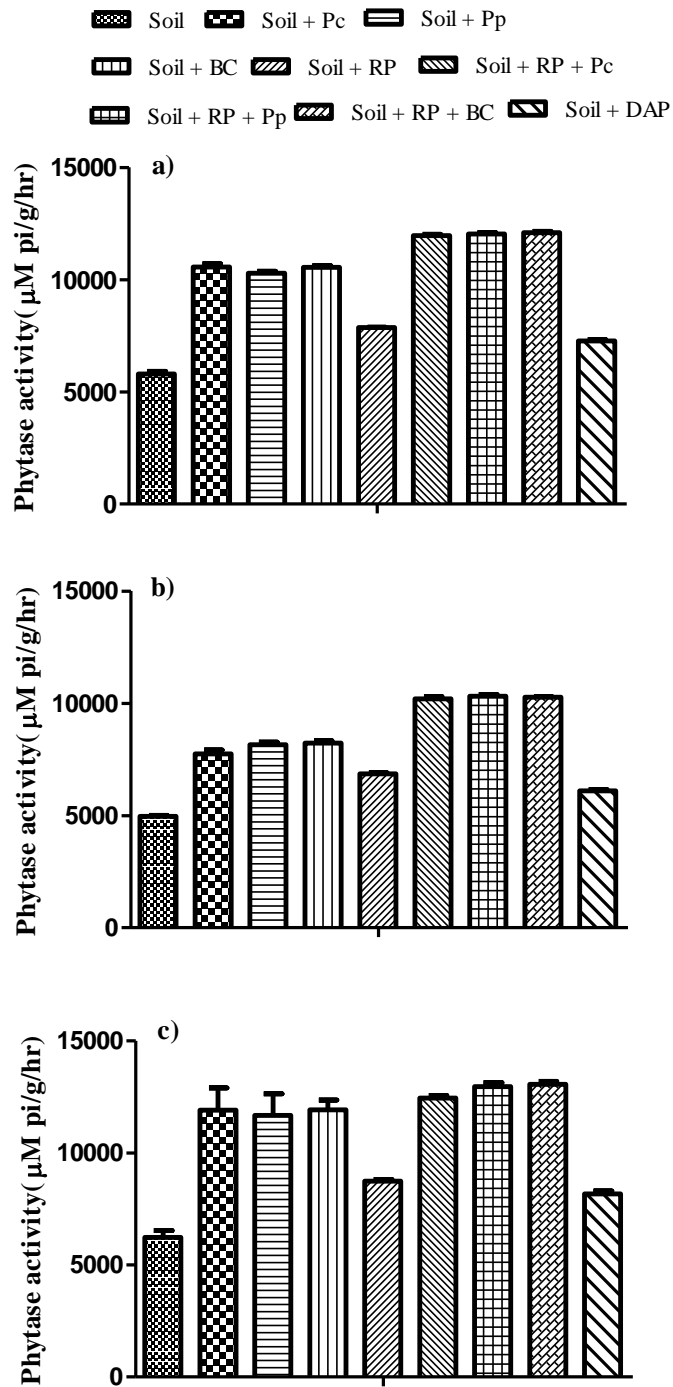


Fig. 7.6 Effect of *Pantoea cyripedii* (Pc) and *Pseudomonas plecoglossicida* (Pp) alone or along with RP fertilization and chemical fertilizer (DAP) on phytase enzyme activities of rhizosphere soil of maize plants grown in a) Central plain region (Thapar university, Patiala, Punjab), b) Sub mountain undulating central region (Balachaur, Punjab) and c) Sub mountain undulating region (Pojewal, Punjab).

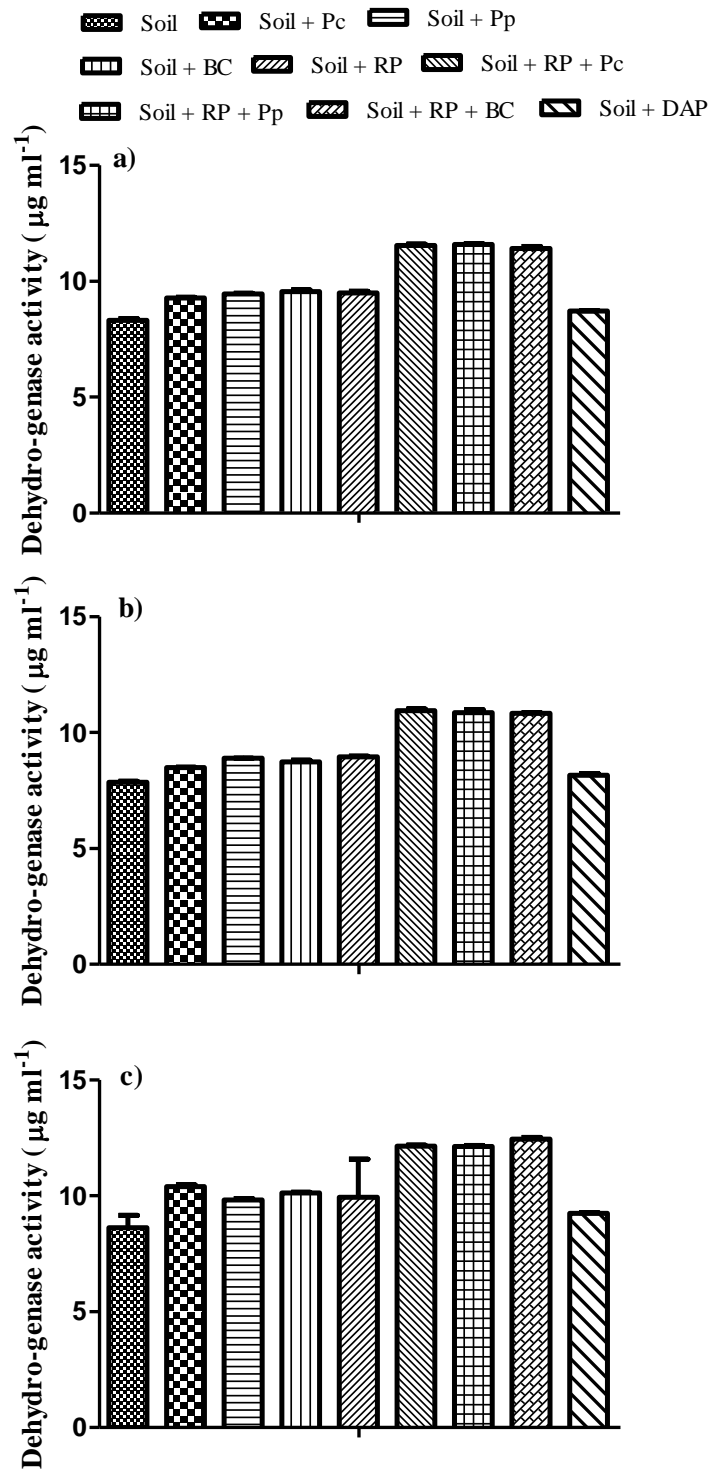


Fig. 7.7 Effect of *Pantoea cyripedii* (Pc) and *Pseudomonas plecoglossicida* (Pp) alone or along with RP fertilization and chemical fertilizer (DAP) on dehydro-genase enzyme activities of rhizosphere soil of maize plants grown in a) Central plain region (Thapar university, Patiala, Punjab), b) Sub mountain undulating central region (Balachaur, Punjab) and c) Sub mountain undulating region (Pojewal, Punjab).

7.1.2 Wheat experiment at multilocational sites with bacterial inoculants

To test the effect of previously (in maize experiment) added RP on second year crop, wheat experiment was conducted at all the three sites. Plant shoot height, shoot and root dry weight at all three different sites were significantly improved with bacterial inoculation alone or along with RP fertilization (Table 7.6). A significant increase in wheat grain yield (Fig. 7.8) (16-20 %) was observed in all the three sites due to inoculation along with RP fertilization treatments, the yield was up to 14 % with inoculation treatments, 13 % with RP fertilization treatments and 6 to 10 % with DAP treatment compared to control soil. Significant improvement in total P uptake in seeds, shoots and roots of wheat crop was observed by introduction of *P. cyripedii* and *P. plecoglossicida* during second year of field study compared to control soil (Table 7.7). Stimulatory effects of inoculation treatments along with RP fertilization on yield and P uptake was found to be more pronounced compared to inoculation alone, RP fertilization alone and DAP treatment. Enhancement in yield and P uptake in wheat was more pronounced at sub mountain undulating region compared to central plain region and sub mountain undulating central region.

Physiochemical properties of wheat rhizospheric soils were significantly improved in all the treatments but the effects were more significant when inoculation was done along with RP fertilization. Bacterial inoculation slightly decreased the soil pH in all the treatments compared to un-inoculated control seed treatments in all field trials (Table 7.8). Inoculation along with RP fertilization increased the soil organic carbon content 25 %, 26 % and 33 % and DAP treatments increased the soil organic carbon content 3 %, 11 % and 13 % at central plain region, sub mountain undulating central region and at sub mountain undulating region compared to control treatment respectively (Fig. 7.9). Organic matter in all the inoculation and RP fertilization treatments was significantly improved, compared to DAP and control treatment (Fig 7.10). Available P level was significantly increased at central plain region (42

%), sub mountain undulating central region (38 %) and at sub mountain undulating region (41 %) due to inoculation but the effect was more pronounced (85 %, 84 % and 86 %) when RP was supplemented along with inoculation compared to control. Acid phosphatase, alkaline phosphatase, phytase and dehydrogenase enzyme activities were more pronounced in inoculation treatments along with RP fertilization compared to other treatments (Figure 7.11, 7.12, 7.13 and 7.14). In all the field trials at different sites phytase enzyme activities were higher than acid phosphatase and alkaline phosphatase enzyme activities.

Population density of phosphate-solubilizing bacteria was tested after harvesting of the wheat crop, at central plain region, sub mountain undulating central region and sub mountain undulating region and it was 1.7×10^5 cfu g⁻¹, 0.6×10^5 cfu g⁻¹ and 2.0×10^6 in control treatments, $7.7-8.4 \times 10^7$ cfu g⁻¹, $6.6-6.9 \times 10^7$ cfu g⁻¹ and $2.1-2.2 \times 10^8$ cfu g⁻¹ in inoculation treatments, 4×10^5 cfu g⁻¹, 2.7×10^5 cfu g⁻¹ and 4.1×10^6 cfu g⁻¹ in RP fertilization treatments, $9.8 \times 10^7-1.3 \times 10^8$ cfu g⁻¹, $8.4-9.6 \times 10^7$ cfu g⁻¹ and $3.6-4.1 \times 10^8$ cfu g⁻¹ in inoculation along with RP fertilization and 2.3×10^5 cfu g⁻¹, 2×10^5 cfu g⁻¹ and 2.1×10^6 cfu g⁻¹ in DAP treatments. There is no significant effect of DAP and RP fertilization treatments alone on increased in population density of PSBs.

Table 7.6 Effect of *Pantoea cypripedii* (Pc) and *Pseudomonas plecoglossicida* (Pp) alone or along with RP fertilization and chemical fertilizer (DAP) on the growth parameters of wheat plants grown in Central plain region (Thapar university, Patiala, Punjab), Sub mountain undulating central region (Balachaur, Punjab) and Sub mountain undulating region (Pojewal, Punjab).

Treatments	Shoot length (cm)	Shoot dry weight (g)	Root dry weight (g)
Central plain region			
Soil	96 ± 1.5mn	1.36 ± 0.03ef	0.54 ± 0.03hi
Soil + Pc	101 ± 0.9hijklm	1.6 ± 0.14cdef	0.64 ± 0.18defghi
Soil + Pp	104 ± 1.6ghijklm	1.73 ± 0.07cde	0.63 ± 0.10defghi
Soil + BC	105 ± 1.7fghijklm	1.74 ± 0.05cde	0.65 ± 0.07defghi
Soil + RP	108 ± 2.0efghijk	1.60 ± 0.02cdef	0.75 ± 0.08cdefgh
Soil + RP + Pc	114 ± 1.2abcdef	2.36 ± 0.03a	0.81 ± 0.01bcde
Soil + RP + Pp	116 ± 2.2abcde	2.39 ± 0.02a	0.83 ± 0.02bcde
Soil + RP + BC	117 ± 4.6abcd	2.35 ± 0.07a	0.85 ± 0.01bcd
DAP	99 ± 0.8jklmn	1.58 ± 0.02cdef	0.62 ± 0.03efghi
Sub mountain undulating central region			
Soil	92 ± 3.4n	1.24 ± 0.08f	0.49 ± 0.08i
Soil + Pc	101 ± 2.8hijklm	1.46 ± 0.09def	0.57 ± 0.05ghi
Soil + Pp	99 ± 1.9jklmn	1.53 ± 0.06cdef	0.56 ± 0.07ghi
Soil + BC	101 ± 1.2hijklm	1.56 ± 0.05cdef	0.58 ± 0.04fghi
Soil + RP	106 ± 2.7fghijkl	1.52 ± 0.03cdef	0.65 ± 0.04defghi
Soil + RP + Pc	108 ± 1.5efghijk	2.16 ± 0.01ab	0.74 ± 0.01cdefgh
Soil + RP + Pp	110 ± 1.4cdefgh	2.17 ± 0.01ab	0.75 ± 0.04cdefgh
Soil + RP + BC	111 ± 1.7bcdefg	2.18 ± 0.07ab	0.76 ± 0.05cdefg
DAP	98 ± 2.3lmn	1.38 ± 0.13ef	0.54 ± 0.03ghi
Sub mountain undulating region			
Soil	99 ± 8.1klmn	1.44 ± 0.10def	0.66 ± 0.07defghi
Soil + Pc	104 ± 5.8ghijklm	1.82 ± 0.03bcd	0.79 ± 0.07cdef
Soil + Pp	104 ± 2.0ghijklm	1.86 ± 0.01bc	0.84 ± 0.08bcd
Soil + BC	109 ± 3.8defghij	1.87 ± 0.07bc	0.82 ± 0.07bcde
Soil + RP	109 ± 3.8defghijkl	1.70 ± 0.05cde	0.79 ± 0.16cdef
Soil + RP + Pc	119 ± 0.9abc	2.56 ± 0.16a	0.93 ± 0.05abc
Soil + RP + Pp	120 ± 1.4ab	2.54 ± 0.16a	1.03 ± 0.06ab
Soil + RP + BC	122 ± 2.2a	2.55 ± 0.22a	1.12 ± 0.003a
DAP	100 ± 1.1ijklmn	1.58 ± 0.46cdef	0.75 ± 0.04cdefgh
LSD (P<0.05)	4.85	0.20	0.111

Values are Mean ± SD (*n* =10). Means sharing a common letter within the column are not significantly different at *P*<0.05. Pronounced results are represented in bold.

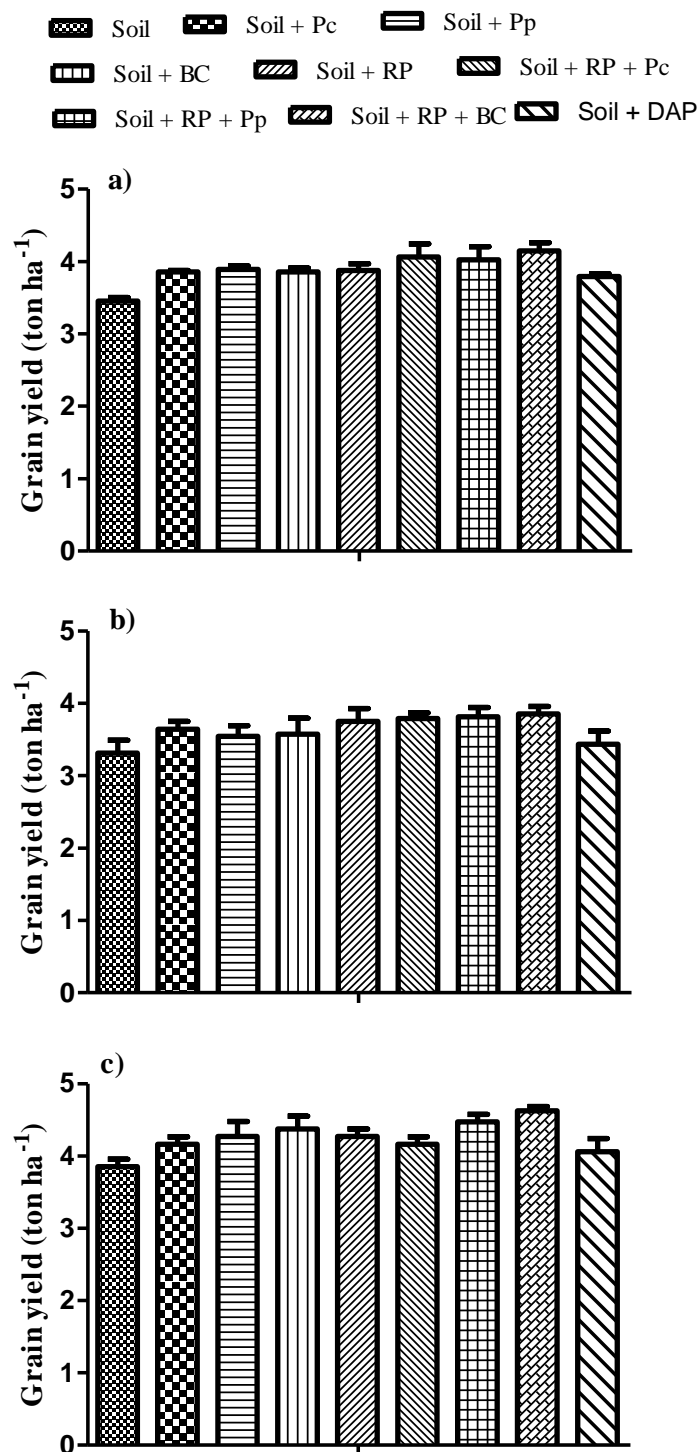


Fig. 7.8 Effect of *Pantoea cyripedii* (Pc) and *Pseudomonas plecoglossicida* (Pp) alone or along with RP fertilization and chemical fertilizer (DAP) on grain yield of wheat plants grown in a) Central plain region (Thapar university, Patiala, Punjab), b) Sub mountain undulating central region (Balachaur, Punjab) and c) Sub mountain undulating region (Pojewal, Punjab).

Table 7.7 Effect of *Pantoea cypripedii* (Pc) and *Pseudomonas plecoglossicida* (Pp) alone or along with RP fertilization and chemical fertilizer (DAP) on P uptake of wheat plants grown in Central plain region (Thapar university, Patiala, Punjab), Sub mountain undulating central region (Balachaur, Punjab) and Sub mountain undulating region (Pojewal, Punjab).

Treatments	Grains (mg kg ⁻¹)	Shoot (mg kg ⁻¹)	Root (mg kg ⁻¹)
Central plain region			
Soil	218 ± 2jk	28 ± 4gh	191 ± 13i
Soil + Pc	243 ± 13hijk	38 ± 2fgh	258 ± 8efg
Soil + Pp	240 ± 6hijk	36 ± 9fgh	256 ± 10efg
Soil + BC	247 ± 19ghijk	34 ± 6fgh	259 ± 13efg
Soil + RP	298 ± 10cdef	41 ± 8fgh	280 ± 9def
Soil + RP + Pc	333 ± 4abc	77 ± 6bc	359 ± 10c
Soil + RP + Pp	330 ± 10cdefg	83 ± 13b	365 ± 9c
Soil + RP + BC	336 ± 13abc	84 ± 10b	368 ± 9bc
DAP	237 ± 4hijk	31 ± 6fgh	250 ± 11fgh
Sub mountain undulating central region			
Soil	213 ± 5k	26 ± 10h	184 ± 13i
Soil + Pc	236 ± 9hijk	33 ± 8fgh	242 ± 23fgh
Soil + Pp	237 ± 18hijk	34 ± 6fgh	245 ± 15fgh
Soil + BC	238 ± 13hijk	37 ± 11fgh	248 ± 13fgh
Soil + RP	277 ± 5defgh	31 ± 9fgh	275 ± 8def
Soil + RP + Pc	318 ± 10bcde	69 ± 9bcde	347 ± 10c
Soil + RP + Pp	320 ± 18bcde	72 ± 9bcd	348 ± 6c
Soil + RP + BC	325 ± 11abcd	75 ± 8bcd	343 ± 14c
DAP	222 ± 16jk	29 ± 11gh	216 ± 17hi
Sub mountain undulating region			
Soil	227 ± 10ijk	38 ± 10fgh	222 ± 6hi
Soil + Pc	263 ± 10fghij	44 ± 6fgh	265 ± 9def
Soil + Pp	294 ± 5cdefg	52 ± 6defg	301 ± 6d
Soil + BC	273 ± 15efghi	54 ± 4cdef	302 ± 6d
Soil + RP	336 ± 23abc	69 ± 6bcde	295 ± 8de
Soil + RP + Pc	372 ± 10a	109 ± 6a	405 ± 10ab
Soil + RP + Pp	350 ± 11ab	93 ± 6ab	429 ± 8a
Soil + RP + BC	366 ± 18ab	112 ± 4a	430 ± 13a
DAP	236 ± 20hijk	47 ± 6efgh	245 ± 26fgh
LSD (P<0.05)	26	13	20

Values are Mean ± SD (n =10). Means sharing a common letter within the column are not significantly different at P<0.05. Pronounced results are represented in bold.

Table 7.8 Effect of *Pantoea cypripedii* (Pc) and *Pseudomonas plecoglossicida* (Pp) alone or along with RP fertilization and chemical fertilizer (DAP) on rhizosphere soil characteristics of wheat plants grown in Central plain region (Thapar university, Patiala, Punjab), Sub mountain undulating central region (Balachaur, Punjab) and Sub mountain undulating region (Pojewal, Punjab).

Treatments	pH	EC (mScm ⁻¹)	TDS (ppm)
Central plain region			
Soil	8.23 ± 0.02b	0.17 ± 0.01efghi	0.11 ± 0.007fghijkl
Soil + Pc	7.62 ± 0.03hijkl	0.20 ± 0.02bcdef	0.14 ± 0.010bcdefg
Soil + Pp	7.66 ± 0.02fghi	0.20 ± 0.02bcdef	0.13 ± 0.013bcdefg
Soil + RP	7.65 ± 0.03ghij	0.22 ± 0.02abcd	0.15 ± 0.010abcde
Soil + BC	8.14 ± 0.05c	0.21 ± 0.02abcde	0.14 ± 0.013abcdef
Soil + RP + Pc	7.60 ± 0.02ijklm	0.24 ± 0.02ab	0.16 ± 0.010ab
Soil + RP + Pp	7.59 ± 0.04jklm	0.25 ± 0.01a	0.17 ± 0.007a
Soil + RP + BC	7.59 ± 0.02jklm	0.24 ± 0.01ab	0.16 ± 0.009abc
DAP	8.17 ± 0.02bc	0.20 ± 0.02bcdef	0.14 ± 0.010bcdefg
Sub mountain undulating central region			
Soil	8.19 ± 0.02bc	0.12 ± 0.01i	0.08 ± 0.007j
Soil + Pc	7.73 ± 0.02ef	0.17 ± 0.02defgh	0.12 ± 0.010efghi
Soil + Pp	7.74 ± 0.03e	0.15 ± 0.01ghi	0.10 ± 0.007hij
Soil + BC	7.73 ± 0.02ef	0.17 ± 0.01efgh	0.11 ± 0.004fghi
Soil + RP	7.97 ± 0.02d	0.16 ± 0.02fghi	0.11 ± 0.010ghij
Soil + RP + Pc	7.70 ± 0.01efg	0.20 ± 0.02bcdef	0.14 ± 0.010bcdefg
Soil + RP + Pp	7.67 ± 0.02fgh	0.23 ± 0.02abc	0.15 ± 0.013abcd
Soil + RP + BC	7.63 ± 0.01ghijk	0.22 ± 0.01abc	0.15 ± 0.007abcd
DAP	7.98 ± 0.01d	0.19 ± 0.02cdefg	0.13 ± 0.010defgh
Sub mountain undulating region			
Soil	8.30 ± 0.02a	0.14 ± 0.01hi	0.09 ± 0.007ij
Soil + Pc	7.67 ± 0.02fgh	0.14 ± 0.02hi	0.09 ± 0.010ij
Soil + Pp	7.61 ± 0.01hijklm	0.15 ± 0.01ghi	0.10 ± 0.007hij
Soil + BC	7.65 ± 0.01ghij	0.22 ± 0.02abcd	0.15 ± 0.014abcde
Soil + RP	8.13 ± 0.02c	0.19 ± 0.01cdefg	0.13 ± 0.007cdefgh
Soil + RP + Pc	7.56 ± 0.03lm	0.19 ± 0.02bcdefg	0.13 ± 0.01bcdefgh
Soil + RP + Pp	7.55 ± 0.01m	0.16 ± 0.01fghi	0.11 ± 0.004ghij
Soil + RP + BC	7.58 ± 0.03klm	0.22 ± 0.01abc	0.15 ± 0.007abcd
DAP	8.19 ± 0.03bc	0.19 ± 0.02bcdefg	0.13 ± 0.010bcdefgh
LSD (P<0.05)	0.036	0.023	0.015

Values are Mean ± SD (n =10). Means sharing a common letter within the column are not significantly different at P<0.05. Pronounced results are represented in bold.

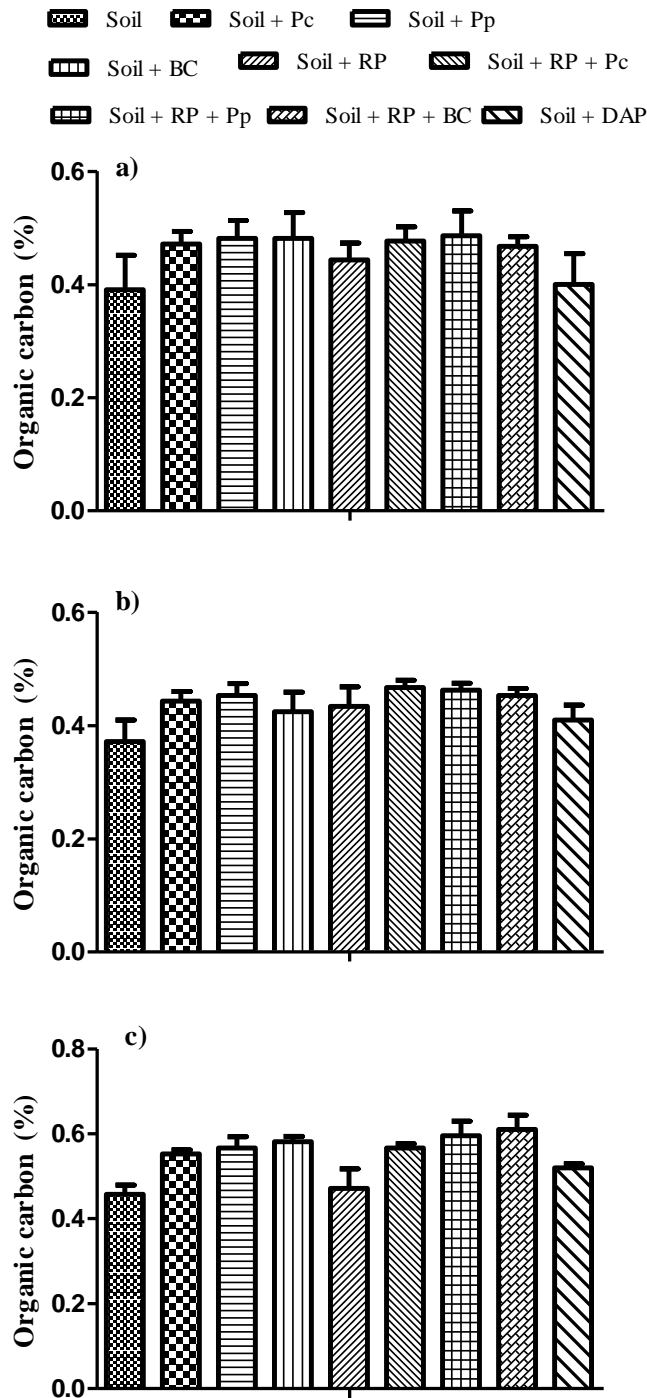


Fig. 7.9 Effect of *Pantoea cyripedii* (Pc) and *Pseudomonas plecoglossicida* (Pp) alone or along with RP fertilization and chemical fertilizer (DAP) on organic carbon of rhizosphere soil characteristics of wheat plants grown in a) Central plain region (Thapar university, Patiala, Punjab), b) Sub mountain undulating central region (Balachaur, Punjab) and c) Sub mountain undulating region (Pojewal, Punjab).

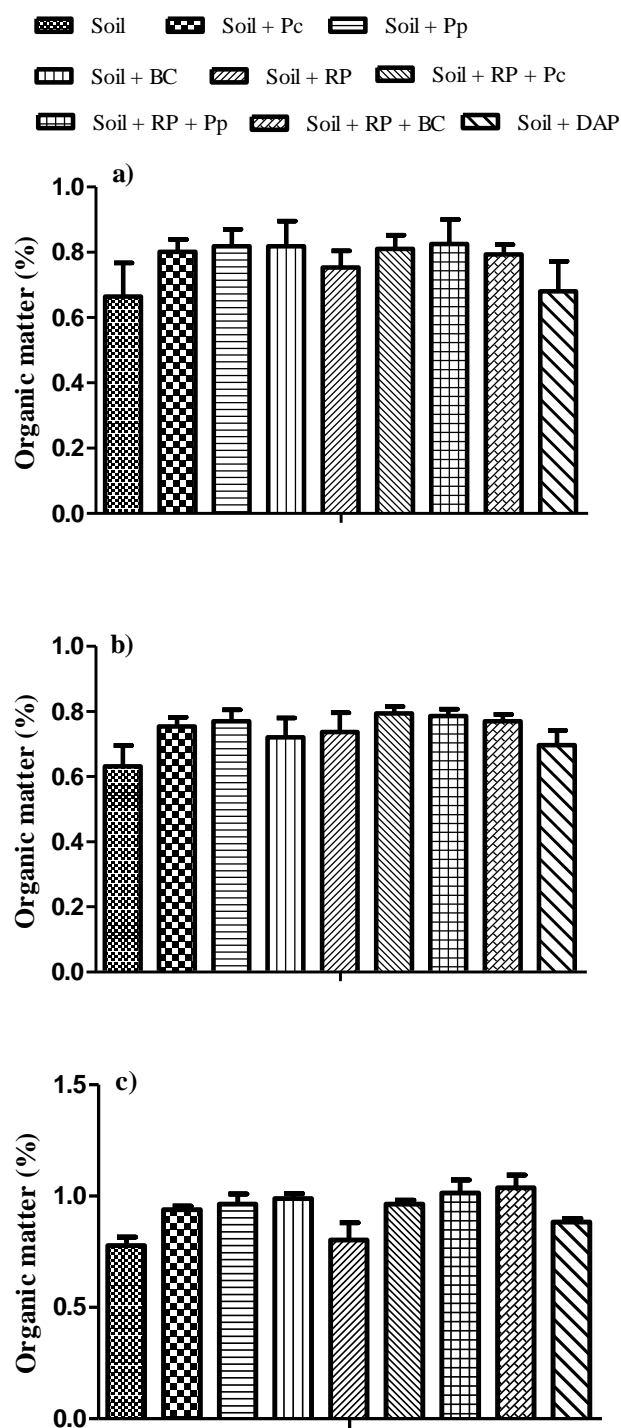


Fig. 7.10 Effect of *Pantoea cyripedii* (Pc) and *Pseudomonas plecoglossicida* (Pp) alone or along with RP fertilization and chemical fertilizer (DAP) on organic matter of rhizosphere soil characteristics of wheat plants grown in a) Central plain region (Thapar university, Patiala, Punjab), b) Sub mountain undulating central region (Balachaur, Punjab) and c) Sub mountain undulating region (Pojewal, Punjab).

Table 7.9 Effect of *Pantoea cypripedii* (Pc) and *Pseudomonas plecoglossicida* (Pp) alone or along with RP fertilization and chemical fertilizer (DAP) on rhizosphere soil characteristics of wheat plants grown in Central plain region (Thapar university, Patiala, Punjab), Sub mountain undulating central region (Balachaur, Punjab) and Sub mountain undulating region (Pojewal, Punjab).

Treatments	Total P (mg kg ⁻¹)	Available P (mg kg ⁻¹)	Total nitrogen (%)
Central plain region			
Soil	225 ± 13bc	3.86 ± 0.09gh	0.045 ± 0.005a
Soil + Pc	238 ± 17bc	5.45 ± 0.21cde	0.039 ± 0.010a
Soil + Pp	233 ± 8bc	5.42 ± 0.31cde	0.045 ± 0.010a
Soil + BC	245 ± 8bc	5.46 ± 0.07cde	0.045 ± 0.005a
Soil + RP	468 ± 15a	5.05 ± 0.34de	0.048 ± 0.005a
Soil + RP + Pc	465 ± 16a	7.10 ± 0.07b	0.056 ± 0.005a
Soil + RP + Pp	466 ± 15a	7.16 ± 0.07b	0.050 ± 0.015a
Soil + RP + BC	463 ± 6 a	7.06 ± 0.09b	0.050 ± 0.008a
DAP	461 ± 15a	4.39 ± 0.09fg	0.053 ± 0.010a
Sub mountain undulating central region			
Soil	213 ± 6bc	3.70 ± 0.11h	0.028 ± 0.010a
Soil + Pc	211 ± 19bc	5.10 ± 0.26de	0.031 ± 0.013a
Soil + Pp	206 ± 17bc	4.93 ± 0.07def	0.028 ± 0.010a
Soil + BC	204 ± 8c	4.97 ± 0.09def	0.042 ± 0.008a
Soil + RP	434 ± 15a	4.87 ± 0.24ef	0.031 ± 0.005a
Soil + RP + Pc	429 ± 8a	6.82 ± 0.13b	0.034 ± 0.008a
Soil + RP + Pp	426 ± 6a	6.81 ± 0.18b	0.036 ± 0.010a
Soil + RP + BC	431 ± 16a	6.77 ± 0.20b	0.045 ± 0.024a
DAP	440 ± 6a	4.02 ± 0.13gh	0.045 ± 0.017a
Sub mountain undulating region			
Soil	204 ± 7c	4.94 ± 0.18def	0.045 ± 0.005a
Soil + Pc	234 ± 25bc	6.72 ± 0.18b	0.050 ± 0.008a
Soil + Pp	245 ± 8bc	6.94 ± 0.18b	0.055 ± 0.011a
Soil + BC	250 ± 8b	6.88 ± 0.39b	0.051 ± 0.009a
Soil + RP	455 ± 6a	5.90 ± 0.18c	0.045 ± 0.010a
Soil + RP + Pc	445 ± 8a	9.11 ± 0.11a	0.061 ± 0.006a
Soil + RP + Pp	434 ± 28a	8.81 ± 0.11a	0.060 ± 0.016a
Soil + RP + BC	441 ± 8a	9.18 ± 0.29a	0.062 ± 0.028a
DAP	437 ± 19a	5.50 ± 0.11cd	0.046 ± 0.003a
LSD (P<0.05)	22	0.31	0.019

Values are Mean ± SD (*n* =10). Means sharing a common letter within the column are not significantly different at *P*<0.05. Pronounced results are represented in bold.

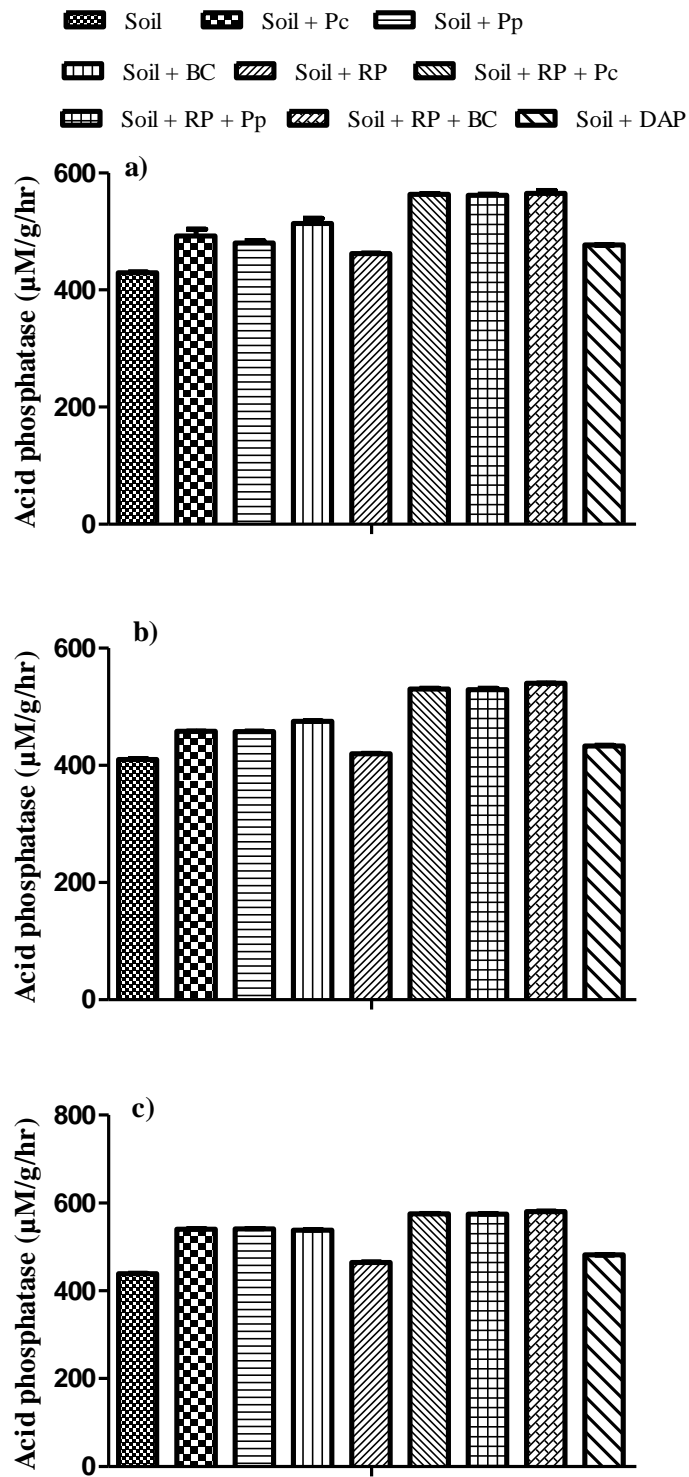


Fig. 7.11 Effect of *Pantoea cyripedii* (Pc) and *Pseudomonas plecoglossicida* (Pp) alone or along with RP fertilization and chemical fertilizer (DAP) on acid phosphatase enzyme activities of rhizosphere soil of wheat plants grown in a) Central plain region (Thapar university, Patiala, Punjab), b) Sub mountain undulating central region (Balachaur, Punjab) and c) Sub mountain undulating region (Pojewal, Punjab).

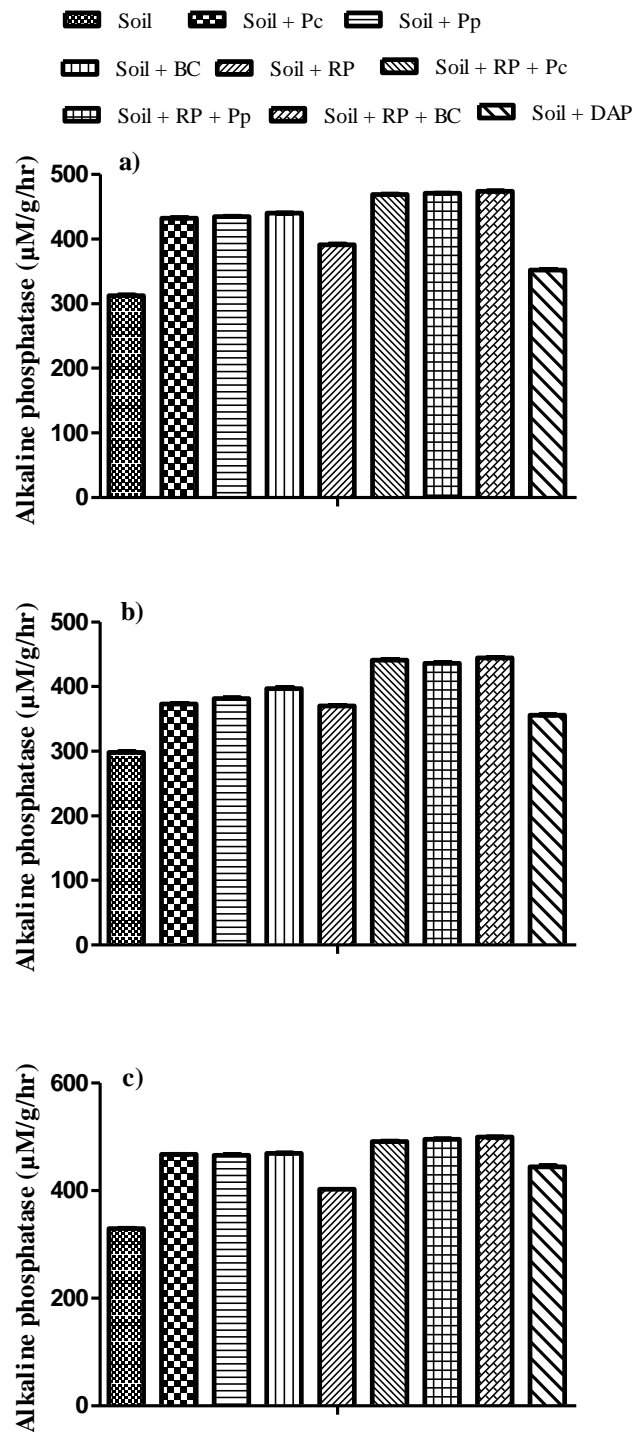


Fig. 7.12 Effect of *Pantoea cyripedii* (Pc) and *Pseudomonas plecoglossicida* (Pp) alone or along with RP fertilization and chemical fertilizer (DAP) on alkaline phosphatase enzyme activities of rhizosphere soil of wheat plants grown in a) Central plain region (Thapar university, Patiala, Punjab), b) Sub mountain undulating central region (Balachaur, Punjab) and c) Sub mountain undulating region (Pojewal, Punjab).

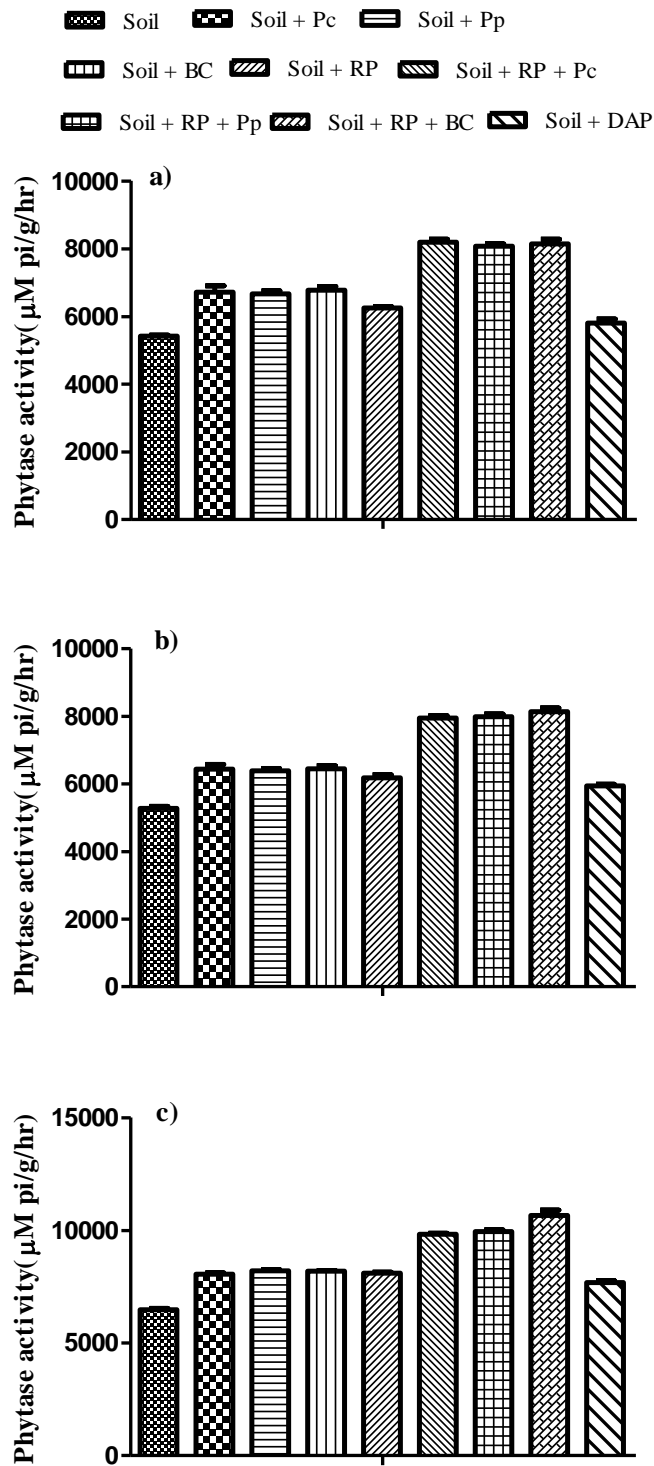


Fig. 7.13 Effect of *Pantoea cyripedii* (Pc) and *Pseudomonas plecoglossicida* (Pp) alone or along with RP fertilization and chemical fertilizer (DAP) on phytase enzyme activities of rhizosphere soil of wheat plants grown in a) Central plain region (Thapar university, Patiala, Punjab), b) Sub mountain undulating central region (Balachaur, Punjab) and c) Sub mountain undulating region (Pojewal, Punjab).

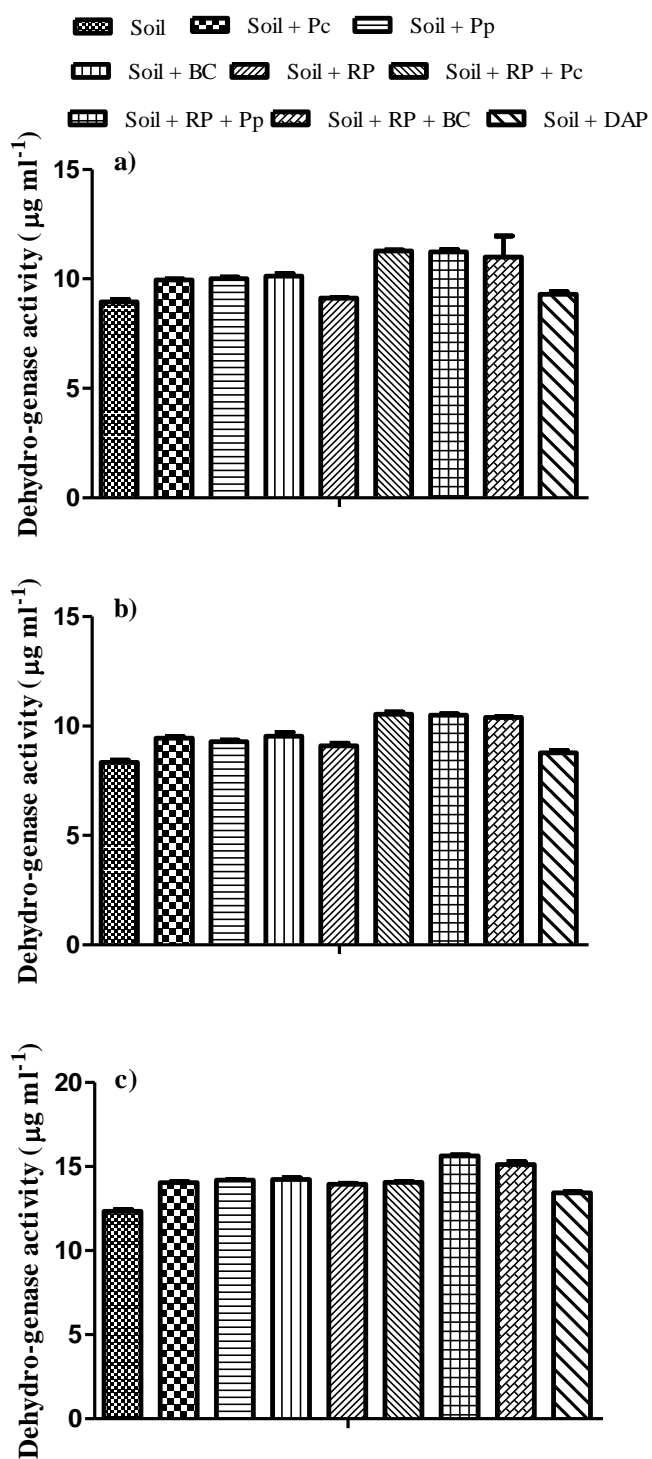


Fig. 7.14 Effect of *Pantoea cyripedii* (Pc) and *Pseudomonas plecoglossicida* (Pp) alone or along with RP fertilization and chemical fertilizer (DAP) on dehydro-genase enzyme activities of rhizosphere soil of wheat plants grown in a) Central plain region (Thapar university, Patiala, Punjab), b) Sub mountain undulating central region (Balachaur, Punjab) and c) Sub mountain undulating region (Pojewal, Punjab).

7.2 Phosphate-solubilizing fungi as bio-inoculants at multilocational sites

7.2.1 Maize crop

Maize plant growth parameters such as plant shoot height, shoot and root dry weight, yield and P uptake at all three different sites were significantly improved with fungal (*Aspergillus tubingensis* or *Aspergillus niger*) inoculation alone or along with RP fertilization (Table 7.10 and 7.11; Fig 7.15). Maize grain yield was increased up to 25 % at all three sites in inoculated and RP fertilization treatments, it was up to 19 % with inoculation treatments, 16 % with RP fertilization treatments and 9.0-13 % with DAP treatment compared to control treatments. Enhancement in yield and P uptake in maize was more pronounced at sub mountain undulating region compared to central plain region and sub mountain undulating central region.

Physiochemical properties of maize rhizospheric soils such as pH, organic carbon, organic matter, total P and available P were significantly improved in all the treatments, but the effects were more pronounced when inoculation was done along with RP fertilization. Fungal inoculation slightly decreased the soil pH in all the treatments compared to control in all field trials (Table 7.12). A significant improvement in organic carbon and organic matter in all the fungal inoculation and RP fertilization treatments was observed compared to DAP and control soil (Fig 7.16 and 7.17). At central plain region, sub mountain undulating central region and at sub mountain undulating region, organic carbon content was improved 44 %, 42 % and 48 % with fungal inoculation along with RP fertilization and 3.2 %, 18 % and 20 % with DAP treatments respectively, compared to control (Fig 7.16). Increase in available P level at central plain region was 84 %, at sub mountain undulating central region 80 % and at sub mountain undulating region it was 87 % due to inoculation but the effect was more pronounced (154 %, 161 % and 146 %) when RP was supplemented along with inoculation

compared to control. Total P of soil was improved significantly with RP fertilization and DAP treatments but available P was significantly improved only in RP fertilization along with inoculation treatments compared to inoculation treatments alone, RP fertilization treatments alone and DAP treatment (Table 7.13). Acid phosphatase, alkaline phosphatase, phytase and dehydrogenase enzyme activities were significantly increased in all the treatments compared to control treatment at different sites (Figure 7.18, 7.19, 7.20 and 7.21). In all the field trials at different sites, phytase enzyme activities were higher than acid phosphatase and alkaline phosphatase.

Population density of P-solubilizing fungi was tested after harvesting of the maize crop, at central plain region, sub mountain undulating central region and sub mountain undulating region and it was 1.3×10^5 cfu g⁻¹, 0.7×10^5 cfu g⁻¹ and 2.0×10^6 control treatment, $5.3-6.7 \times 10^6$ cfu g⁻¹, $4.3-6 \times 10^6$ cfu g⁻¹ and $5.3-7.0 \times 10^6$ cfu g⁻¹ in fungal inoculation treatments alone, 3×10^5 cfu g⁻¹, 2.7×10^5 cfu g⁻¹ and 3.3×10^6 cfu g⁻¹ in RP fertilization treatments alone, $7.7-9.0 \times 10^6$ cfu g⁻¹, $7.0-8.0 \times 10^6$ cfu g⁻¹ and $3.0-4.7 \times 10^7$ cfu g⁻¹ in inoculation along with RP fertilization and 2×10^5 cfu g⁻¹, 1.3×10^5 cfu g⁻¹ and 2.3×10^6 cfu g⁻¹ in DAP treatment.

Table 7.10 Effect of *Aspergillus tubingensis* (At) and *Aspergillus niger* (An) alone or along with RP fertilization and chemical fertilizer (DAP) on the growth parameters of maize plants grown in Central plain region (Thapar university, Patiala, Punjab), Sub mountain undulating central region (Balachaur, Punjab) and Sub mountain undulating region (Pojewal, Punjab).

Treatments	Shoot length (cm)	Shoot dry weight (g)	Root dry weight (g)
Central plain region			
Soil	217 ± 5jk	34 ± 1.4ij	9.49 ± 0.3fgh
Soil + At	245 ± 5 defgh	56 ± 1.4cdefg	12.9 ± 0.3abcdef
Soil + An	247 ± 11defgh	57 ± 1.3cdef	13.5 ± 0.2abcd
Soil + FC	246 ± 3defgh	61 ± 7.8bcdef	13.9 ± 0.9abc
Soil + RP	233 ± 4ghij	51 ± 5.3efgh	9.95 ± 0.7h
Soil + RP + At	259 ± 7abcde	65 ± 5.8abcde	14.6 ± 0.2ab
Soil + RP + An	262 ± 5abcd	68 ± 6.0abc	14.2 ± 1.0abc
Soil + RP + FC	257 ± 4abcde	67 ± 8.6abcd	14.4 ± 0.6abc
DAP	233 ± 6ghij	39 ± 2.0hij	11.1 ± 0.1bcdefg
Sub mountain undulating central region			
Soil	214 ± 6k	32 ± 1.7j	8.72 ± 0.1gh
Soil + At	238 ± 8fghi	53 ± 1.7defgh	12.07 ± 1.6abcdefg
Soil + An	245 ± 5defgh	55 ± 5.0cdefg	12.3 ± 0.2abcdefg
Soil + FC	243 ± 8efghi	52 ± 8.1efgh	12.6 ± 0.3abcdefg
Soil + RP	232 ± 6ghijk	39 ± 2.1hij	9.80 ± 0.3defgh
Soil + RP + At	250 ± 3defg	62 ± 3.5bcdef	13.0 ± 0.2abcdef
Soil + RP + Pp	253 ± 6bcdef	59 ± 2.1cdef	13.3 ± 0.1abcdef
Soil + RP + FC	255 ± 4abcdef	60 ± 3.9bcdef	13.4 ± 0.2abcde
DAP	231 ± 5hijk	42 ± 9.4ghij	9.5 ± 0.3efgh
Sub mountain undulating region			
Soil	225 ± 3.3ijk	36 ± 1.9il	9.70 ± 1.0efgh
Soil + At	258 ± 4.7abcde	58 ± 1.3cdef	14.2 ± 0.9abc
Soil + An	250 ± 3defg	64 ± 6.0bcde	15.0 ± 0.9a
Soil + FC	252 ± 6.3cdef	67 ± 1.0abcd	14.8 ± 1.1a
Soil + RP	238 ± 3.0fghi	51 ± 5.1efgh	10.0 ± 0.5efgh
Soil + RP + At	271 ± 3.0ab	74 ± 0.7ab	15.3 ± 0.4a
Soil + RP + An	270 ± 1.8abc	75 ± 1.2ab	15.8 ± 0.9a
Soil + RP + FC	272 ± 4.7a	78 ± 2.6a	15.3 ± 1.2a
DAP	239 ± 6.3fghi	49 ± 1.5fghi	10.6 ± 0.8cdefg
LSD (P<0.05)	9.48	7.50	2.017

Values are Mean ± SD ($n = 10$). Means sharing a common letter within the column are not significantly different at $P < 0.05$. Pronounced results are represented in bold.

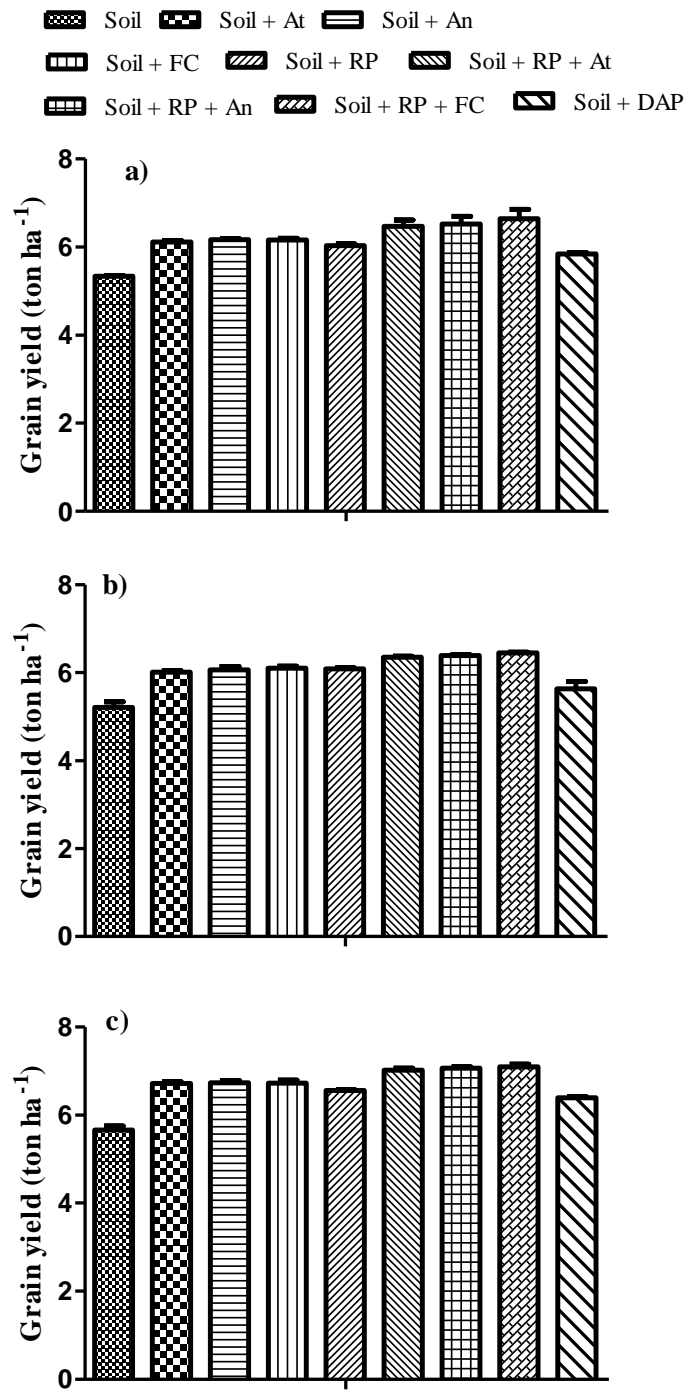


Fig. 7.15 Effect of *Aspergillus tubingensis* (At) and *Aspergillus niger* (An) alone or along with RP fertilization and chemical fertilizer (DAP) on the grain yield of maize plants grown in a) Central plain region (Thapar university, Patiala, Punjab), b) Sub mountain undulating central region (Balachaur, Punjab) and c) Sub mountain undulating region (Pojewal, Punjab).

Table 7.11 Effect of *Aspergillus tubingensis* (At) and *Aspergillus niger* (An) alone or along with RP fertilization and chemical fertilizer (DAP) on P uptake of maize plants grown in Central plain region (Thapar university, Patiala, Punjab), Sub mountain undulating central region (Balachaur, Punjab) and Sub mountain undulating region (Pojewal, Punjab).

Treatments	Grains (mg kg ⁻¹)	Shoot (mg kg ⁻¹)	Root (mg kg ⁻¹)
Central plain region			
Soil	136 ± 9ij	129 ± 4hi	123 ± 5l
Soil + At	179 ± 8cdefghij	166 ± 7bcdefgh	172 ± 6efgh
Soil + An	172 ± 10defghij	163 ± 13bcdefgh	169 ± 10efghi
Soil + FC	145 ± 17ghij	169 ± 6bcdefg	173 ± 5efgh
Soil + RP	169 ± 6efghij	152 ± 13defghi	133 ± 1ijkl
Soil + RP + At	223 ± 10abc	184 ± 6abcde	220 ± 8abcd
Soil + RP + An	222 ± 9abcd	188 ± 10abcd	219 ± 9abcd
Soil + RP + FC	228 ± 13abc	184 ± 10abcde	225 ± 8abc
DAP	161 ± 9ghij	145 ± 8fghi	159 ± 6fghijk
Sub mountain undulating central region			
Soil	129 ± 13j	125 ± 11i	120 ± 4l
Soil + At	168 ± 9fghij	155 ± 10defghi	165 ± 13efghij
Soil + An	170 ± 4defghij	159 ± 5cdefghi	162 ± 8efghij
Soil + FC	141 ± 8hij	169 ± 15bcdefg	169 ± 10efghi
Soil + RP	163 ± 6ghij	145 ± 15fghi	150 ± 4ghijkl
Soil + RP + At	218 ± 6abcdef	170 ± 8bcdefg	218 ± 6abcd
Soil + RP + An	218 ± 9abcdef	176 ± 13abcdef	211 ± 10bcd
Soil + RP + FC	220 ± 4abcde	175 ± 15abcdef	212 ± 13abcd
DAP	156 ± 6abc	137 ± 8ghi	141 ± 11hijkl
Sub mountain undulating region			
Soil	143 ± 10hij	136 ± 9ghi	127 ± 10kl
Soil + At	187 ± 11bcdefghi	172 ± 4bcdefg	176 ± 9efg
Soil + An	197 ± 17abcdefg	177 ± 10abcdef	194 ± 24cde
Soil + FC	191 ± 4bcdefgh	176 ± 19abcdef	191 ± 4def
Soil + RP	179 ± 13cdefghij	170 ± 11bcdefg	148 ± 6ghijkl
Soil + RP + At	230 ± 15abc	212 ± 17a	229 ± 18ab
Soil + RP + An	238 ± 15ab	197 ± 15abc	236 ± 10ab
Soil + RP + FC	248 ± 17a	201 ± 17ab	244 ± 15a
DAP	155 ± 13ghij	150 ± 11efghi	139 ± 6ijkl
LSD (P<0.05)	27	19	17

Values are Mean ± SD (n =10). Means sharing a common letter within the column are not significantly different at P<0.05. Pronounced results are represented in bold.

Table 7.12 Effect of *Aspergillus tubingensis* (At) and *Aspergillus niger* (An) alone or along with RP fertilization and chemical fertilizer (DAP) on rhizosphere soil characteristics of maize plants grown in Central plain region (Thapar university, Patiala, Punjab), Sub mountain undulating central region (Balachaur, Punjab) and Sub mountain undulating region (Pojewal, Punjab).

Treatments	pH	EC (mScm ⁻¹)	TDS (ppm)
Central plain region			
Soil	8.24 ± 0.03b	0.16 ± 0.02gh	0.11 ± 0.010fg
Soil + At	7.93 ± 0.02ef	0.21 ± 0.02cdefg	0.14 ± 0.014cdefg
Soil + An	7.91 ± 0.02f	0.23 ± 0.02cdefg	0.15 ± 0.012cdef
Soil + FC	7.82 ± 0.03g	0.22 ± 0.02cdefg	0.15 ± 0.014cdef
Soil + RP	7.80 ± 0.02gh	0.21 ± 0.02cdefg	0.14 ± 0.013cdef
Soil + RP + At	7.71 ± 0.01jklm	0.26 ± 0.04abcde	0.17 ± 0.027bcde
Soil + RP + An	7.65 ± 0.01mn	0.28 ± 0.02abc	0.19 ± 0.010bc
Soil + RP + FC	7.61 ± 0.02n	0.32 ± 0.02ab	0.21 ± 0.013ab
DAP	8.15 ± 0.06c	0.23 ± 0.03cdefg	0.15 ± 0.018cdef
Sub mountain undulating central region			
Soil	8.19 ± 0.02bc	0.13 ± 0.015h	0.08 ± 0.01g
Soil + At	7.82 ± 0.02g	0.19 ± 0.015defgh	0.13 ± 0.01defg
Soil + An	7.80 ± 0.01ghi	0.19 ± 0.015efgh	0.13 ± 0.01defg
Soil + FC	7.81 ± 0.01gh	0.19 ± 0.03defgh	0.3 ± 0.02defg
Soil + RP	7.82 ± 0.02g	0.19 ± 0.025efgh	0.13 ± 0.02defg
Soil + RP + At	7.69 ± 0.02klm	0.23 ± 0.015cdefg	0.15 ± 0.01cdef
Soil + RP + An	7.64 ± 0.02mn	0.23 ± 0.020cdefg	0.16 ± 0.01cdef
Soil + RP + FC	7.69 ± 0.02klm	0.23 ± 0.02cdefg	0.15 ± 0.01cdef
DAP	7.98 ± 0.03de	0.20 ± 0.02defgh	0.13 ± 0.01defg
Sub mountain undulating region			
Soil	8.33 ± 0.03a	0.18 ± 0.02fgh	0.12 ± 0.01efg
Soil + At	7.77 ± 0.01ghij	0.25 ± 0.02bcdef	0.17 ± 0.02bcde
Soil + An	7.74 ± 0.01hijk	0.23 ± 0.03cdefg	0.16 ± 0.02cdef
Soil + FC	7.81 ± 0.01gh	0.23 ± 0.05cdefg	0.15 ± 0.03cdef
Soil + RP	7.94 ± 0.02def	0.19 ± 0.02defgh	0.13 ± 0.01defg
Soil + RP + At	7.67 ± 0.03lmn	0.32 ± 0.04ab	0.22 ± 0.02ab
Soil + RP + An	7.70 ± 0.02klm	0.27 ± 0.04abcd	0.18 ± 0.02bcd
Soil + RP + FC	7.73 ± 0.04ijkl	0.33 ± 0.4a	0.22 ± 0.02a
DAP	8.01 ± 0.04d	0.25 ± 0.02bcdef	0.17 ± 0.01bcde
LSD (P<0.05)	0.037	0.039	0.028

Values are Mean ± SD (n =10). Means sharing a common letter within the column are not significantly different at P<0.05. Pronounced results are represented in bold.

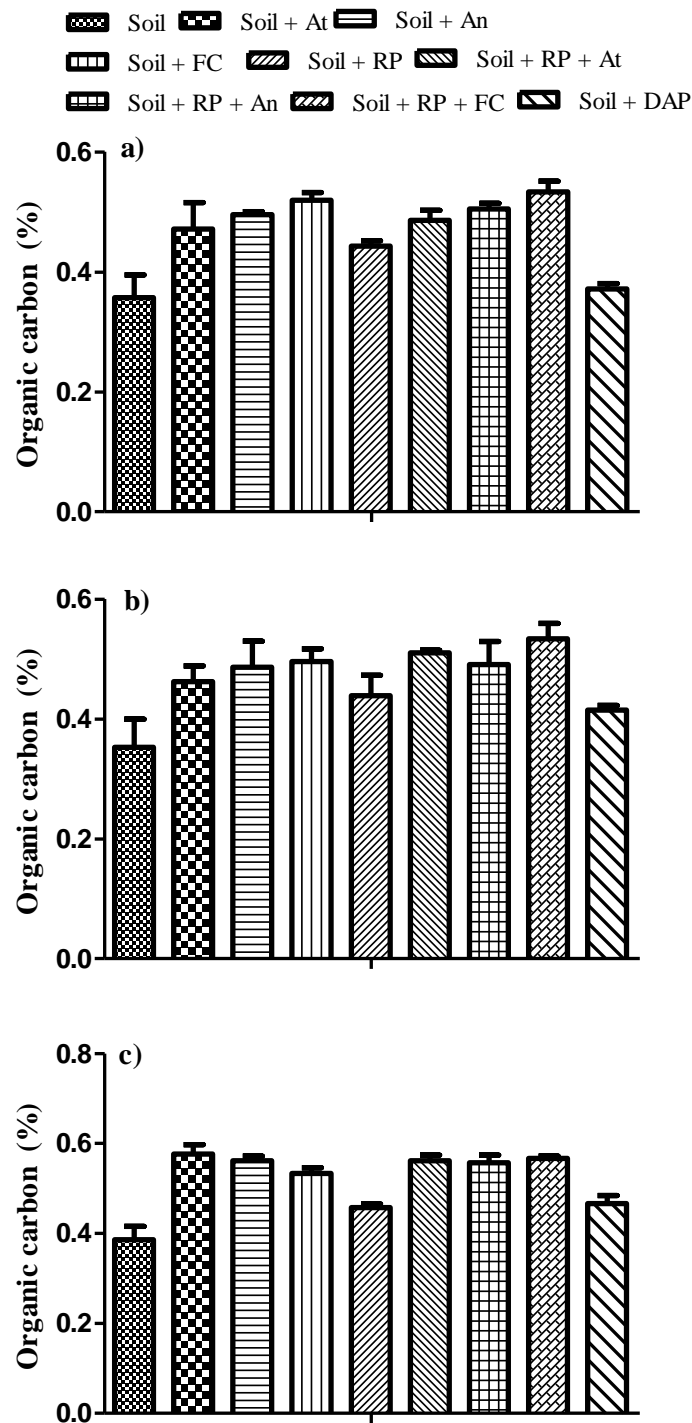


Fig. 7.16 Effect of *Aspergillus tubingensis* (At) and *Aspergillus niger* (An) alone or along with RP fertilization and chemical fertilizer (DAP) on organic carbon of rhizosphere soil of maize plants grown in a) Central plain region (Thapar university, Patiala, Punjab), b) Sub mountain undulating central region (Balachaur, Punjab) and c) Sub mountain undulating region (Pojewal, Punjab).

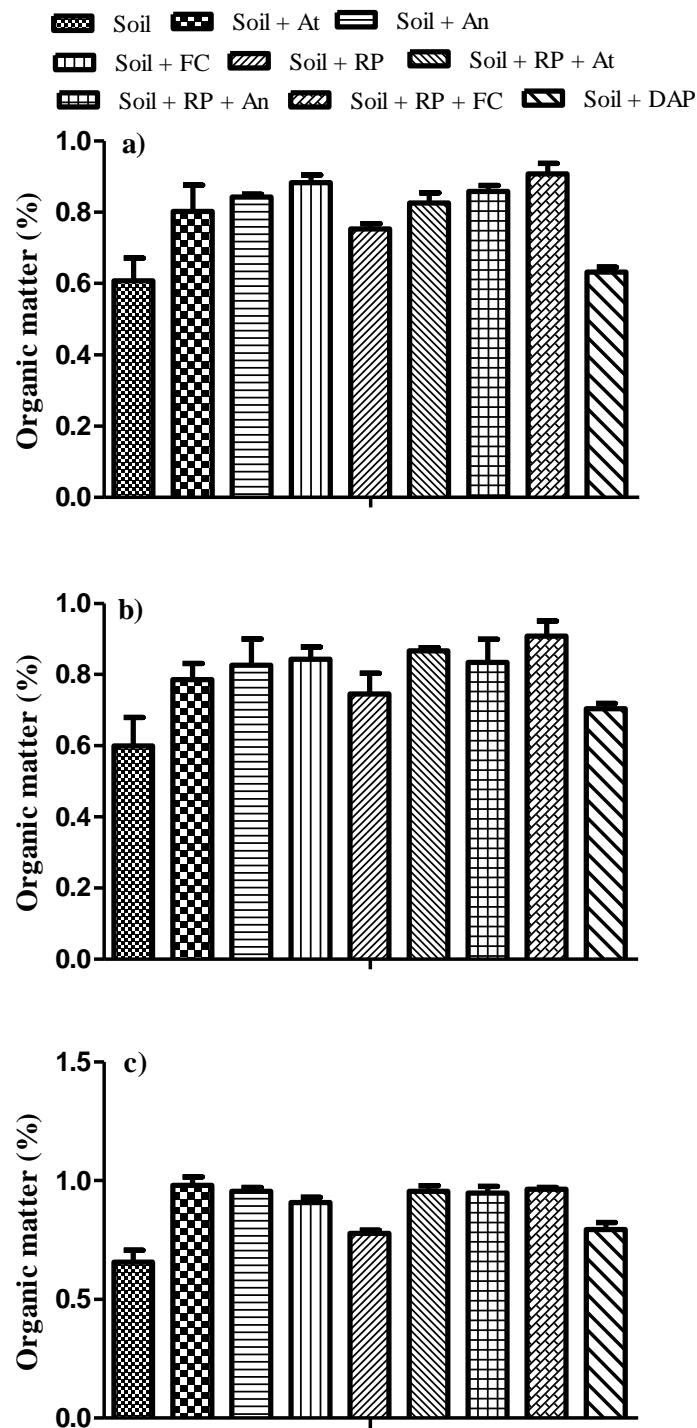


Fig. 7.17 Effect of *Aspergillus tubingensis* (At) and *Aspergillus niger* (An) alone or along with RP fertilization and chemical fertilizer (DAP) on organic matter of rhizosphere soil of maize plants grown in a) Central plain region (Thapar university, Patiala, Punjab), b) Sub mountain undulating central region (Balachaur, Punjab) and c) Sub mountain undulating region (Pojewal, Punjab).

Table 7.13 Effect of *Aspergillus tubingensis* (At) and *Aspergillus niger* (An) alone or along with RP fertilization and chemical fertilizer (DAP) on rhizosphere soil characteristics of maize plants grown in Central plain region (Thapar university, Patiala, Punjab), Sub mountain undulating central region (Balachaur, Punjab) and Sub mountain undulating region (Pojewal, Punjab).

Treatments	Total P (mg kg ⁻¹)	Available P (mg kg ⁻¹)	Total nitrogen (%)
Central plain region			
Soil	251 ± 15e	3.37 ± 0.19ij	0.031 ± 0.005a
Soil + At	254 ± 17e	5.83 ± 0.15de	0.034 ± 0.008a
Soil + An	265 ± 19e	6.19 ± 0.21d	0.036 ± 0.010a
Soil + FC	256 ± 2e	5.51 ± 0.28efg	0.036 ± 0.013a
Soil + RP	483 ± 8abcd	5.11 ± 0.13fg	0.035 ± 0.009a
Soil + RP + At	480 ± 6abcd	8.45 ± 0.29b	0.036 ± 0.013a
Soil + RP + An	504 ± 4ab	8.51 ± 0.42b	0.034 ± 0.008a
Soil + RP + FC	468 ± 6abcd	8.46 ± 0.39b	0.034 ± 0.015a
DAP	494 ± 6abc	4.11 ± 0.07h	0.036 ± 0.005a
Sub mountain undulating central region			
Soil	227 ± 15e	3.22 ± 0.17j	0.028 ± 0.005a
Soil + At	247 ± 9e	5.61 ± 0.13def	0.034 ± 0.008a
Soil + An	230 ± 19e	5.81 ± 0.09de	0.034 ± 0.015a
Soil + FC	245 ± 8e	5.79 ± 0.03de	0.042 ± 0.008a
Soil + RP	447 ± 21d	4.89 ± 0.09g	0.036 ± 0.005a
Soil + RP + At	462 ± 22cd	8.34 ± 0.29b	0.036 ± 0.005a
Soil + RP + An	484 ± 30abcd	8.42 ± 0.40b	0.034 ± 0.008a
Soil + RP + FC	476 ± 13abcd	8.27 ± 0.20b	0.031 ± 0.010a
DAP	504 ± 13abc	3.87 ± 0.22hi	0.031 ± 0.005a
Sub mountain undulating region			
Soil	237 ± 8e	4.02 ± 0.17h	0.035 ± 0.002a
Soil + At	248 ± 2e	7.51 ± 0.14c	0.045 ± 0.018a
Soil + An	250 ± 3e	7.23 ± 0.09c	0.042 ± 0.008a
Soil + FC	250 ± 4e	7.37 ± 0.07c	0.039 ± 0.005a
Soil + RP	465 ± 9bcd	5.29 ± 0.07efg	0.042 ± 0.017a
Soil + RP + At	459 ± 9cd	9.96 ± 0.12a	0.053 ± 0.010a
Soil + RP + An	508 ± 8a	9.86 ± 0.05a	0.050 ± 0.008a
Soil + RP + FC	469 ± 9abcd	9.91 ± 0.15a	0.048 ± 0.013a
DAP	487 ± 8abcd	4.94 ± 0.10g	0.039 ± 0.005a
LSD (P<0.05)	21	0.33	0.02

Values are Mean ± SD (n =10). Means sharing a common letter within the column are not significantly different at P<0.05. Pronounced results are represented in bold.

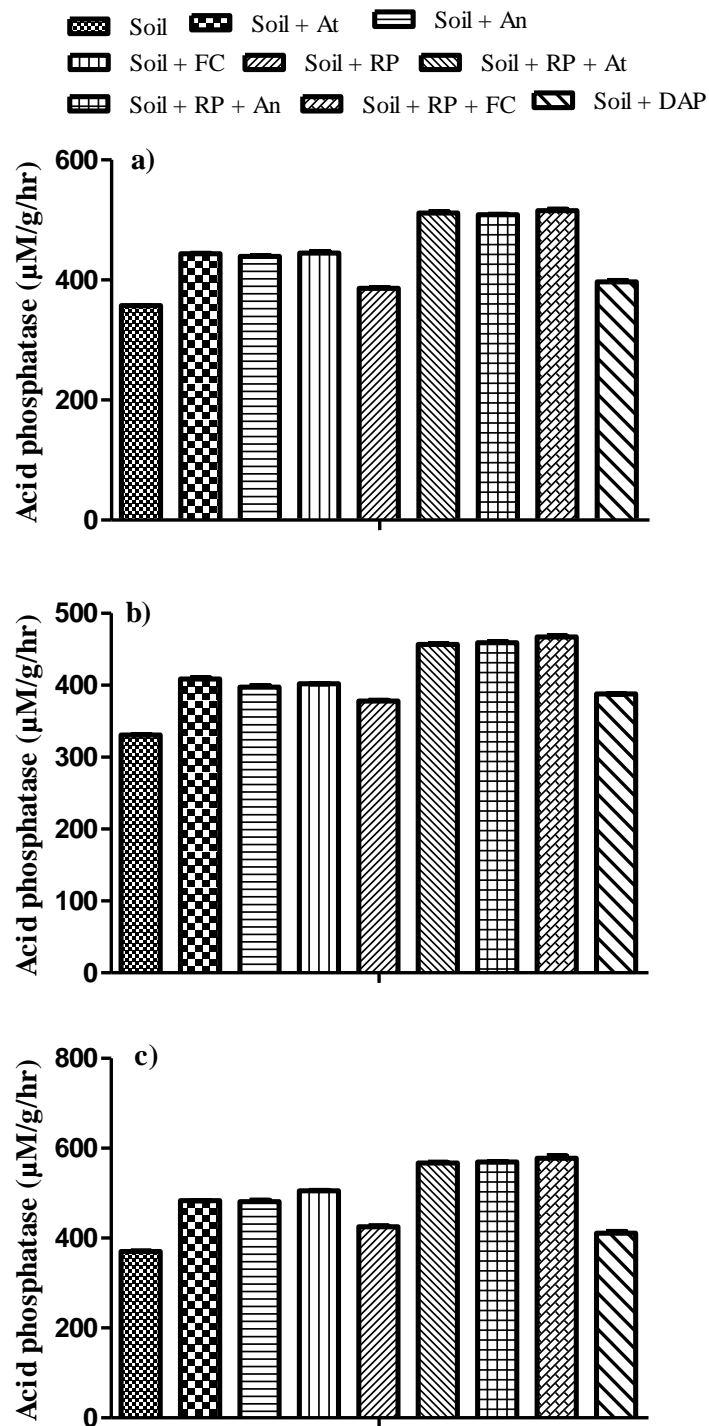


Fig. 7.18 Effect of *Aspergillus tubingensis* (At) and *Aspergillus niger* (An) alone or along with RP fertilization and chemical fertilizer (DAP) on acid phosphatase enzyme activities of rhizosphere soil of maize plants grown in a) Central plain region (Thapar university, Patiala, Punjab), b) Sub mountain undulating central region (Balachaur, Punjab) and c) Sub mountain undulating region (Pojewal, Punjab).

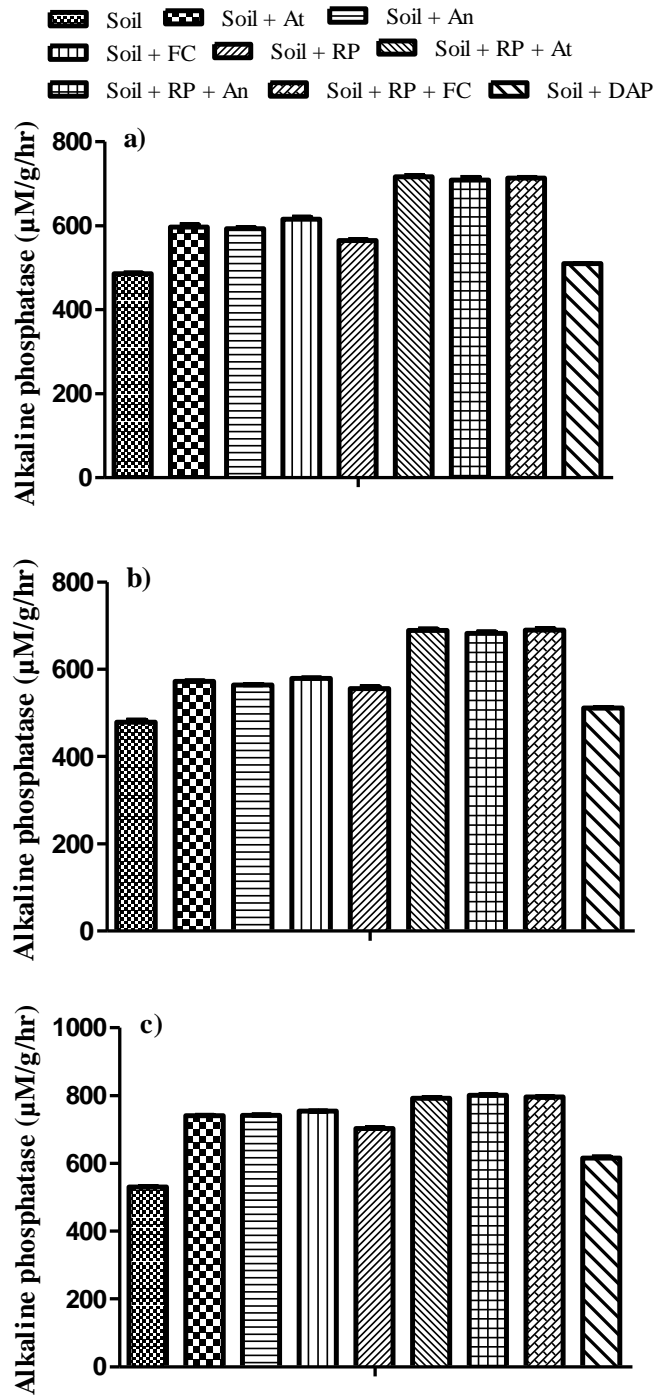


Fig. 7.19 Effect of *Aspergillus tubingensis* (At) and *Aspergillus niger* (An) alone or along with RP fertilization and chemical fertilizer (DAP) on alkaline phosphatase enzyme activities of rhizosphere soil of maize plants grown in a) Central plain region (Thapar university, Patiala, Punjab), b) Sub mountain undulating central region (Balachaur, Punjab) and c) Sub mountain undulating region (Pojewal, Punjab).

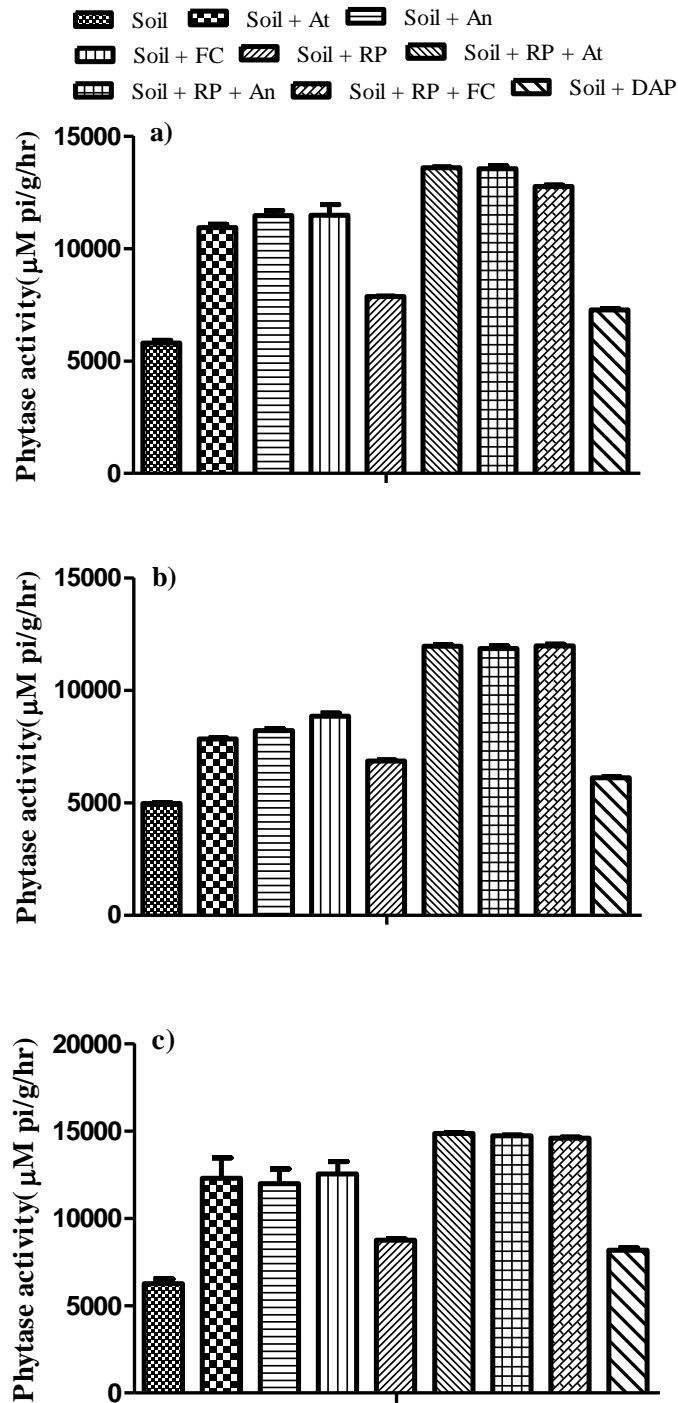


Fig. 7.20 Effect of *Aspergillus tubingensis* (At) and *Aspergillus niger* (An) alone or along with RP fertilization and chemical fertilizer (DAP) on phytase enzyme activities of rhizosphere soil of maize plants grown in a) Central plain region (Thapar university, Patiala, Punjab), b) Sub mountain undulating central region (Balachaur, Punjab) and c) Sub mountain undulating region (Pojewal, Punjab).

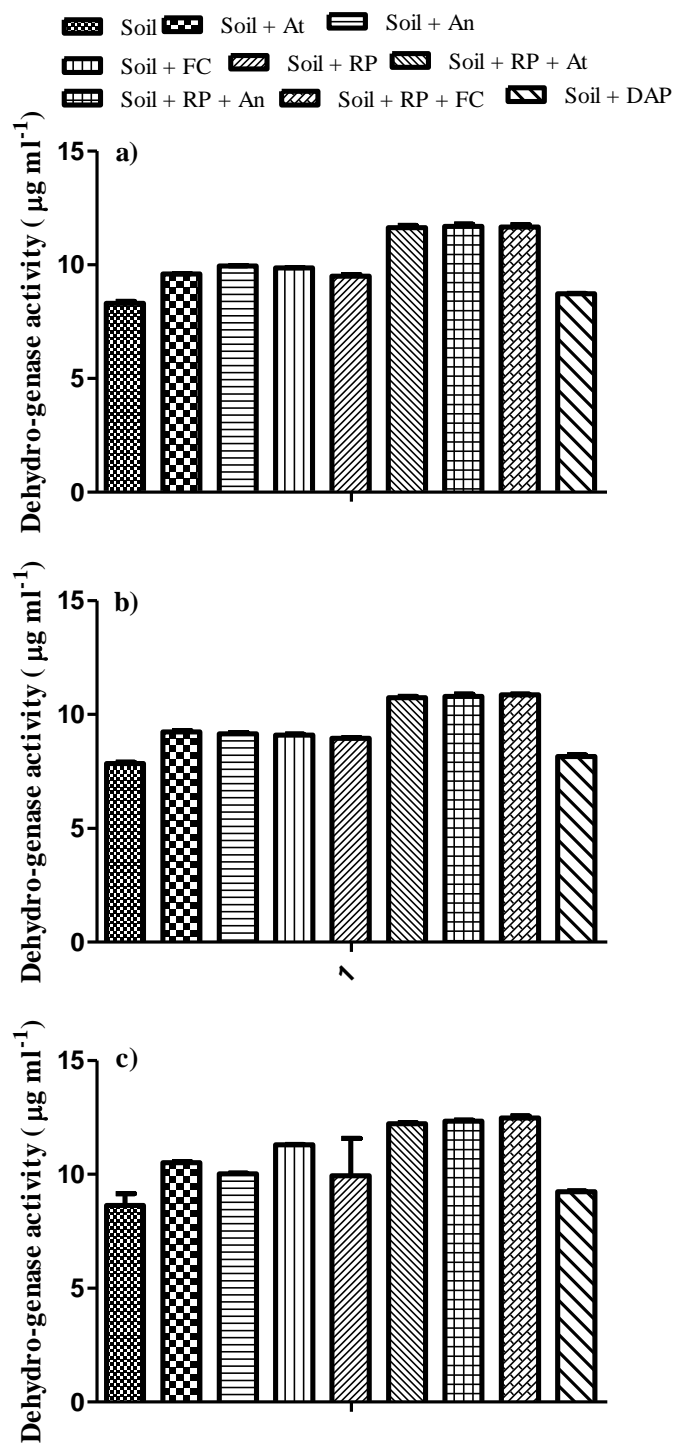


Fig. 7.21 Effect of *Aspergillus tubingensis* (At) and *Aspergillus niger* (An) alone or along with RP fertilization and chemical fertilizer (DAP) on dehydro-genase enzyme activities of rhizosphere soil of maize plants grown in a) Central plain region (Thapar university, Patiala, Punjab), b) Sub mountain undulating central region (Balachaur, Punjab) and c) Sub mountain undulating region (Pojewal, Punjab).

7.2.2 Wheat crop

Inoculation with *A. tubingensis* and *A. niger* alone or along with RP fertilization showed positive effects on plant growth promotion such as plant shoot height, shoot and root dry weight, yield and P uptake (Table 7.14 and 7.15; Fig. 7.22). Increase in yield up to 38 % was observed at all three sites in inoculated and RP fertilized soil treatments, it was up to 28 % with inoculation, 13 % with RP fertilization and 6 to 10 % with DAP treatment compared to control treatments. Stimulatory effects of inoculation treatments along with RP fertilization on growth parameters, yield and P uptake was found to be more pronounced compared to inoculation, RP fertilization and DAP treatments.

Soil pH slightly decreases in all the treatments compared to un-inoculated control in all field trials (Table 7.16). Results showed that there was a significant improvement in organic carbon and organic matter of the soil in all the inoculation and RP fertilization treatments compared to DAP and control treatments (Fig 7.23 and 7.24). During second year of field study on wheat crop, inoculation along with RP fertilization increased the soil organic carbon content 48 %, 48 % and 54 % and DAP treatments increased the soil organic carbon content 3 %, 11 % and 13 % at central plain region, sub mountain undulating central region and at sub mountain undulating region compared to control treatments, respectively. Available P level was significantly increased at central plain region (86 %), sub mountain undulating central region (77 %) and at sub mountain undulating region (54 %) due to inoculation but the effect was more pronounced (151 %, 149 % and 127 %) when RP was supplemented along with inoculation compared to control (Table 7.17). Acid phosphatase, alkaline phosphatase, phytase and dehydrogenase enzyme activities were significantly increased in all the treatments compared to control, but the results were more pronounced with inoculation treatments along with RP fertilization (Fig. 7.25, 7.26, 7.27 and 7.28). In all the field trials at different sites phytase enzyme activities were higher than acid phosphatase and alkaline

phosphatase enzyme activities. It was also observed that alkaline phosphatase activities were slightly decreased, as compared to the alkaline phosphatase activities in maize crop field at all different sites.

After harvesting of the wheat crop, rhizospheric soil was examined for phosphate-solubilizing fungal population density, and it was found that, at central plain region, sub mountain undulating central region and sub mountain undulating region PSFs population density was 1.5×10^5 cfu g⁻¹, 1.3×10^5 cfu g⁻¹ and 2.3×10^6 in control treatment, $6.5-8.0 \times 10^5$ cfu g⁻¹, $6.6-6.7 \times 10^5$ cfu g⁻¹ and $6.0-7.3 \times 10^6$ cfu g⁻¹ in inoculation treatments, 4×10^5 cfu g⁻¹, 3.0×10^5 cfu g⁻¹ and 4.3×10^6 cfu g⁻¹ in RP fertilization treatments, $8.5-9.0 \times 10^6$ cfu g⁻¹, $7.3-9.0 \times 10^6$ cfu g⁻¹ and $5-7.7 \times 10^7$ cfu g⁻¹ in inoculation along with RP fertilization and 2.5×10^5 cfu g⁻¹, 2×10^5 cfu g⁻¹ and 2.7×10^5 cfu g⁻¹ in DAP treatment. Field study of wheat crop at different sites showed that, there was a significant improvement in crop yield, total P uptake and soil fertility in RP fertilization treatments along with inoculation compared to inoculation alone and DAP treatment.

Table 7.14 Effect of *Aspergillus tubingensis* (At) and *Aspergillus niger* (An) alone or along with RP fertilization and chemical fertilizer (DAP) on the growth parameters of wheat plants grown in Central plain region (Thapar university, Patiala, Punjab), Sub mountain undulating central region (Balachaur, Punjab) and Sub mountain undulating region (Pojewal, Punjab).

Treatments	Shoot length (cm)	Shoot dry weight (g)	Root dry weight (g)
Central plain region			
Soil	96 ± 1.5no	1.36 ± 0.03ij	0.54 ± 0.03gh
Soil + At	110 ± 1.5fghijk	1.89 ± 0.03defgh	0.74 ± 0.10efgh
Soil + An	111 ± 3.8efghij	1.93 ± 0.25cdefg	0.79 ± 0.07efg
Soil + FC	113 ± 1.7efghij	2.01 ± 0.18bcdef	0.77 ± 0.11efgh
Soil + RP	108 ± 2.0hijklm	1.60 ± 0.02fghij	0.75 ± 0.08efgh
Soil + RP + At	116 ± 4.3defghi	2.37 ± 0.06abc	1.16 ± 0.10abcd
Soil + RP + An	119 ± 2.4bcdef	2.46 ± 0.11ab	1.20 ± 0.10abcd
Soil + RP + FC	126 ± 4.7abcd	2.48 ± 0.11ab	1.24 ± 0.11abc
DAP	99 ± 0.8klmno	1.58 ± 0.02fghij	0.62 ± 0.03gh
Sub mountain undulating central region			
Soil	92 ± 3.4o	1.24 ± 0.08j	0.49 ± 0.08h
Soil + At	107 ± 1.4ijklm	1.67 ± 0.04fghij	0.61 ± 0.05gh
Soil + An	109 ± 1.3ghijkl	1.69 ± 0.03efghij	0.65 ± 0.14fgh
Soil + FC	105 ± 1.4jklmn	0.72 ± 0.03efghi	0.70 ± 0.10efg
Soil + RP	106 ± 2.7ijklmn	1.52 ± 0.03ghij	0.65 ± 0.04fgh
Soil + RP + At	114 ± 4.6efghij	2.17 ± 0.26abcde	0.96 ± 0.02cde
Soil + RP + Pp	117 ± 3.4cdefgh	2.21 ± 0.10abcd	0.93 ± 0.03def
Soil + RP + FC	120 ± 2.2bcde	2.15 ± 0.03abcde	0.97 ± 0.02cde
DAP	98 ± 2.3mno	1.38 ± 0.13ij	0.54 ± 0.03gh
Sub mountain undulating region			
Soil	99 ± 8lmno	1.44 ± 0.10hij	0.66 ± 0.07fgh
Soil + At	115 ± 1efghij	1.99 ± 0.12cdef	0.94 ± 0.05def
Soil + An	119 ± 2cdefg	1.92 ± 0.06cdefg	1.01 ± 0.05bcde
Soil + FC	116 ± 2cdefgh	2.15 ± 0.04abcde	0.92 ± 0.05def
Soil + RP	109 ± 4ghijkl	1.70 ± 0.05efghij	0.79 ± 0.16efg
Soil + RP + At	131 ± 3a	2.58 ± 0.20a	1.33 ± 0.14a
Soil + RP + An	126 ± 4abc	2.54 ± 0.06a	1.28 ± 0.18ab
Soil + RP + FC	129 ± 2ab	2.62 ± 0.25a	1.27 ± 0.07ab
DAP	100 ± 1klmno	1.59 ± 0.46fghij	0.75 ± 0.04efgh
LSD (P<0.05)	5.26	0.24	0.15

Values are Mean ± SD (*n* =10). Means sharing a common letter within the column are not significantly different at *P*<0.05. Pronounced results are represented in bold.

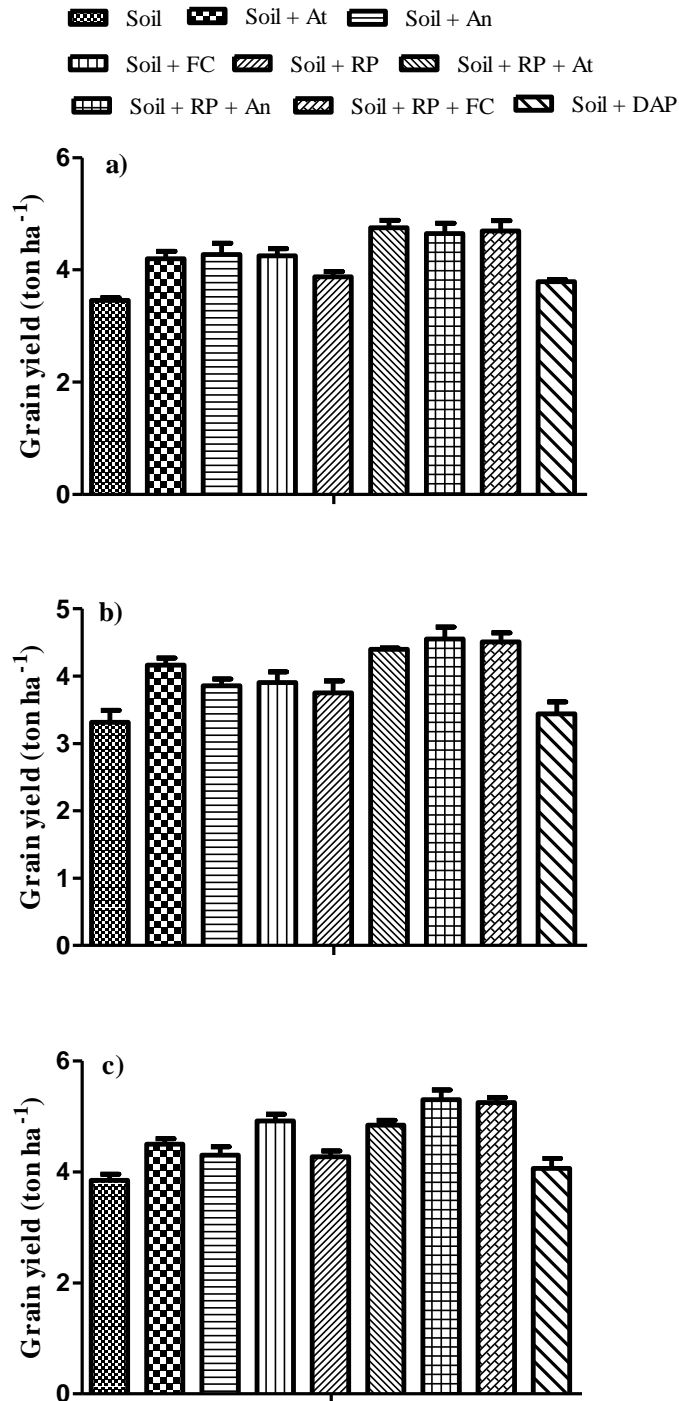


Fig. 7.22 Effect of *Aspergillus tubingensis* (At) and *Aspergillus niger* (An) alone or along with RP fertilization and chemical fertilizer (DAP) on the grain yield of wheat plants grown in Central plain region (Thapar university, Patiala, Punjab), Sub mountain undulating central region (Balachaur, Punjab) and Sub mountain undulating region (Pojewal, Punjab).

Table 7.15 Effect of *Aspergillus tubingensis* (At) and *Aspergillus niger* (An) alone or along with RP fertilization and chemical fertilizer (DAP) on P uptake of wheat plants grown in Central plain region (Thapar university, Patiala, Punjab), Sub mountain undulating central region (Balachaur, Punjab) and Sub mountain undulating region (Pojewal, Punjab).

Treatments	Grains (mg kg ⁻¹)	Shoot (mg kg ⁻¹)	Root (mg kg ⁻¹)
Central plain region			
Soil	218 ± 2l	29 ± 4l	191 ± 13k
Soil + At	295 ± 8fghi	66 ± 8defghi	293 ± 6fghi
Soil + An	286 ± 13ghi	72 ± 13defg	283 ± 8ghi
Soil + FC	272 ± 20ijk	68 ± 6defghi	301 ± 6efg
Soil + RP	298 ± 10efghi	41 ± 8hijkl	280 ± 9ghi
Soil + RP + At	344 ± 6cd	86 ± 17cde	369 ± 10bcd
Soil + RP + An	350 ± 8bcd	91 ± 15bcd	375 ± 14bc
Soil + RP + FC	345 ± 11cd	90 ± 15cd	397 ± 16b
DAP	237 ± 4jkl	31 ± 6kl	250 ± 11hij
Sub mountain undulating central region			
Soil	213 ± 5l	26 ± 10l	184 ± 13k
Soil + At	275 ± 4ij	48 ± 9ghijkl	290 ± 9fghi
Soil + An	286 ± 10ghi	54 ± 4fghijkl	279 ± 4gh
Soil + FC	270 ± 13ijk	61 ± 6cdefghijk	288 ± 6f
Soil + RP	277 ± 5hi	37 ± 8jkl	275 ± 8ghi
Soil + RP + At	343 ± 13cd	66 ± 4defghij	375 ± 8cde
Soil + RP + An	336 ± 13cde	69 ± 2defgh	366 ± 15bcd
Soil + RP + FC	340 ± 6cd	72 ± 2defg	372 ± 6bc
DAP	222 ± 16l	29 ± 11l	216 ± 17jk
Sub mountain undulating region			
Soil	227 ± 10l	38 ± 10ijkl	222 ± 6jk
Soil + At	326 ± 17def	63 ± 6defghij	336 ± 17cdef
Soil + An	313 ± 17defgh	81 ± 9def	322 ± 10defg
Soil + FC	320 ± 15defg	83 ± 11cdef	352 ± 6bcd
Soil + RP	336 ± 23cde	69 ± 6defgh	295 ± 8efgh
Soil + RP + At	373 ± 10abc	112 ± 4abc	458 ± 8a
Soil + RP + An	384 ± 6ab	120 ± 4ab	463 ± 6a
Soil + RP + FC	400 ± 4a	129 ± 15a	459 ± 6a
DAP	236 ± 20kl	47 ± 6ghijkl	245 ± 26ij
LSD (P<0.05)	19	15	24

Values are Mean ± SD (n =10). Means sharing a common letter within the column are not significantly different at P<0.05. Pronounced results are represented in bold.

Table 7.16 Effect of *Aspergillus tubingensis* (At) and *Aspergillus niger* (An) alone or along with RP fertilization and chemical fertilizer (DAP) on rhizosphere soil characteristics of wheat plants grown in Central plain region (Thapar university, Patiala, Punjab), Sub mountain undulating central region (Balachaur, Punjab) and Sub mountain undulating region (Pojewal, Punjab).

Treatments	pH	EC (mScm ⁻¹)	TDS (ppm)
Central plain region			
Soil	8.23 ± 0.02ab	0.17 ± 0.01efgh	0.11 ± 0.007efgh
Soil + At	7.60 ± 0.02defghi	0.22 ± 0.02abcde	0.15 ± 0.010abcde
Soil + An	7.56 ± 0.02fghi	0.23 ± 0.02abc	0.15 ± 0.010abc
Soil + FC	7.58 ± 0.04fghi	0.23 ± 0.02abc	0.15 ± 0.013abc
Soil + RP	8.14 ± 0.05b	0.21 ± 0.02abcdef	0.14 ± 0.013abcdef
Soil + RP + At	7.49 ± 0.07ghi	0.25 ± 0.02ab	0.17 ± 0.010ab
Soil + RP + An	7.53 ± 0.12ghi	0.25 ± 0.03a	0.17 ± 0.018a
Soil + RP + FC	7.53 ± 0.11ghi	0.24 ± 0.02abc	0.16 ± 0.010abc
DAP	8.17 ± 0.02ab	0.20 ± 0.02abcdef	0.14 ± 0.010abcdef
Sub mountain undulating central region			
Soil	8.19 ± 0.02ab	0.12 ± 0.01h	0.08 ± 0.007h
Soil + At	7.71 ± 0.02def	0.16 ± 0.02fgh	0.11 ± 0.010fgh
Soil + An	7.74 ± 0.02d	0.17 ± 0.02defg	0.12 ± 0.014defg
Soil + FC	7.74 ± 0.02de	0.20 ± 0.02bcdef	0.13 ± 0.010bcdef
Soil + RP	7.97 ± 0.02c	0.16 ± 0.02fgh	0.11 ± 0.010fgh
Soil + RP + At	7.60 ± 0.07defghi	0.22 ± 0.02abcd	0.15 ± 0.010abcd
Soil + RP + An	7.63 ± 0.02defg	0.20 ± 0.01abcdef	0.13 ± 0.007abcdef
Soil + RP + FC	7.62 ± 0.04defgh	0.23 ± 0.02abc	0.17 ± 0.014abc
DAP	7.98 ± 0.01c	0.19 ± 0.02cdef	0.13 ± 0.010adefg
Sub mountain undulating region			
Soil	8.30 ± 0.02a	0.14 ± 0.01gh	0.09 ± 0.01gh
Soil + At	7.59 ± 0.04efghi	0.17 ± 0.02defg	0.12 ± 0.01defg
Soil + An	7.58 ± 0.02fghi	0.22 ± 0.02abcde	0.15 ± 0.01abcde
Soil + FC	7.56 ± 0.03fghi	0.17 ± 0.02defg	0.12 ± 0.01defg
Soil + RP	8.13 ± 0.02b	0.19 ± 0.02cdefg	0.13 ± 0.01cdefg
Soil + RP + At	7.50 ± 0.05ghi	0.21 ± 0.02abcdef	0.14 ± 0.01abcdef
Soil + RP + An	7.46 ± 0.05i	0.24 ± 0.01abc	0.16 ± 0.01abc
Soil + RP + FC	7.47 ± 0.08hi	0.25 ± 0.02a	0.17 ± 0.01a
DAP	8.19 ± 0.03ab	0.19 ± 0.02cdef	0.13 ± 0.01cdef
LSD (P<0.05)	0.075	0.026	0.0178

Values are Mean ± SD (n =10). Means sharing a common letter within the column are not significantly different at P<0.05. Pronounced results are represented in bold.

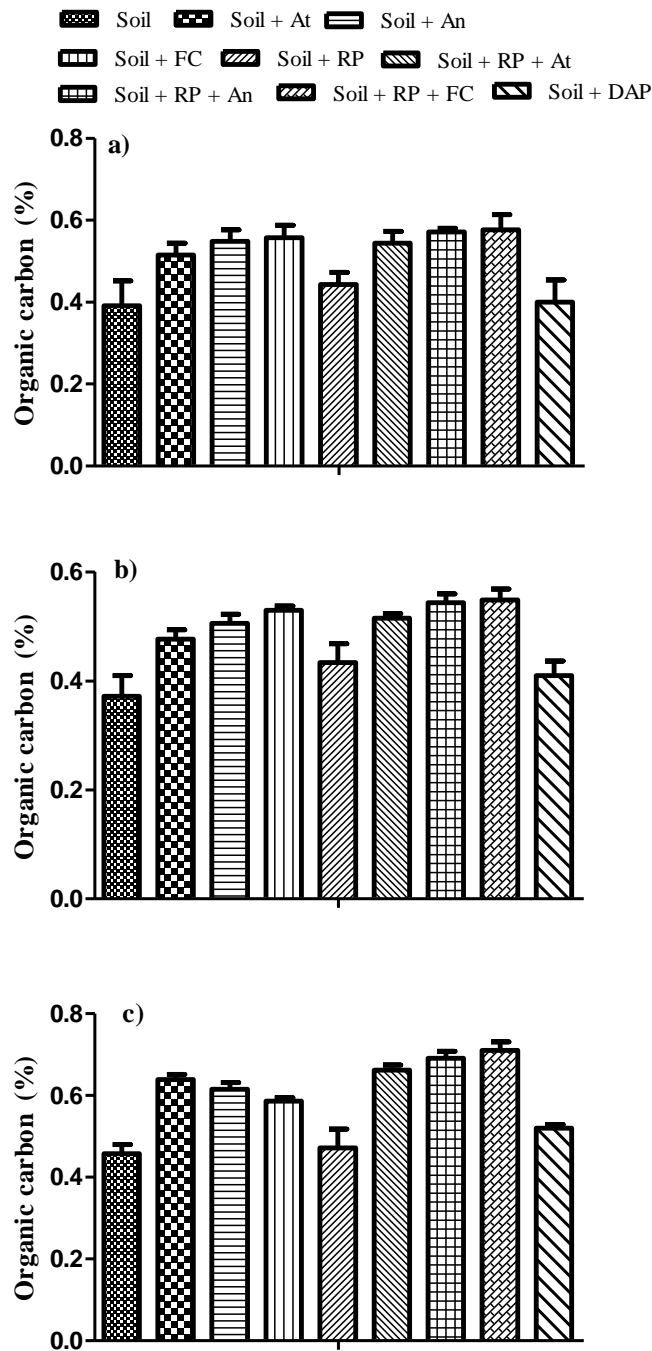


Fig. 7.23 Effect of *Aspergillus tubingensis* (At) and *Aspergillus niger* (An) alone or along with RP fertilization and chemical fertilizer (DAP) on organic carbon of rhizosphere soil characteristics of wheat plants grown in a) Central plain region (Thapar university, Patiala, Punjab), b) Sub mountain undulating central region (Balachaur, Punjab) and c) Sub mountain undulating region (Pojewal, Punjab).

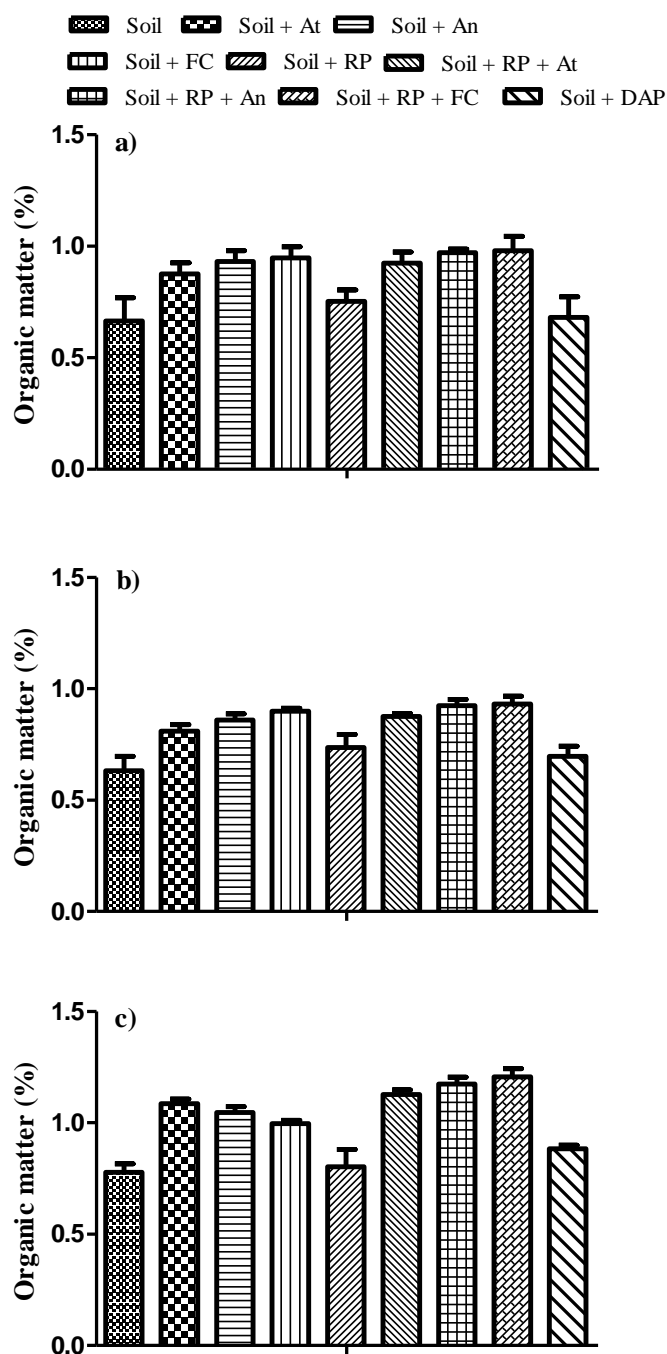


Fig. 7.24 Effect of *Aspergillus tubingensis* (At) and *Aspergillus niger* (An) alone or along with RP fertilization and chemical fertilizer (DAP) on organic matter of rhizosphere soil characteristics of wheat plants grown in a) Central plain region (Thapar university, Patiala, Punjab), b) Sub mountain undulating central region (Balachaur, Punjab) and c) Sub mountain undulating region (Pojewal, Punjab).

Table 7.17 Effect of *Aspergillus tubingensis* (At) and *Aspergillus niger* (An) alone or along with RP fertilization and chemical fertilizer (DAP) on rhizosphere soil characteristics of wheat plants grown in Central plain region (Thapar university, Patiala, Punjab), Sub mountain undulating central region (Balachaur, Punjab) and Sub mountain undulating region (Pojewal, Punjab)

Treatments	Total P (mg kg ⁻¹)	Available P (mg kg ⁻¹)	Total nitrogen (%)
Central plain region			
Soil	225 ± 13cdefg	3.86 ± 0.09n	0.045 ± 0.005a
Soil + At	245 ± 8cd	6.84 ± 0.07fgh	0.050 ± 0.008a
Soil + An	237 ± 4cde	6.95 ± 0.16fg	0.048 ± 0.013a
Soil + FC	227 ± 6cdef	7.17 ± 0.09ef	0.050 ± 0.015a
Soil + RP	468 ± 15a	5.05 ± 0.34jk	0.048 ± 0.005a
Soil + RP + At	452 ± 20ab	9.49 ± 0.27bc	0.053 ± 0.010a
Soil + RP + An	445 ± 8ab	9.59 ± 0.09bc	0.042 ± 0.008a
Soil + RP + FC	459 ± 9a	9.67 ± 0.15b	0.056 ± 0.005a
DAP	461 ± 15a	4.39 ± 0.09lm	0.053 ± 0.010a
Sub mountain undulating central region			
Soil	213 ± 6defg	3.70 ± 0.11n	0.028 ± 0.010a
Soil + At	205 ± 17efg	6.46 ± 0.07h	0.036 ± 0.005a
Soil + An	191 ± 8g	6.56 ± 0.09gh	0.039 ± 0.013a
Soil + FC	195 ± 8fg	6.55 ± 0.11gh	0.039 ± 0.010a
Soil + RP	434 ± 15ab	4.87 ± 0.24kl	0.031 ± 0.005a
Soil + RP + At	441 ± 8ab	8.73 ± 0.09d	0.039 ± 0.005a
Soil + RP + An	425 ± 8b	9.21 ± 0.11bcd	0.042 ± 0.008a
Soil + RP + FC	448 ± 10ab	9.17 ± 0.08cd	0.048 ± 0.005a
DAP	440 ± 6ab	4.02 ± 0.13mn	0.045 ± 0.017a
Sub mountain undulating region			
Soil	204 ± 7efg	4.94 ± 0.18k	0.045 ± 0.005a
Soil + At	223 ± 6cdefg	7.23 ± 0.18ef	0.063 ± 0.013a
Soil + An	247 ± 9c	7.59 ± 0.15e	0.056 ± 0.012a
Soil + FC	250 ± 8c	7.11 ± 0.18ef	0.066 ± 0.011a
Soil + RP	455 ± 6ab	5.90 ± 0.18i	0.045 ± 0.009a
Soil + RP + At	437 ± 8ab	10.95 ± 0.13a	0.060 ± 0.012a
Soil + RP + An	434 ± 5ab	10.90 ± 0.09a	0.059 ± 0.019a
Soil + RP + FC	443 ± 6ab	11.22 ± 0.18a	0.064 ± 0.050a
DAP	437 ± 19ab	5.51 ± 0.11ij	0.046 ± 0.003a
LSD (P<0.05)	17	0.25	0.023

Values are Mean ± SD (n =10). Means sharing a common letter within the column are not significantly different at P<0.05. Pronounced results are represented in bold.

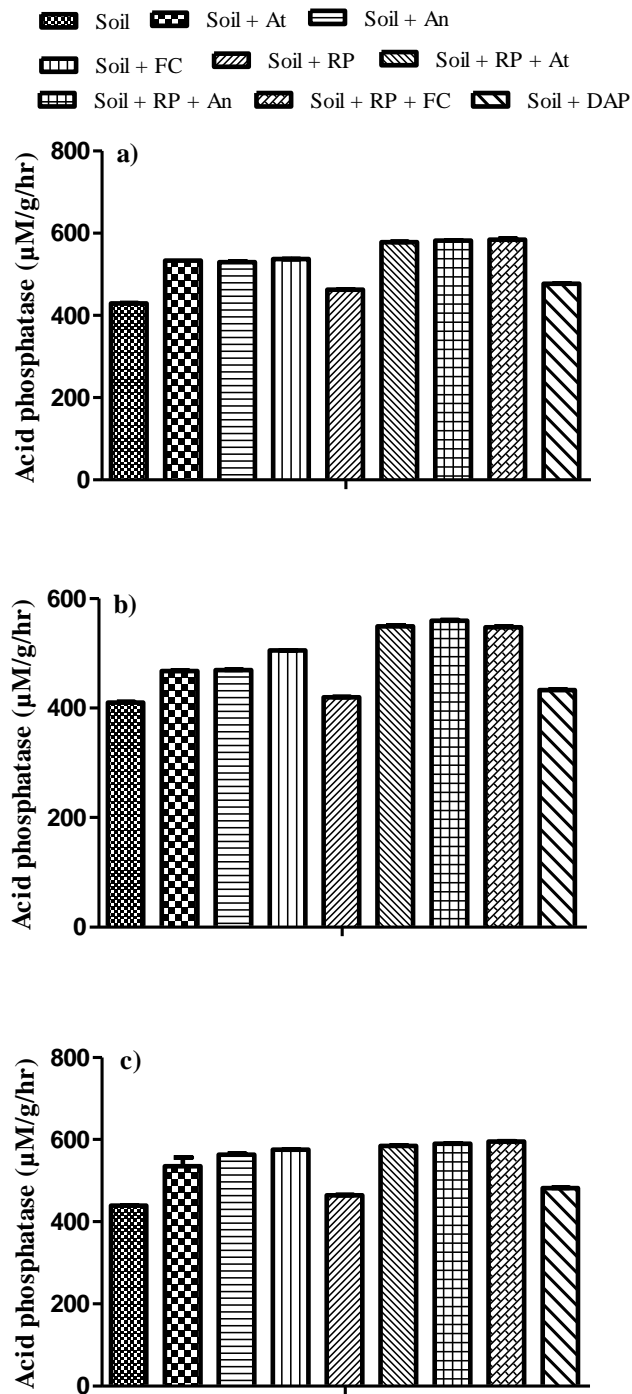


Fig. 7.25 Effect of *Aspergillus tubingensis* (At) and *Aspergillus niger* (An) alone or along with RP fertilization and chemical fertilizer (DAP) on acid phosphatase enzyme activities of rhizosphere soil of wheat plants grown in a) Central plain region (Thapar university, Patiala, Punjab), b) Sub mountain undulating central region (Balachaur, Punjab) and c) Sub mountain undulating region (Pojewal, Punjab).

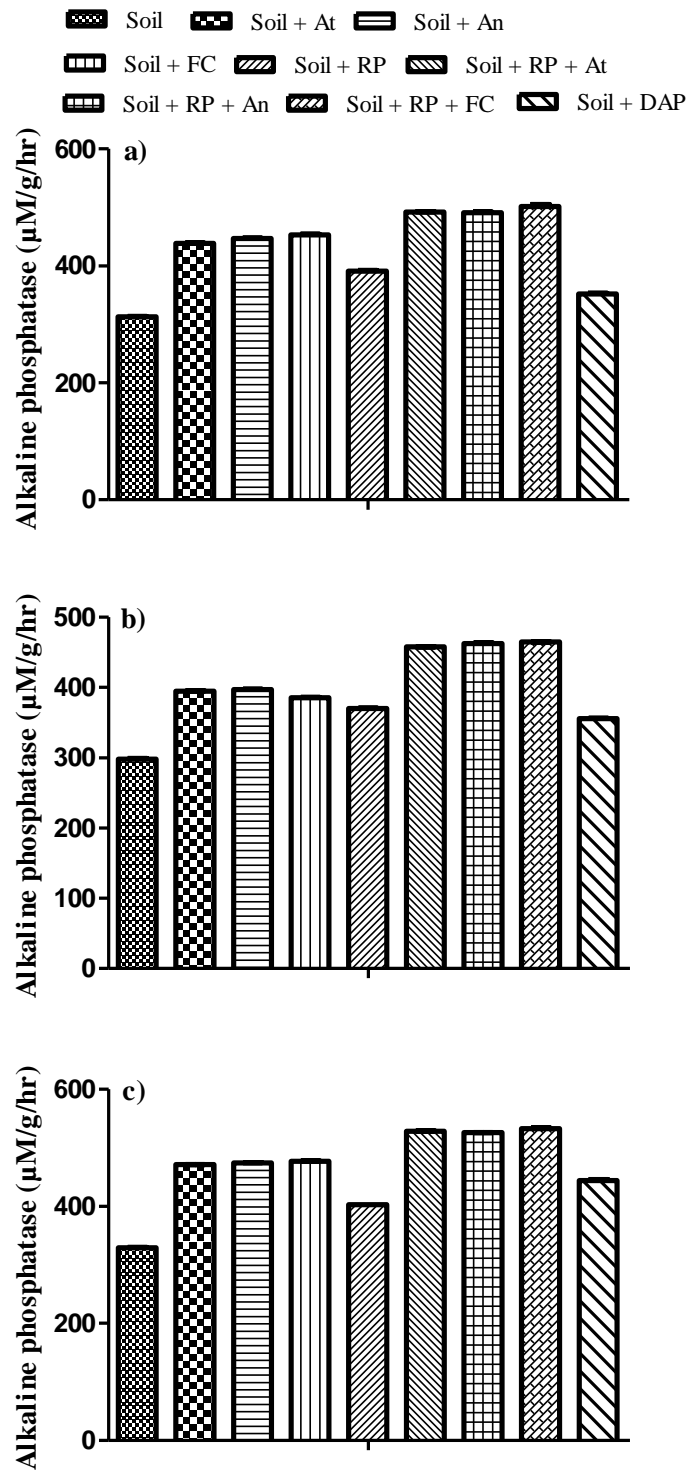


Fig. 7.26 Effect of *Aspergillus tubingensis* (At) and *Aspergillus niger* (An) alone or along with RP fertilization and chemical fertilizer (DAP) on alkaline phosphatase enzyme activities of rhizosphere soil of wheat plants grown in a) Central plain region (Thapar university, Patiala, Punjab), b) Sub mountain undulating central region (Balachaur, Punjab) and c) Sub mountain undulating region (Pojewal, Punjab).

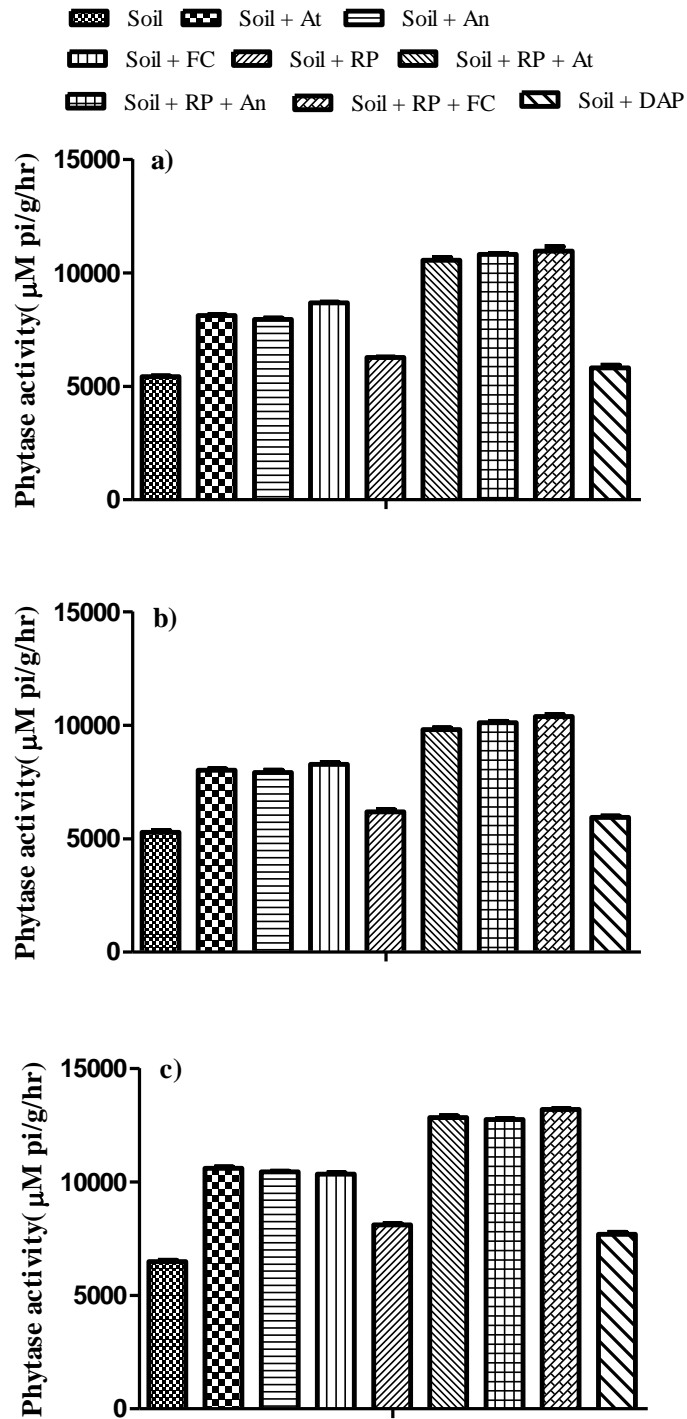


Fig. 7.27 Effect of *Aspergillus tubingensis* (At) and *Aspergillus niger* (An) alone or along with RP fertilization and chemical fertilizer (DAP) on phytase enzyme activities of rhizosphere soil of wheat plants grown in a) Central plain region (Thapar university, Patiala, Punjab), b) Sub mountain undulating central region (Balachaur, Punjab) and c) Sub mountain undulating region (Pojewal, Punjab).

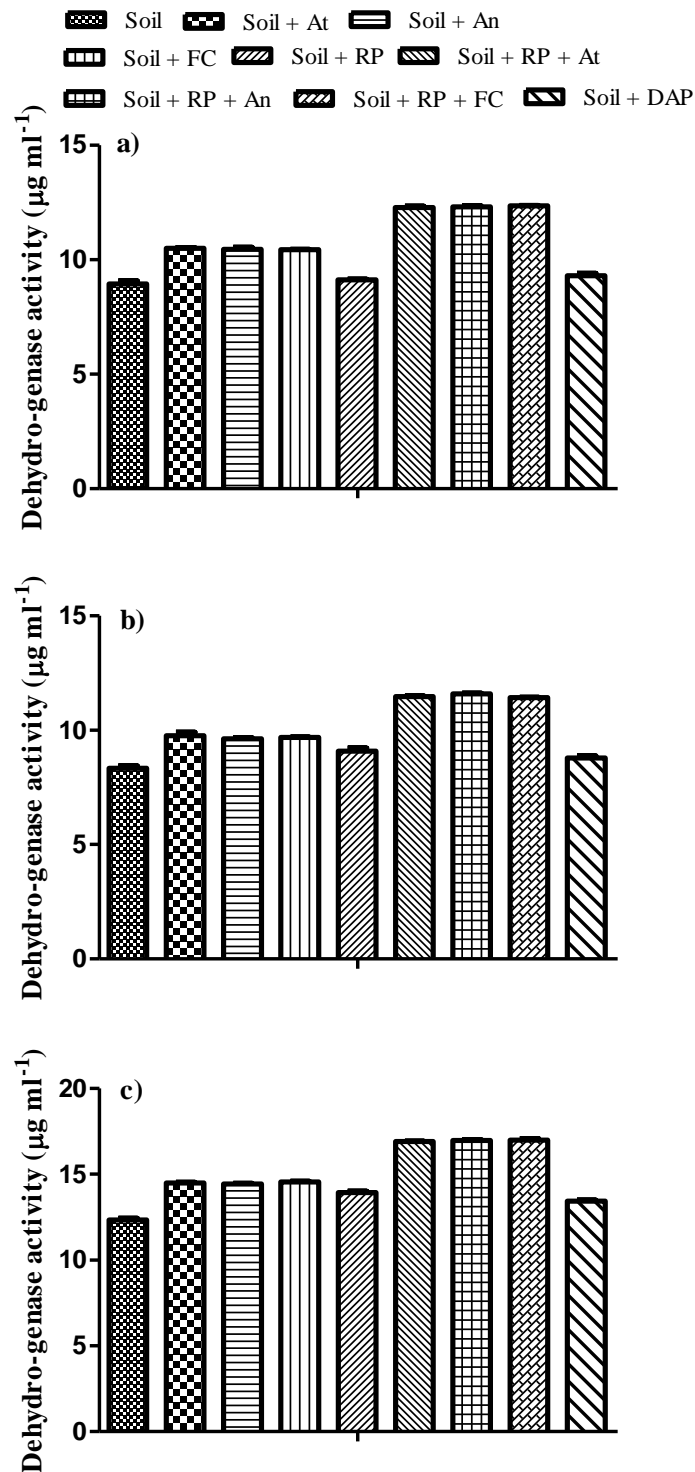


Fig. 7.28 Effect of *Aspergillus tubingensis* (At) and *Aspergillus niger* (An) alone or along with RP fertilization and chemical fertilizer (DAP) on dehydro-genase enzyme activities of rhizosphere soil of wheat plants grown in a) Central plain region (Thapar university, Patiala, Punjab), b) Sub mountain undulating central region (Balachaur, Punjab) and c) Sub mountain undulating region (Pojewal, Punjab).