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Quantifying the contribution of microbial inoculation and zinc fertilization to growth, yield and economics of wheat (*Triticum aestivum*) in different methods of cultivation

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ABSTRACT

A field experiment was conducted at research farm of ICAR-Indian Agricultural Research Institute, New Delhi in winter (*rabi)* season of 2013-14 and 2014-15 with the aim to quantity the contribution of two microbial inoculations and zinc (Zn) fertilization to growth, yield and economics of wheat (*Triticum aestivum* L.). Experiment was conducted in split-plot design (variety HD 2967) involving three different methods of cultivation, viz. conventional wheat (CW), system of wheat intensification (SWI) and zero tillage (ZT) as main plot and nine nutrient management options as subplot in each method of cultivation involving recommended dose ($N_{120}P_{25.8}$), 75% recommended dose ($N_{90}P_{19.35}$), 75% recommended dose + *Anabaena* sp (CR1) + *Providencia* sp (PR3) and 75% recommended dose + *Anabaena- Pseudomonas* (An-Ps) biofilmed formulation with and without Zn which make total eight options along with one absolute control ($N_0P_0Zn_0$). Zinc was applied to soil @ 5 kg Zn/ha through zinc sulphate heptahydrate. Results of two years study revealed that, contribution of CR1 + PR3 consortia and An-Ps biofilmed formulation to yield improvement is 360 and 370 kg/ha with Zn and 190 and 230 kg/ha without Zn fertilization; while increase in net return was ₹ 5 370 and ₹ 5 520/ha respectively with Zn and ₹ 3 080 and ₹ 3 650/ha without Zn, respectively. Soil microbial biomass carbon (MBC) is more in all inoculated treatments than uninoculated treatment with highest in 75% recommended dose ($N_{90}P_{19.35}$) + An-Ps biofilmed formulation + Zn (372 µg/g soil) at 90 days after sowing. Total nitrogen uptake was increased by 37.5 and 39.8 kg/ha due to application of CR1 + PR3 consortia and An-Ps biofilmed formulation along with Zn, respectively. Zinc fertilization increased grain yield and net returns by 180 kg/ha and ₹ 2 340/ha, respectively with treatment containing recommended dose ($N_{120}P_{25.8}$). Total uptake of Zn at harvest was significantly higher in treatment containing recommended dose ($N_{120}P_{25.8}$) with Zn (327.7 g/ha) than same treatment without zinc application (289.2 g/ha). Zero tillage wheat recorded significantly higher yield (4.56 tonnes/ha) than both conventional (4.33 tonnes/ha) and SWI (4.31 tonnes/ha) methods of cultivation which leads to higher net return in ZT wheat (₹ 53.86×10^3/ha) than other methods of cultivation. Uptake of nitrogen, phosphorus, zinc and soil MBC was significantly higher in zero tillage wheat. In nutshell, application of any one inoculation along with 75% recommended dose ($N_{90}P_{19.35}$) + Zn fertilization was promising nutrient management option by considering their quantifiable contribution and among cultivation methods ZT method found superior than CW and SWI method.

Key words: Biological nitrogen fixation, Economics, System of wheat intensification (SWI), Wheat, Zero tillage (ZT), Zinc fertilization

Importance of wheat lies in its capacity to provide more calories and proteins to world population than any other cereal crops in the world (Kumar *et al*. 2011). In India wheat stand second after rice occupying 30.47 million ha area and produce 95.85 million tonnes wheat with an average productivity of 3.145 tonnes/ha during 2013-14 (Fertiliser Statistics 2014-15). Most of the wheat in India is grown after harvest of rainy (*kharif*) season crops, like rice, cotton, pigeonpea, etc under irrigated condition. Time availability after harvesting of rainy season crop and before planting of wheat generally remains less in most cases. At the same time, more energy is required to prepare field for wheat sowing if previous crop is rice which mainly occurs in Indo-Gangatic plains. Increase in price of all forms of energy and more energy is required for field preparation which leads to higher cost of cultivation in conventional drill sown wheat. In such situation, diversifying cultivation methods from conventional drill sown wheat to other methods like zero tillage (ZT) (Gupta and Seth 2007) and system of wheat intensification (SWI) are promising options. Along with wastage of energy in tillage operation, low nutrient use efficiency (NUE) is also important problem as nitrogen use efficiency remains only 50-60%, while in case of phosphorus, it is only 15-20% in most of crops (Hegde *et al.* 2007). Problems like depletion of soil fertility and nutrient

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deficiencies in wheat was also underlined by Timsina and Connor (2001) while discussing issues and challenges in rice-wheat cropping system. Share of inorganic fertilizers in total nutrient application was the highest which was 64% for nitrogen and 78% for phosphorus (Pathak *et al.* 2010). In this scenario, diversifying this dominance of inorganic fertilizer through economically viable options such as biological nitrogen fixation (BNF) and phosphorus solubilising bacteria (PSB) need due attention. Along with major nutrients like N, P and K, application of micronutrients like Zn was essential. It is estimated that nearly half of the soil in which food crops are grown are deficient in Zn and even with balanced N, P and K fertilization, extensive micronutrient deficiencies leads to decline in factor productivity (Shukla *et al.* 2012). In order to diversify N and P nutrient sources with BNF and PSB and involvement of Zn fertilization in different methods of wheat cultivation, it is necessary to quantify the their contribution to change in growth, yield and economics of wheat as compared to current cultivation practices. With this background, study was planned to quantify the contribution of microbial inoculation and Zn fertilization to growth, yield and economics of wheat in different methods of wheat cultivation.

MATERIALS AND METHODS

Field experiment was conducted in winter (*Rabi)* season for two consecutive years (2013-14 and 2014-15) on the Research Farm of ICAR-Indian Agricultural Research Institute, New Delhi located at the latitude of 28°38' N, longitude of 77°10' E and altitude of 228.6 amsl. The climate of Delhi is of sub-tropical and semi-arid type with hot and dry summer and cold winter and falls under the agro-climatic zone Trans-Gangatic plains. The mean annual normal rainfall is 650 mm and annual mean pan evaporation is about 850 mm. Total rainfall received during first and second crop growing season of wheat was 147.6 mm and 308.6 mm, respectively; while evaporation losses in first and second crop growing season of wheat was 542.5 mm and 580.5 mm, respectively. The highest temperature was recorded during 14^{th} (33.8°C) and 16^{th} (36.5°C) meteorological weeks and lowest in 3^{rd} (4.3°C) and 1^{st} (3.4°C) meteorological week in first and second wheat crop growing season, respectively. The soil of experimental field was sandy clay loam in texture having pH 7.6, organic carbon (0.54%), and available N, P, K and DTPA extractable Zn of 200.3 kg/ha, 23.3 kg/ha, 284.6 kg/ha and 0.87 mg/kg, respectively (Prasad *et al.* 2006).

The experiment involving wheat variety HD 2967 was planned in split-plot design comprised three main plots as a methods of wheat cultivation [conventional method (CM), system of wheat intensification (SWI) and zero tillage (ZT)] with nine nutrient management options as sub-plot treatments. Subplot treatments involves recommended dose ($N_{120}P_{25.8}$), 75% recommended dose ($N_{90}P_{19.35}$), 75% recommended dose + *Anabaena* sp (CR1) + *Providencia* sp (PR3) and 75% recommended dose + *Anabaena-Pseudomonas* (An-Ps) biofilmed formulation with and without Zn which make total eight options along with one absolute control ($N_0P_0Zn_0$). In order to have same crop growth duration in all three methods of cultivation, sowing was done on same date. For ZT, direct sowing of seed (seed rate 20% higher than recommended) was done with spacing of 20 cm between two rows using seed-drill. In SWI, 1-2 seeds were dibbled per spot at a spacing of 20 cm × 20 cm. In conventional wheat (CW) sowing was done with seed drill, seed rate 100 kg/ha with a spacing of 22.5 cm between two rows. For application of inculcations, a thick paste of respective culture was made in carboxy methyl cellulose (CMC) and seeds were treated with this thick pest and dried in shade for half an hour just before sowing. Nitrogen was applied in three equal split at sowing, at 30 days after sowing (DAS) and 60 DAS. Potassium (K) was applied uniformly at the rate of 49.8 kg K/ha and in case of Zn soil application of 5 kg Zn/ha through Zn sulphate heptahydrate was followed in both seasons of wheat crop. Application of all doses of P, K and Zn was done at the time of sowing as per treatment details. For weed management hand weeding was done twice in all methods of cultivation. Irrigation was given as per standard recommended practices.

Plant height was measured with ordinary scale from ground surface to tallest spike from selected hill and tillers was counted from randomly selected one meter square area from each plot at harvest. For measurement of above ground shoot dry matter and air dried plant samples were further dried in a hot air oven at $60^0±2^0$C till constant weight was obtained; while for leaf area index (LAI) calculation, leaf area meter was used. Yield attributes were measured from a sample of ten spikes drawn at random from each plot at harvesting. The net plots were harvested and sun-dried in the field and then weighed to record the total biomass yield. Rice grain yield was measured after cleaning and drying. Weighing of the grain was done at 14% moisture content, while straw yield was calculated by subtracting grain yield from the total biomass yield. Gross and net returns were calculated based on grain and straw yield and their prevailing market prices and B:C ratio was calculated by dividing net returns with the cost of cultivation. All the data obtained from the experiment were statistically analysed using the F-test as per the standard statistical procedure (Gomez and Gomez 1984) and least significant difference (LSD) values ($P = 0.05$) were used to determine the significance of difference between treatment means.

RESULTS AND DISCUSSION

Biometric parameters

Plant height of wheat at harvest was significantly higher in ZT wheat (102.3 cm) than both CW and SWI. The highest height was recorded with recommended dose ($N_{120}P_{25.8}$) + Zn (102.2 cm) (Table 1). The highest tillers/m^2 was recorded in ZT (501.5) which was statistically superior to both CW and SWI. This higher tillers/m^2 in zero tillage might be due to higher seed rate used in ZT (20% higher than CW) and better germination and stand establishment in ZT as compared to both CW and SWI.

Table 1 Influence of cultivation methods and nutrient management options on plant biometric parameters and yield attributes of wheat (mean of two years data)

Treatment	Plant height at harvest (cm)	Tillers/ m^2 at harvest	Shoot dry matter accumulation at 90 DAS (g/m^2)	Leaf area index at 90 DAS (LAI)	Spikes/ m^2	Spike weight (g)	Spike length (cm)	Grains/ spike (Nos.)
Methods of cultivation								
Conventional wheat (CW)	97.9	490.3	678.5	3.87	478.1	3.47	10.3	59.9
System of wheat intensification (SWI)	97.9	490.9	678.3	3.87	477.4	3.44	10.3	60.1
Zero tillage (ZT)	102.3	501.5	692.9	3.94	488.5	3.69	10.4	63.1
SEm±	0.45	0.84	1.46	0.008	0.29	0.013	0.02	0.17
CD (P = 0.05)	1.75	3.30	5.72	0.030	1.13	0.050	0.08	0.68
Nutrient management options								
Control ($N_0P_0Zn_0$)	91.5	450.6	601.0	3.41	434.1	2.92	8.6	46.7
Recommended dose ($N_{120}P_{25.8}$)	101.2	500.5	697.7	3.98	488.0	3.63	10.6	62.9
Recommended dose ($N_{120}P_{25.8}$) + Zn*	102.2	509.4	716.8	4.05	495.6	3.81	10.7	64.9
75% recommended dose ($N_{90}P_{19.35}$)	97.4	486.6	655.3	3.79	475.9	3.39	10.3	59.9
75% recommended dose ($N_{90}P_{19.35}$) + Zn	97.6	491.9	663.3	3.84	480.5	3.42	10.3	61.1
75% recommended dose ($N_{90}P_{19.35}$) + CR1 + PR3	100.7	497.7	694.2	3.96	485.1	3.55	10.6	62.4
75% recommended dose ($N_{90}P_{19.35}$) + CR1 + PR3+ Zn	101.4	506.1	711.8	4.03	492.9	3.75	10.7	64.3
75% recommended dose ($N_{90}P_{19.35}$) + An-Ps biofilmed formulation	100.7	498.5	695.7	3.96	486.3	3.56	10.6	62.5
75% recommended dose ($N_{90}P_{19.35}$) + An-Ps biofilmed formulation + Zn	101.7	506.9	713.3	4.03	493.5	3.77	10.7	64.4
SEm±	0.79	1.52	2.58	0.015	0.76	0.037	0.04	0.35
CD (P = 0.05)	2.24	4.31	7.34	0.042	2.16	0.104	0.11	0.99

*Zn= Soil applied 5 kg Zn/ha through zinc sulphate heptahydrate

Contribution of ZT to increase in tillers/m^2 as compared to CW and SWI was 10.2 and 10.6 tillers/m^2, respectively. Higher plant height and number of plants/m^2 at harvest in ZT as compared to conventional drill sown wheat was also reported by Singh *et al*. (2014) even at same seed rate in both methods of cultivation. Among nutrient management options, recommended dose ($N_{120}P_{25.8}$) + Zn (509.4) recorded the highest tillers/m^2 which remained on a par with two treatments, viz. 75% recommended dose ($N_{90}P_{19.35}$) + CR1 + PR3 + Zn (506.1) and 75% recommended dose ($N_{90}P_{19.35}$) + An-Ps biofilmed formulation + Zn (506.9). These three treatments were statistically superior to all other treatments. Barik and Goswami (2003) also observed that effective tillers/m^2 in two treatments, viz. recommended dose of nitrogen (RDN) and 75% RDN + *Azotobacter* remained on a par with each other.

Contribution of Zn fertilization to increase in tillers/m^2 was 8.9 tillers/m^2 with recommended dose ($N_{120}P_{25.8}$), 8.4 tillers/m^2 with 75% recommended dose ($N_{90}P_{19.35}$) + CR1 + PR3 and 8.4 tillers/m^2 with 75% recommended dose ($N_{90}P_{19.35}$) + An-Ps biofilmed formulation. Increase in tillers due to application of Zn was also reported by Shivay *et al*. (2008). Contribution of microbial inoculation of CR1 + PR3 to increase in tillers/m^2 was 14.2 and 11.1 with and without Zn as compared to treatment having same amount of chemical fertilizer application. In case of An-Ps biofilmed formulation increase in tillers/m^2 was 15.0 and 11.9 with and without Zn. Kachroo and Razdan (2006) also found that, inoculation of *Azotobacter* and *Azospirillum* separately and in combination had significantly higher tillers/m^2 at harvest than uninoculated treatments.

Shoot dry matter production and leaf area index (LAI) at 90 DAS in ZT was statistically superior to both CW and SWI, while CW and SWI remained on a par with each other. This higher dry matter was mainly due to higher tillers/m^2 in ZT than CW and SWI. Trend in dry matter production among nutrient management options was similar as that of tillers/m^2 which also indicated that increase in tillers/m^2 contribute to increase in dry matter production. Contribution of microbial inoculation of CR1 + PR3 to increase in dry matter was 48.5 and 38.9 g/m^2 with and without Zn and same for An-Ps biofilmed formulation was 50.0 and 40.4 g/m^2 with and without Zn, respectively as compared to treatment having same amount of fertilizer application. Significantly higher dry matter at harvest was also recorded in An-Ps biofilm applied treatment in a study conducted by Swarnalakshmi *et al*. (2013). Improvement in shoot dry matter (Kachroo and Razdan 2006, Singh *et al*. 2013) and LAI (Barik and Goswami 2003) due to inoculation of *Azotobacter* and *Azospirillum* separately and in combination was also reported. Improvement in dry matter of wheat with inoculation of three strains of cyanobacteria (*Calothrix ghosei, Hapalosiphon intricatus* and *Nostoc* sp.) along with 40 kg N/ha in green house study was reported by Karthikeyan *et al*. (2007). Contribution of Zn fertilization to improvement in shoot dry matter accumulation was highest with recommended dose ($N_{120}P_{60}$) (19.1 g/m^2) and the lowest in 75% recommended dose ($N_{90}P_{45}$) (8.0 g/m^2). This indicates that, optimum fertilization of nitrogen and phosphorus was needed to be applied for achieving maximum benefits of Zn fertilization.

Yield attributing characters

Yield attributing characters of wheat including spikes/m^2, spike weight, spike length and grains/spike was found statistically superior in ZT than both CW and SWI which was due to better wheat growth in ZT (Table 1). Among nutrient management options, recommended dose ($N_{120}P_{60}$) + Zn recorded the highest value for all yield attributing characters and stand statistically identical with 75% recommended dose ($N_{90}P_{19.35}$) + CR1 + PR3 + Zn and 75% recommended dose ($N_{90}P_{19.35}$) + An-Ps biofilmed formulation + Zn. These three above-mentioned treatments had statistically superior to rest of treatments. Contribution of microbial inoculation of CR1 + PR3 to increase in spike weight was 0.33 and 0.16 g/spike with and without Zn and same for An-Ps biofilmed formulation was 0.35 and 0.17 g/spike with and without Zn as compared to treatment having same amount of chemical fertilizer application. This indicates that, microbial inoculation contributes higher to spike weight with Zn fertilization. Singh and Rai (2002) also reported significantly higher spikes/m^2 and grains/spike in *Pseudomonas striata* and *Aspergillus awamori* inoculated treatment than uninoculated treatment in wheat. Contribution of Zn fertilization to increase in spike weight was highest in 75% recommended dose ($N_{90}P_{19.35}$) + An-Ps biofilmed formulation + Zn (0.21 g/spike) which was followed by treatment containing 75% recommended dose ($N_{90}P_{19.35}$) + CR1 + PR3 + Zn (0.20 g/spike). Increase in grains/spike due to An-Ps biofilmed formulation was 2.6 and 3.3 grains/spike with and without Zn as compared to treatments having same quantity of fertilizer application. Similarly for CR1 + PR3 consortia it was 2.5 and 3.2 grains/spike with and without Zn. Increase in grains/spike due to Zn fertilization was 2, 1.9 and 1.9 grains/spike in treatment having recommended dose of N and P, An-Ps biofilmed formulation and CR1 + PR3 consortia, respectively.

Grain, straw, biological yield and harvest index

Contribution of ZT to increase in grain and straw yield was 0.230 and 0.340 tonne/ha and 0.250 and 0.370 tonne/ha as compared to CW and SWI, respectively (Table 2). Higher yield in ZT over CW wheat was also reported by Tripathi *et al*. (2013). Increase in grain and straw yields due to Zn fertilization was 0.220 and 0.290 tonnes/ha with 75% recommended dose ($N_{90}P_{19.35}$) + CR1 + PR3, 0.190 and 0.260 tonnes/ha within 75% recommended dose ($N_{90}P_{19.35}$) + An-Ps biofilmed formulation and 0.180 and 0.240 tonne/ha with recommended dose ($N_{120}P_{25.8}$). Lowest increase in grain and straw yield due to Zn fertilization was recorded with 75% recommended dose ($N_{90}P_{19.35}$) (0.050 and 0.080 tonne/ha). Contribution of An-Ps biofilmed formulation to increase in grain and straw yield was 0.370 and 0.490 tonne/ha with Zn application, respectively; while without Zn application, increase in grain and straw yields was and 0.230 and 0.310 tonne/ha, respectively. In case of CR1 + PR3 consortia increase in grain and straw yield was 0.360 and 0.480 tonne/ha with Zn application and 0.190 and 0.270 tonne/ha without Zn application, respectively. Biological yield followed similar trend as that of grain and straw yields. Increase in grain yield of wheat due to combined inoculation of *Providencia* sp. (PW5) and *Anabaena* sp. (CW1) was observed in a study conducted by Rana *et al*. (2012). Interaction effect between cultivation methods and nutrient management options was found significant on grain yield of wheat (Table 3). Performances of all treatments were superior in ZT wheat as compared to same treatment applied in CW and SWI. The 1000–grain weight and harvest index was not affected due to cultivation methods; while among nutrient management treatments, all treatments were identical in both 1000–grain weight and harvest index except control which remained inferior to all other treatments.

Cost of cultivation, gross returns, net returns and B:C ratio

Saving in cost of cultivation due to ZT wheat was 2,510 ₹/ha and 1410 ₹/ha as compared to CW and SWI method, respectively. Application of microbial inoculation saved 340 ₹/ha over treatment containing same quantity of fertilizer application due to reduced quantity of fertilizer application. Gross and net returns was higher in ZT wheat by 4130 and 6470 ₹/ha as compared to CW, respectively; while increase in gross and net returns in ZT was 4448 and 5,880 ₹/ha as compared to SWI. Increase in net returns was higher than gross returns which was mainly because gross returns were affected due to increase in yield while net returns were affected due to increase in yield as well as decrease in cost of cultivation in ZT. B:C ratio in ZT wheat (2.06) was higher than both CW (1.66) and SWI method (1.74). Reducing cost of cultivation and increasing net returns and B:C ratio in ZT wheat was reported by Tripathi *et al*. (2013) and Singh *et al*. (2014).

Among nutrient management treatments, increase in gross and net returns due to Zn fertilization was 3250 and 2430 ₹/ha with recommended dose ($N_{120}P_{25.8}$), 3 280 and 2450 ₹/ha with 75% recommended dose ($N_{90}P_{19.35}$) + An-Ps biofilmed formulation and 3690 and 2870 ₹/ha with 75% recommended dose ($N_{90}P_{19.35}$) + CR1 + PR3. The lowest increase in gross and net returns due to Zn application was recorded in 75% recommended dose ($N_{90}P_{19.35}$) (910 and 580 ₹/ha). This indicates that, to achieve maximum return

Table 2 Effect of cultivation methods and nutrient management options on yield and economics of wheat (mean of two year data)

Treatment	Grain yield (tonnes/ ha)	Straw yield (tonnes/ ha)	Biological yield (tonnes/ ha)	1000-grain weight (g)	Harvest index (%)	Cost of cultivation (₹ × 10^3/ ha)	Gross returns (₹ × 10^3/ ha)	Net returns (₹ × 10^3/ ha)	B:C ratio
Methods of cultivation									
Conventional wheat (CW)	4.33	6.24	10.56	43.9	41.0	28.68	75.90	47.39	1.66
System of wheat intensification (SWI)	4.31	6.21	10.52	43.9	41.0	27.58	75.55	47.98	1.74
Zero tillage (ZT)	4.56	6.58	11.14	43.9	41.0	26.17	80.03	53.86	2.06
SEm±	0.021	0.032	0.052	0.02	0.07		0.37	0.37	0.01
CD (P = 0.05)	0.082	0.124	0.206	NS	NS		1.45	1.45	0.06
Nutrient management options									
Control ($N_0P_0Zn_0$)	3.75	5.65	9.40	43.0	39.9	25.01	66.34	41.34	1.67
Recommended dose ($N_{120}P_{25.8}$)	4.50	6.45	10.94	44.0	41.1	27.67	78.75	51.08	1.86
Recommended dose ($N_{120}P_{25.8}$) + Zn*	4.68	6.69	11.38	44.1	41.2	28.49	82.00	53.51	1.89
75% recommended dose ($N_{90}P_{19.35}$)	4.23	6.08	10.31	44.0	41.0	27.05	74.11	47.06	1.75
75% recommended dose ($N_{90}P_{19.35}$) + Zn	4.28	6.16	10.43	44.0	41.0	27.88	75.02	47.64	1.75
75% recommended dose ($N_{90}P_{19.35}$) + CR1 + PR3	4.42	6.35	10.77	44.0	41.1	27.39	77.53	50.14	1.84
75% recommended dose ($N_{90}P_{19.35}$) + CR1 + PR3 + Zn	4.64	6.64	11.28	44.1	41.1	28.22	81.22	53.01	1.89
75% recommended dose ($N_{90}P_{19.35}$) + An-Ps biofilmed formulation	4.46	6.39	10.85	44.0	41.1	27.39	78.09	50.71	1.86
75% recommended dose ($N_{90}P_{19.35}$) + *An-Ps* biofilmed formulation + Zn	4.65	6.65	11.30	44.1	41.1	28.22	81.37	53.16	1.89
SEm±	0.040	0.060	0.100	0.03	0.11		0.71	0.71	0.03
CD (P = 0.05)	0.114	0.171	0.285	0.09	0.32		2.01	2.01	0.08

*Zn= Soil applied 5 kg Zn/ha through zinc sulphate heptahydrate

Table 3 Interaction effect between cultivation methods and nutrient management options on grain yield (tonnes/ha) in wheat (mean of two year)

Treatment	T1	T2	T3	T4	T5	T6	T7	T8	T9	Mean
Conventional wheat (CW)	3.58	4.43	4.63	4.17	4.21	4.37	4.58	4.40	4.58	4.33
System of wheat intensification (SWI)	3.70	4.41	4.58	4.13	4.20	4.32	4.54	4.36	4.54	4.31
Zero tillage (ZT)	3.98	4.64	4.84	4.38	4.43	4.58	4.79	4.61	4.82	4.56
Mean	3.75	4.50	4.68	4.23	4.28	4.42	4.64	4.46	4.65	
		SEm±			0.070					
		CD (P = 0.05)			0.198					

T1: Control ($N_0P_0Zn_0$); T2: Recommended dose ($N_{120}P_{25.8}$); T3: Recommended dose ($N_{120}P_{25.8}$) + Zn*; T4: 75% recommended dose ($N_{90}P_{19.35}$); T5: 75% recommended dose ($N_{90}P_{19.35}$) + Zn; T6: 75% recommended dose ($N_{90}P_{19.35}$) + *Anabaena sp* (CR1) + *Providencia sp* (PR3); T7: 75% recommended dose ($N_{90}P_{19.35}$) + *Anabaena sp* (CR1) + *Providencia sp* (PR3) + Zn; T8: 75% recommended dose ($N_{90}P_{19.35}$) + *Anabaena- Pseudomonas* (AS-Ps) biofilmed formulation; T9: 75% recommended dose ($N_{90}P_{19.35}$) + *Anabaena- Pseudomonas* (AS-Ps) biofilmed formulation + Zn.

from Zn fertilization, application of recommended dose of nitrogen and phosphorus was needed. Microbial inoculation of An-Ps biofilmed formulation increase gross and net returns by 6 350 and 5 520 ₹/ha with Zn application; while without Zn application increase in gross and net return was 3 980 and 3 650 ₹/ha, respectively. Similarly consortia of CR1 + PR3 increase gross and net returns by 6 200 and 5 370 ₹/ha with Zn application. Contribution of CR1 + PR3 consortia

Table 4 Influence of cultivation methods and nutrient management options on total plant nutrient uptake and soil microbial biomass carbon content (mean of two years data)

Treatment	Nitrogen uptake (kg/ha)	Phosphorus uptake (kg/ha)	Zinc uptake (g/ha)	Microbial biomass carbon (µg/g soil)	
				60 DAS	90 DAS
Methods of cultivation					
Conventional wheat (CW)	129.4	17.2	252.7	174.3	337.8
System of wheat intensification (SWI)	128.8	17.2	253.8	174.9	338.8
Zero tillage (ZT)	156.6	18.6	318.0	180.4	342.7
SEm±	1.18	0.09	0.80	0.47	0.54
CD (P = 0.05)	4.65	0.34	3.13	1.86	2.11
Nutrient management options					
Control ($N_0P_0Zn_0$)	85.0	14.5	150.1	97.1	183.7
Recommended dose ($N_{120}P_{25.8}$)	145.1	18.2	289.2	177.7	349.3
Recommended dose ($N_{120}P_{25.8}$) + Zn*	166.1	19.0	327.7	178.2	350.2
75 % recommended dose ($N_{90}P_{19.35}$)	120.6	16.9	246.9	176.3	347.8
75 % recommended dose ($N_{90}P_{19.35}$) + Zn	123.7	17.1	252.3	176.9	348.5
75 % recommended dose ($N_{90}P_{19.35}$) + CR1 + PR3	138.8	17.8	280.0	193.2	367.1
75 % recommended dose ($N_{90}P_{19.35}$) + CR1 + PR3+ Zn	161.2	18.8	319.5	194.2	367.8
75 % recommended dose ($N_{90}P_{19.35}$) + An-Ps biofilmed formulation	140.3	18.0	284.0	197.2	371.2
75 % recommended dose ($N_{90}P_{19.35}$) + An-Ps biofilmed formulation + Zn	163.5	18.8	323.8	197.9	372.0
SEm±	2.88	0.14	1.47	0.85	1.12
CD (P = 0.05)	8.19	0.40	4.19	2.43	3.18

*Zn= Soil applied 5 kg Zn/ha through zinc sulphate heptahydrate

to increase gross and net returns without Zn application was 3 420 and 3 080 ₹/ha, respectively.

Total nutrient uptake in plant and microbial biomass carbon content of soil

Total uptake of nitrogen, phosphorus and zinc was significantly higher in zero tillage method (156.6 kg/ha, 18.6 kg/ha and 318.0 g/ha, respectively) which was due to higher dry matter production and yield of wheat in zero tillage method than both conventional and SWI method (Table 4). Among nutrient management treatments, improvement in nitrogen uptake due to application of An-Ps biofilmed formulation was 39.8 and 19.7 kg/ha with and without Zn fertilization. Similarly, CR1+ PR3 consortia increase nitrogen uptake by 37.5 and 18.2 kg/ha with and without Zn fertilization as compared to the treatment containing same quantity of fertilizer application. Improvement in phosphorus uptake due to An-Ps biofilmed formulation and CR1 + PR3 consortia was 1.7 and 1.7 kg/ha with Zn and 1.1 and 0.9 kg/ha without Zn application. Improvement in nitrogen and phosphorus uptake due to microbial inoculation was also reported in Swarnalakshmi *et al*. (2013). Higher uptake on both nitrogen and phosphorus with application of Zn fertilizer also indicates importance of Zn fertilization in wheat. In case of total Zn uptake, all treatments having Zn application stand statistically superior to same treatment without Zn application. Increase in MBC due to application of microbial inoculants was also mentioned in Nain *et al*. (2010).

Microbial biomass carbon (MBC) at 60 and 90 DAS was significantly higher in zero tillage wheat which showed better soil condition in ZT wheat for microbial growth. Microbial biomass carbon was significantly higher in all inoculated treatments than uninoculated treatment. This indicates that, applied microbial inoculations contribute significantly to MBC than soil inherent microbial population.

For the forgoing discussion it can be concluded that, microbial inoculation and Zn fertilization has quantifiable contribution to growth and yield of wheat, which was also reflected in gross and net returns of wheat. Involvement of An-Ps biofilmed formulation or CR1 + PR3 consortia with 75% recommended dose ($N_{90}P_{19.35}$) and Zn found one of the good nutrient management options for wheat. Zero tillage wheat gave higher yield and had a least cost of cultivation among methods studied hence can be a good option for wheat cultivation.

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