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Improved Nutrient Management Practices for Enhancing Productivity and Profitability of Wheat under Mid-Indo-Gangetic Plains of India

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Abstract: Two-year field experiments were conducted to study the effect of different levels of inorganic fertilizers, farmyard manure (FYM), and bio-inoculants on wheat productivity and profitability. Results specified that judicious application of inorganic fertilizers, FYM, and bio-inoculants significantly increased the productivity and profitability of wheat. Data suggested that the aggregate levels of fertilizer up to 100% NPK ha^{-1} resulted in significant increases in all growth attributes, grain yield (+206%), straw yield (+177%), and harvest index (+7%) as compared to control. Meanwhile, plots with the application of 10 t ha^{-1} FYM significantly ($p < 0.05$) increased grain yield (+26%) and straw yield (+22%) as compared to the control. Similarly, significant enhancement in grain and straw yields was observed with the application of PGPR + VAM over no-inoculation. Results showed that the significantly higher grain and straw yield attained by application of 75% NPK fertilizer + 10 t ha^{-1} FYM was at par with the application of 100% NPK fertilizer alone. Further, net returns (profitability) and B:C ratio (2.37) were significantly higher with fertilization with 75% NPK + 10 t ha^{-1} FYM along with PGPR + VAM as compared to 100% NPK alone. Overall, it can be concluded that the combination of 75% NPK and 10 t ha^{-1} FYM along with PGPR + VAM represented the optimum for net return and B:C ratio and reduced (25%) dose of NPK as compared to the rest of the treatment combinations.

Keywords: fertilizer levels; FYM; bio-inoculants; nutrient uptake; wheat

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1. Introduction

As the cultivable land area is decreasing with time, increasing cropping intensity with inadequate and imbalanced use of agrochemicals and with slight or negligible use of organic manure (OM) has caused severe land degradation resulting in stagnated or even declined crop productivity in South Asia (i.e., India, Nepal, Bangladesh, Afghanistan, Bhutan, Maldives, Nepal, Pakistan, and Sri Lanka) and some other countries [1–5]. Inorganic fertilizers are important sources of plant nutrients for increasing sustainable food production to feed the rapidly growing global population [6,7]. Fertilizers such as urea (for N), diammonium phosphate (for N and P), and muriate of potash (for K) provide only primary nutrients, and excessive use of agrochemicals leads to devastating environmental impacts [8]. To get higher benefits in terms of crop yield and nutrient use efficiency (fertilizer savings), integration of farmyard manure (FYM) and composite plant growth-promoting rhizobacteria (PGPR)-based inoculation technology should be utilized along with appropriate levels of inorganic fertilizers [9]. Integrated use of inorganic fertilizers and farmyard manure (FYM) or compost provides N, P, K [10] and also acts as an excellent supplier of micronutrients to plant and soil [11,12], and resists the occurrence of multiple nutrient deficiencies [13]. FYM was used by farmers traditionally as an excellent source of various nutrients for growing different agricultural crops [14]; however, regular application of FYM is still lacking. PGPR is the group of soil bacteria that habituate in rhizosphere soil and around/on the root surface, and they improve plant growth and development by direct and indirect mechanisms and environmental sustainability [15–17]. Efficient bio-inoculants can fix atmospheric nitrogen (i.e., nitrogen fixers), solubilize and mineralize the fixed/residual phosphorus (i.e., phosphorous solubilizing and mobilizing microbes) and potassium solubilization/mobilizations (i.e., potassium solubilizing and mobilizing microbes) and enhance their availability, and improve overall nutrient use efficiency [18–21]. The function of PGPR is affected by the bacterium, plant species/genotype, soil condition and type, inoculant density, strains, and environmental conditions [20,22–24]. The use of efficient PGPR as bio-fertilizers and bio-control agents is considered an appropriate substitute for minimizing the use of agrochemicals in agricultural productivity [25–29].

Integrated nutrient management (INM) is a flexible tactic for the judicious application of inorganic fertilizers and organic manures to maximize the efficiency of production and farmers' profits [30,31]. Recently, several researchers reported that conjunctive use of inorganic fertilizers and organic manures (FYM, compost, vermicompost, etc.) with bio-inoculants is becoming a promising practice for achieving sustainable crop production and sustaining soil health [32–35]. Apart from this, INM also has a good residual effect on subsequent crops [36,37].

The aim of this study was (i) to investigate fertilization treatment combinations along with FYM and bio-inoculants on growth and yield attributes of wheat productivity, (ii) to access the impact of different nutrient management practices on profitability, and (iii) to identify the best nutrient management practices in the combination of inorganic fertilizers, organic manure, and bioinoculants. Thus, we can maintain a sustainable food production system by adopting various improved management practices (IMP) and best management practices (BMP) such as integrated plant nutrition system (IPNS), use of efficient microbes, and organic manures. These are sustainable options to feed the global population without deteriorating the available resources. Some fundamental questions remain unexplored, such as (i) how integrated nutrient management options could influence wheat productivity? (ii) does organic manure application affect crop productivity? (iii) does the use of plant growth-promoting microbes options alleviate the adverse effects of climatic change? (iv) how does the relationship between different levels of fertility, organic manure, and combinations of microbes influence wheat productivity and profitability? Therefore, the effects of best management practices were tested in order to appraise their impact on productivity and profitability. Based on the literature discussed above and the questions raised here, we hypothesized that integrated nutrient management could be a crucial factor in improving productivity. Consequently, we intend to elucidate a two-year BMP field experiment's effects (i) to quantify the BMP options on wheat productivity and (ii) to assess the best nutrient supply options and profitability and relationship compared to different nutrient supply options with a broad view to assess optimization of nutrient management practices in order to maintain wheat productivity.

2. Materials and Methods

2.1. Experimental Site

The present investigation was conducted by establishing a two-year field experiment during the Rabi seasons (2009–10 and 2010–11) on sandy loam soils at the Agricultural Research Farm of the Institute of Agricultural Sciences (IAS), Banaras Hindu University (BHU), located at Varanasi (25°18′ N latitude, 83°30′ E longitude, 128.93 m altitude), Uttar

Pradesh, India (Figure 1). The initial soil properties of experimental soils were sandy loam in texture having 0.38% organic carbon, pH 7.3, cation exchange capacity [18.70 Cmol (P^{+}) kg^{-1} soil], 207.87, 17.9, and 227.0 kg ha^{-1} available N, P, and K, respectively.

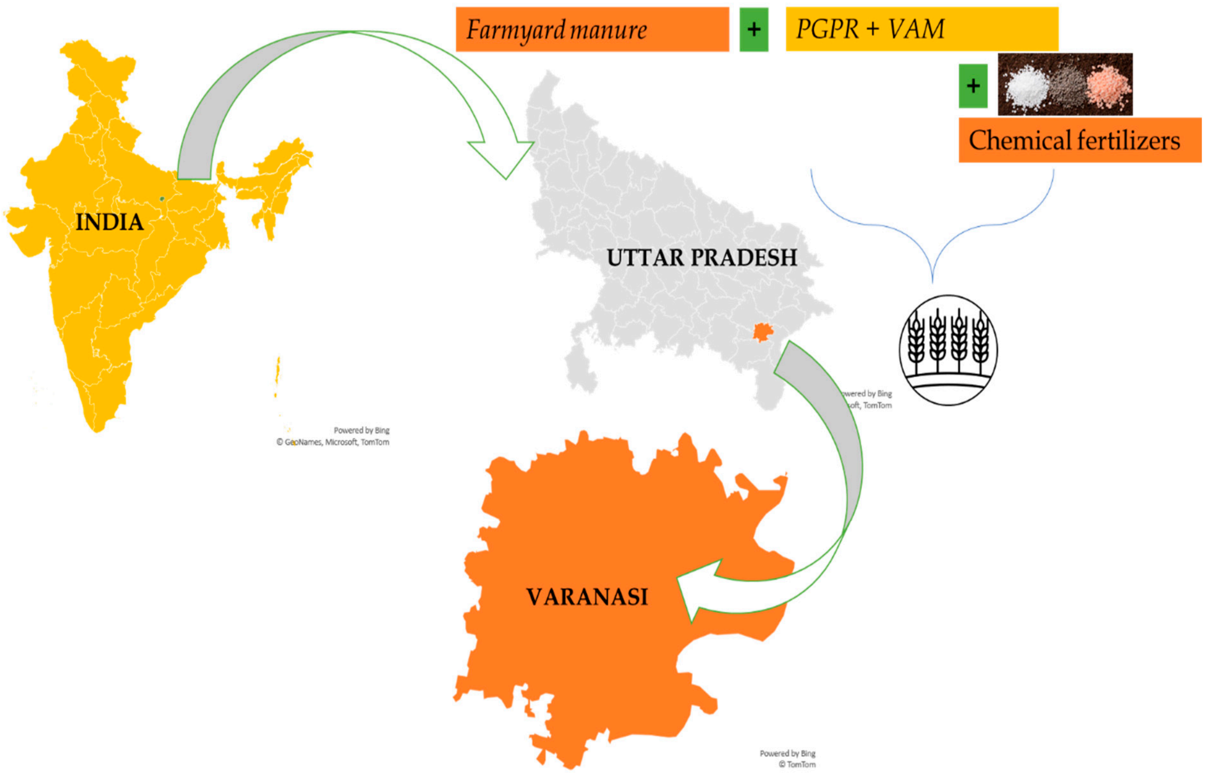

Figure 1. Experimental site for the two-year field experiment.

The physical properties of the experimental soil were also analyzed by adopting standard procedures. The initial soil has a 1.41 Mg M^{-3} bulk density, 2.62 Mg M^{-3} particle density, and 45.7% water-holding capacity. The biological properties of the experimental soil showed dehydrogenase activity of 143.2 μg TPF g^{-1} soil 24 h^{-1}, phosphatase activity of 33.6 μg PNP g^{-1} soil h^{-1}, soil microbial biomass carbon of 170 mg kg^{-1} soil, bacterial population of 20 cfu × 10^5 g^{-1} soil and fungal population of 9 cfu × 10^4 g^{-1} soil.

2.2. Climatic Conditions

The average annual rainfall in the area is 1080.4 mm, most of which is received during June to September, and the annual potential evapotranspiration (PET) is 110 mm. The mean weekly meteorological data of the cropping period were collected from the Agro-Meteorological Observatory of the Agricultural Research Farm, IAS, BHU, Varanasi. The maximum temperature ranged from 15.1 to 43.0 °C and 14.2 to 38.2 °C and minimum temperatures ranged from 7.1 to 25.2 °C (Figure 2) and 4.8 to 22.5 °C (Figure 3) during 2009–10, 2010–11, respectively.

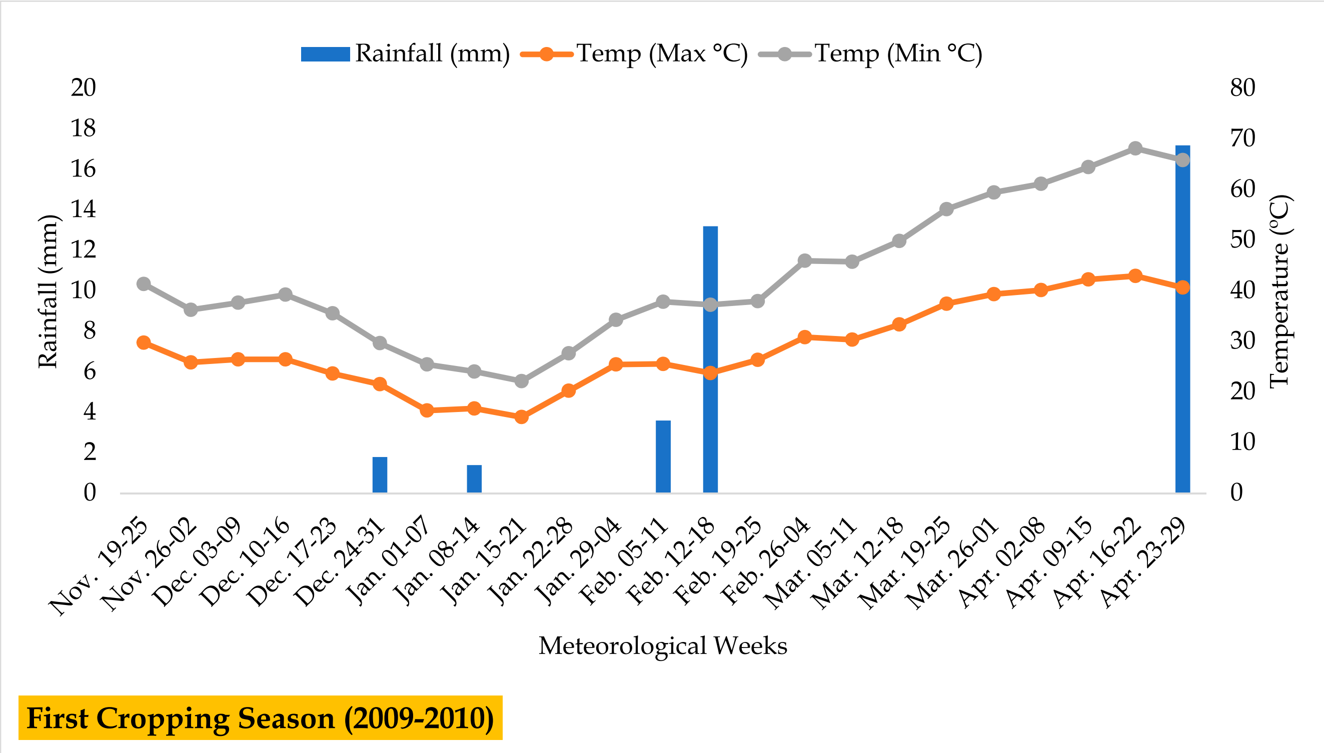

Figure 2. Climatic conditions during the first cropping season (Rabi 2009–2010).

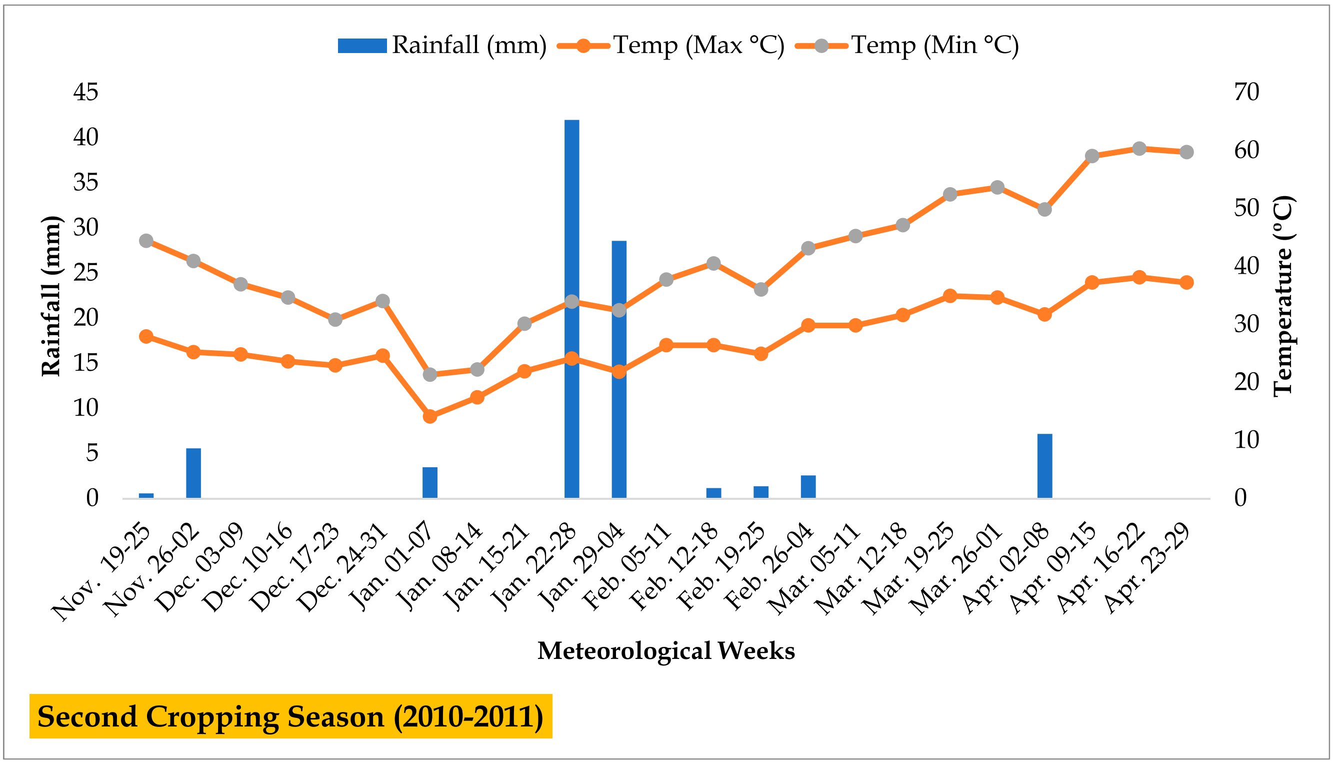

Figure 3. Climatic conditions during the second cropping season (Rabi 2010–2011).

2.3. Experimental Design and Treatment Details

The experiment was laid out in a double split–split plot design with three replications (Figure 4) in each treatment.

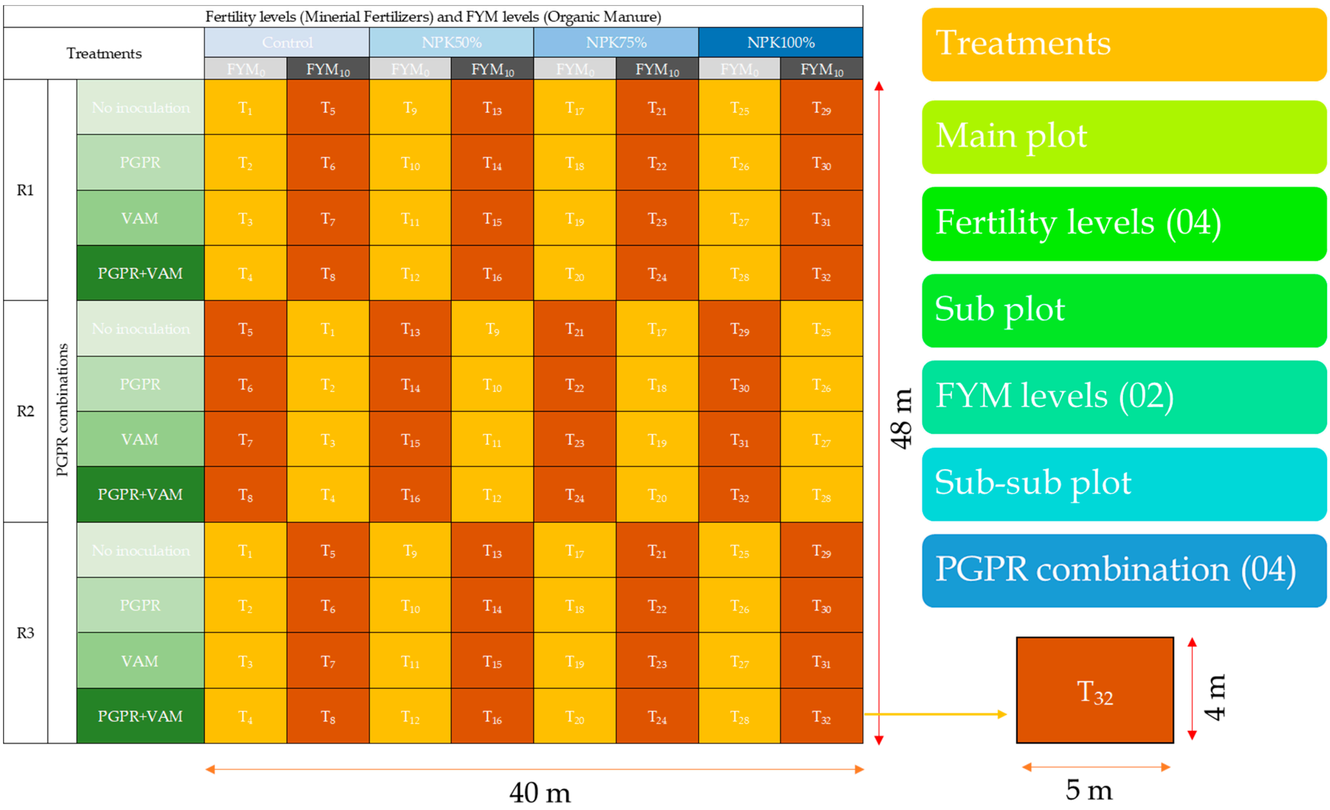

Figure 4. Two-year field experimental layout with treatment details (total number of plots: 96).

Four levels of inorganic fertilizer (i.e., 0%, 50%, 75%, and 100% NPK) were assigned in the main plots, two levels of organic manure (i.e., without FYM and with 10 t ha^{-1} FYM) in the sub plots, and four sources of bio-fertilizers (i.e., no-inoculation, composite plant growth promoting rhizobacteria [*Azotobacter chroococcum* W5 + *Azospirillum brasilence* Cd + *Bacillus megaterium* BHUPSB14 + *Pseudomonas fluorescens* BHUPSB06], vesicular arbuscular mycorrhiza [VAM], and composite PGPR+VAM [*Glomus fasciculatum*] inoculum in the sub-sub plots) (Figure 4).

2.4. Microbial Inoculants

The mass cultures of these inoculums (i.e., *Azotobacter*, *Azospirillum*, and mycorrhiza, and pure cultures of *B. megaterium* and *P. fluorescens*) were collected from the Department of Microbiology, ICAR-Indian Agricultural Research Institute (ICAR-IARI), New Delhi, India and the Department of Soil Science and Agricultural Chemistry (SSAC), IAS, BHU, Varanasi, India, respectively.

2.5. Crop Cultivar

Healthy seeds of the wheat variety HUW-234 were weighed for each plot and separately inoculated as per treatments. The recommended management practices were also followed.

2.6. Crop Management Practices

The full details of crop management starting from the land preparation, organic manure application, seeding, inorganic fertilizer application, irrigation and weed management, input use details, and harvesting details are presented in Table 1.

Table 1. The schedule of field operations followed during the crop growth period (Rabi, 2009–10 and 2010–11).

Field Operation/Activities	First Cropping Season (2009–10)	Second Cropping Season (2010–11)
Design	Double split plot design	
Layout	13-11-2009	15-11-2010
Incorporation of FYM	13-11-2009	15-11-2010
Sowing	11-12-09	08-12-10
Seed rate (kg ha^{-1})	120	
Row spacing (cm)	22.5	
Variety	HUW-234	
Fertilizer management		
Fertilizer application (RDF of N-P-K = 120-60-60 kg ha^{-1})	(a) $\frac{1}{2}$ N + Full P_2O_5 + Full K_2O (b) $\frac{1}{2}$ N as top dressing in 2 split doses after first and second irrigation.	
Water management		
(a) At Crown root initiation (CRI)	01-01-10	29-12-10
(b) Before ear initiation stage	09-02-10	06-02-11
(c) At grain filling stage	11-03-10	08-03-11
Weed management		
Weeding type	Manual weeding	
Weeding date	15-01-10	12-01-11
Harvesting	15-04-10	07-04-11
Threshing and winnowing	26-04-2010	20-04-2011

2.7. Statistical Analysis

The generated pool data were processed for analysis of variance (ANOVA) of split–split plot design analysis with the help of Microsoft Excel. Pooled analysis of the data for two years was carried out using the standard analysis of variance suggested by Gomez and Gomez [38].

3. Results and Discussion

3.1. Effect on Growth Characters

Results revealed that different fertilizer doses, FYM levels, and bio-inoculants individually had a significant effect on the growth characteristics of wheat, along with the fertilizer doses × FYM level interaction. Plant height and number of tillers at harvest of the wheat were significantly enhanced with successive levels of inorganic fertilizers (Table 2). Significantly ($p < 0.05$) higher plant height and number of tillers, to the tune of 102.04 cm and 104.71, respectively at harvest, were recorded with treatment receiving 100% NPK, while the lowest was in the control (73.75 and 75.13).

Table 2. Effect of various treatments on the growth, yield attributes, and yield of wheat (mean of two years).

Treatments	Plant Height (cm)	Number of Tillers per Meter Row	Number of Ear Head per Meter Row	No. of Grain per Ear	Ear Head Length (cm)	Test Weight (g)	Grain Yield (q ha^{-1})	Straw Yield (q ha^{-1})	Harvest Index (%)
Fertility levels									
Control	73.75	75.13	63.67	30.63	6.89	35.26	16.40	25.52	39.04
$NPK_{50\%}$	80.57	90.92	75.50	35.04	7.86	39.59	26.27	40.33	39.26
$NPK_{75\%}$	97.46	101.42	85.38	38.13	8.32	41.59	41.03	59.17	40.84
$NPK_{100\%}$	102.04	104.71	95.71	40.71	8.82	42.33	50.22	70.68	41.55
SE m±	0.369	0.310	0.591	0.33	0.042	0.048	0.164	0.421	0.237
CD 5%	1.274	1.071	2.038	1.136	0.146	0.166	0.565	1.453	0.818
FYM levels (t ha^{-1})									
FYM_0	85.27	89.44	78.00	34.98	7.70	39.01	29.58	44.18	39.56
FYM_{10}	91.64	96.65	82.13	37.27	8.25	40.37	37.37	53.67	40.79
SE m±	0.223	0.289	0.406	0.195	0.029	0.050	0.132	0.169	0.110
CD 5%	0.726	0.940	1.321	0.635	0.093	0.163	0.431	0.551	0.359
PGPR									
No-inoculation	86.90	87.92	75.75	34.54	7.73	39.57	31.62	46.89	39.87
PGPR	88.29	94.58	80.33	36.08	7.98	39.74	33.81	48.96	40.38
VAM	88.74	92.54	80.42	36.21	8.01	39.64	33.16	48.46	40.15
PGPR + VAM	89.88	97.13	83.75	37.67	8.16	39.83	35.31	51.40	40.29
SE m±	0.355	0.267	0.586	0.197	0.037	0.083	0.147	0.158	0.118
CD 5%	1.010	0.760	1.666	0.559	0.106	NS	0.417	0.450	0.334

The growth attributes i.e., increase in wheat plant height due to the recommended dose of fertilizer (RDF), might be due to the high availability of nutrients, and, therefore, significant plant growth was obtained. Parallel findings were also reported by Malghani et al. [39], Abd El-Razek and El-Sheshtawy [40], and Lavakush et al. [41]. Plots applied with 10 t ha^{-1} FYM recorded the significant ($p < 0.05$) highest value of plant height (91.6 cm) which was 6.3 cm more than that recorded with control. A significant ($p < 0.05$) number of tillers (97 m^{-1}), which was ~7% higher than the control, was recorded with the incorporation of 10 t ha^{-1} FYM. Agamy et al. [42], Devi et al. [43], and Puli et al. [44] also stated that the incorporation of FYM in soil supplies continuously various nutrients to crops, and therefore, plant growth attributes could be increased. The increase in the growth characters of wheat with the application of FYM was also reported by many researchers [45–47]. Plant height and number of tillers at harvest were significantly increased with the application of bio-inoculants over no-inoculation (Table 2). PGPR have the ability to secrete various phytohormones which enhance root growth, nutrient availability, and absorption of nutrients in the rhizosphere soil [9,48]. Similarly, wheat plant height also increased through inoculation with different strains of beneficial bacteria [49]. These results are akin to the findings of other researchers [42,50].

3.2. Effect on Yield Attributes

Data showed that doses of fertilizer, FYM level, and bio-inoculants applied individually had a significant ($p < 0.05$) effect on yield attributes and grain yield of wheat each year, along with the fertilizer levels × FYM level interaction. Plots with the use of 100% NPK produced more ~50% the number of ear heads per meter row, ~32% the number of grains per ear; ~28% ear head length, and ~21% test weight as compared to control. The higher level of NPK improved the soil fertility and created congenial conditions for the overall development of the plants, and thus improved the yield attributes. These results are in conformity with those reported by other researchers [30,51].

All yield attributes of wheat were also increased by FYM application as compared to no FYM application. The mean values of number of ear head/meter row, number of grain per ear, ear head length, test weight, and harvest index were 5.29%, 6.55%, 7.14%, 3.49%, and 3.11% higher, respectively with the application of 10 t ha^{-1} FYM than with no FYM treatment. The higher yield attributes recorded in FYM treated plot might be due to the rapid mineralization of the manure. The results are in conformity with those of Agamy et al. [42] and Parewa et al. [52].

All yield attributes were significantly increased with bio-inoculation over no-inoculation except test weight (Table 2). The maximum values were obtained due to combined inoculations of PGPR + *Glomus fasciculatum* (VAM) followed by PGPR and *Glomus fasciculatum* (VAM) treatments, which were significantly higher over control (no-inoculation). The significant increase in yield attributes with bio-inoculants might be due to nitrogen fixation and synthesis of biologically active substances by the beneficial bio-inoculants [53,54].

3.3. Effect on Wheat Productivity

Mean data showed that the productivity of wheat (grain and straw yield) increased significantly with successivly higher levels of fertilizer. Application of 100% NPK gave significantly ($p < 0.05$) higher grain and straw yields over that of control, 50%, and 75% NPK. The two years' mean data showed that 60.18, 150.18, and 206.22% grain yield increased with 50% NPK, 75% NPK, and 100% NPK application, respectively, over control. Application of 100% NPK contributed significantly ($p < 0.05$) to higher straw yield (~71 q ha^{-1}), registering an increase of ~177, 75, and 19% compared with those of control, 50, and 75% NPK, respectively. The productivity of wheat (grain and straw) increased with an increasing dose of fertilizer and might have supplied N, P, and K directly, which led to an increase in the leaf area index, photosynthesis, and translocation of nutrients from the soil to plant [55].

Results revealed that the plots with FYM treatments (10 t ha^{-1} FYM) had significantly ($p < 0.05$) higher grain yield 37.37 q ha^{-1} and straw yield 53.67 q ha^{-1}, respectively, as compared to FYM treatment. The increment in grain and straw yield of wheat might be due to the easy availability of all nutrients in the soil [30,56]. The grain and straw yield due to PGPR + VAM inoculation resulted in 35.31 and 51.40 q ha^{-1}, respectively (Table 2). The bio-fertilizer may fix atmospheric nitrogen and the production of plant growth regulating (PGR) hormones such as auxin indole-3-acetic acid (IAA), gibberellins (GAs), and cytokinins (CK) [16,20].

3.4. Effect on Interaction

The interaction effect of fertility levels (NPK) and FYM treatment were significant on growth, ear head length, test weight, and yield of wheat (Tables 3 and 4). Data revealed that 100% NPK along with 10 t ha^{-1} FYM yielded the highest results for all parameters. Combined application of 75% NPK along with 10 t ha^{-1} FYM gave significantly ($p < 0.05$) higher plant height, number of tillers, and test weight to the order of 3.32, 4.93, and 1.01% over 100% NPK alone, respectively. The ear head length and grain and straw yield recorded by the application of 75% NPK fertilizer + 10 t^{-1} FYM were at par with those recorded by the application of 100% NPK fertilizer alone. The beneficial effect of all nutrients present in manure in combination with fertilizer (75% NPK + 10 t ha^{-1} FYM) increased crop productivity [57,58]. The maximum number of ear head per meter row and yield were recorded in FYM along with PGPR + VAM, which was 14.85% and 35.31% higher than the control (Tables 5 and 6). Farmyard manure also acted as a source of energy for free-living heterotrophic N_2-fixing microbes [19]. The highest yield of grain (~53 q ha^{-1}) and straw (~74 q ha^{-1}) was noted with the highest dose of fertilizer, i.e., 100% NPK along with composite bio-inoculants (PGPR + *Glomus fasciculatum*). The application of all inorganics, organic fertilizer, and various bio-inoculants might supply available nutrients and increase soil health [59–61]. Enhanced yield with compost and fertilizer; bio-inoculants and fertilizer might be owing to an increased supply of plant nutrients [50,62,63].

Table 3. Interaction effect of fertility levels and FYM on growth attributes of wheat (mean data of two years).

Treatments	Plant Height				Number of Tillers per m Row				Ear Head Length (cm)			
	Control	$NPK_{50\%}$	$NPK_{75\%}$	$NPK_{100\%}$	Control	$NPK_{50\%}$	$NPK_{75\%}$	$NPK_{100\%}$	Control	$NPK_{50\%}$	$NPK_{75\%}$	$NPK_{100\%}$
FYM_0	71.99	77.46	92.45	99.18	72.33	87.50	98.17	99.75	6.42	7.68	8.28	8.41
FYM_{10}	75.51	83.68	102.47	104.90	77.92	94.33	104.67	109.67	7.36	8.04	8.36	9.23
	SEm± = 0.446, CD (5%) = 1.452				SEm± = 0.577, CD (5%) = 1.881				SEm± = 0.186, CD (5%) = 0.186			

Table 4. Interaction effect of fertility levels and FYM on the yield attributes and yield of wheat (mean data of two years).

Treatments	Test Weight (g)				Grain Yield (q ha^{-1})				Straw Yield (q ha^{-1})			
	Control	$NPK_{50\%}$	$NPK_{75\%}$	$NPK_{100\%}$	Control	$NPK_{50\%}$	$NPK_{75\%}$	$NPK_{100\%}$	Control	$NPK_{50\%}$	$NPK_{75\%}$	$NPK_{100\%}$
FYM_0	34.46	38.83	41.26	41.50	13.93	21.65	35.79	46.95	22.30	35.25	54.06	65.11
FYM_{10}	36.06	40.34	41.92	43.16	18.87	30.89	46.26	53.48	28.74	45.41	64.29	76.25
	SEm± = 0.100, CD (5%) = 0.327				SEm± = 0.264, CD (5%) = 0.861				SEm± = 0.338, CD (5%) = 1.101			

Table 5. Interaction effect of FYM and composite PGPR on the number of ear head and the straw yield of wheat (mean data of two years).

Treatments	Number of Ear Head per Meter Row				Straw Yield (q ha^{-1})			
	No-Inoculation	PGPR	VAM	PGPR + VAM	No-Inoculation	PGPR	VAM	PGPR + VAM
FYM_0	75.17	78.00	77.67	81.17	41.63	44.50	44.12	46.47
FYM_{10}	76.33	82.67	83.17	86.33	52.15	53.42	52.79	56.33
	SEm± = 0.828, CD (5%) = 2.356				SEm± = 0.224, CD (5%) = 0.637			

Table 6. Interaction effect of fertility levels and composite PGPR on the grain and straw yield (q ha^{-1}) of wheat (mean data of two years).

Treatments	Grain Yield (q ha^{-1})				Straw Yield (q ha^{-1})			
	Control	$NPK_{50\%}$	$NPK_{75\%}$	$NPK_{100\%}$	Control	$NPK_{50\%}$	$NPK_{75\%}$	$NPK_{100\%}$
No-inoculation	15.68	24.23	39.58	47.01	24.69	38.27	56.77	67.85
PGPR	16.41	26.65	41.34	50.83	25.34	40.38	59.35	70.77
VAM	16.12	26.19	40.36	49.99	25.27	39.92	58.89	69.75
PGPR + VAM	17.40	28.00	42.82	53.'04	26.79	42.76	61.69	74.37
	SEm± = 0.293, CD (5%) = 0.834				SEm± = 0.317, CD (5%) = 0.900			

3.5. *Effect on Crop Profitability*

Results revealed that economics (cost of cultivation practices, gross and net return, and B: C ratio) were influenced by different levels of NPK, FYM, and bio-inoculants (Tables 7 and 8). Among the NPK levels, the maximum gross return (₹ ~ 83969 ha^{-1}), net return (₹ ~ 60,008 ha^{-1}), and B: C ratio (2.50) were recorded with 100% NPK, which was significantly superior to the rest of the fertilizer (NPK) levels. This might be due to the high wheat yield obtained and the minimum cost of cultivation. These results are in conformity with the findings of Singh et al. [31] and Ullasa et al. [64]. Plots with 10 t ha^{-1} FYM application resulted in the highest net returns with a B:C ratio of 1.72 (Tables 7 and 8).

Table 7. Effect of fertility levels, FYM, and bio-inoculants on the economics of wheat (mean of two years).

Treatments	Gross Return (₹ ha^{-1})	Cost of Cultivation (₹ ha^{-1})	Net Return (₹ ha^{-1})	Benefit: Cost
Fertility levels				
Control	28,154.67	17,655	10,499.67	0.59
$NPK_{50\%}$	44,928.67	20,808	24,120.46	1.15
$NPK_{75\%}$	69,028.71	22,385	46,643.71	2.07
$NPK_{100\%}$	83,969.29	23,961	60,007.83	2.50
SEm±	216.21		216.24	0.010
CD 5%	746.23		746.32	0.035
FYM levels (t ha^{-1})				
FYM_0	50,225.48	19,952	30,273.08	1.43
FYM_{10}	62,815.19	22,452	40,362.75	1.72
SE m±	172.15		172.17	0.007
CD 5%	560.74		560.80	0.024
PGPR				
No inoculation	53,593.13	21,152	32,440.67	145
PGPR	56,940.58	21,212	35,728.29	1.59
VAM	55,988.58	21,192	34,796.21	1.55
PGPR + VAM	59,559.04	21,252	38,306.50	1.71
SEm±	192.74		192.72	0.008
CD 5%	548.17		548.12	0.024

Prices—wheat grain = 1250 ₹ q^{-1} (Department of Agriculture and Cooperation, Directorate of Economics and Statistics), wheat straw = 300 ₹ q^{-1} (Local Market).

Table 8. Interaction effect of fertility levels, FYM, and bio-inoculants on the economics (B:C ratio) of wheat (mean of two years).

Treatments	Control		$NPK_{50\%}$		$NPK_{75\%}$		$NPK_{100\%}$	
	FYM_0	FYM_{10}	FYM_0	FYM_{10}	FYM_0	FYM_{10}	FYM_0	FYM_{10}
No inoculation	0.39	0.65	0.80	1.19	1.73	2.19	2.27	2.46
PGPR	0.45	0.70	0.94	1.39	1.93	2.25	2.48	2.58
VAM	0.45	0.66	0.92	1.35	1.83	2.23	2.43	2.52
PGPR + VAM	0.56	0.78	1.02	1.52	2.03	2.37	2.58	2.78
SEm± = 0.024, CD (5%) = 0.068								

Significantly ($p < 0.05$) highest gross return (₹ ~ 59,559 ha^{-1}), net return (₹ ~ 38,307 ha^{-1}), and B:C ratio (1.71) were recorded with the combined application of composite PGPR + VAM, and this combination was found to be significantly better than other applications of bio-inoculants. This finding has been closely confirmed by Singh et al. [31]. Data revealed that 75% NPK + 10 t ha^{-1} FYM and PGPR + VAM gave a significantly ($p < 0.05$) higher net return (₹ 56,160 ha^{-1}) and B:C ratio (2.37). While 100% NPK contributed net return (₹ 51,605 ha^{-1}) and B:C ratio (2.31) only.

3.6. Relationship between Grain Yield and Other Components

Regression analysis was performed to show the correlations between grain yield and yield components (Figure 5a–d). Regression analysis showed that test weight (g), number of ear head per meter row, number of tillers per meter row, and number of grains were positively correlated with the grain yield (kg ha^{-1}) of wheat with correlation coefficients of 0.884, 0.961, 0.903, and 0.943, respectively (Figure 5a–d). The present study reflected a significant ($p < 0.05$) increase in wheat growth and yield attributes and profitability with the combination of 75% NPK + 10 t ha^{-1} FYM and bio-inoculants (PGPR + VAM) application as compared with balanced fertilization (100% NPK) and the rest of the treatment combinations in the two-year wheat field experiment.

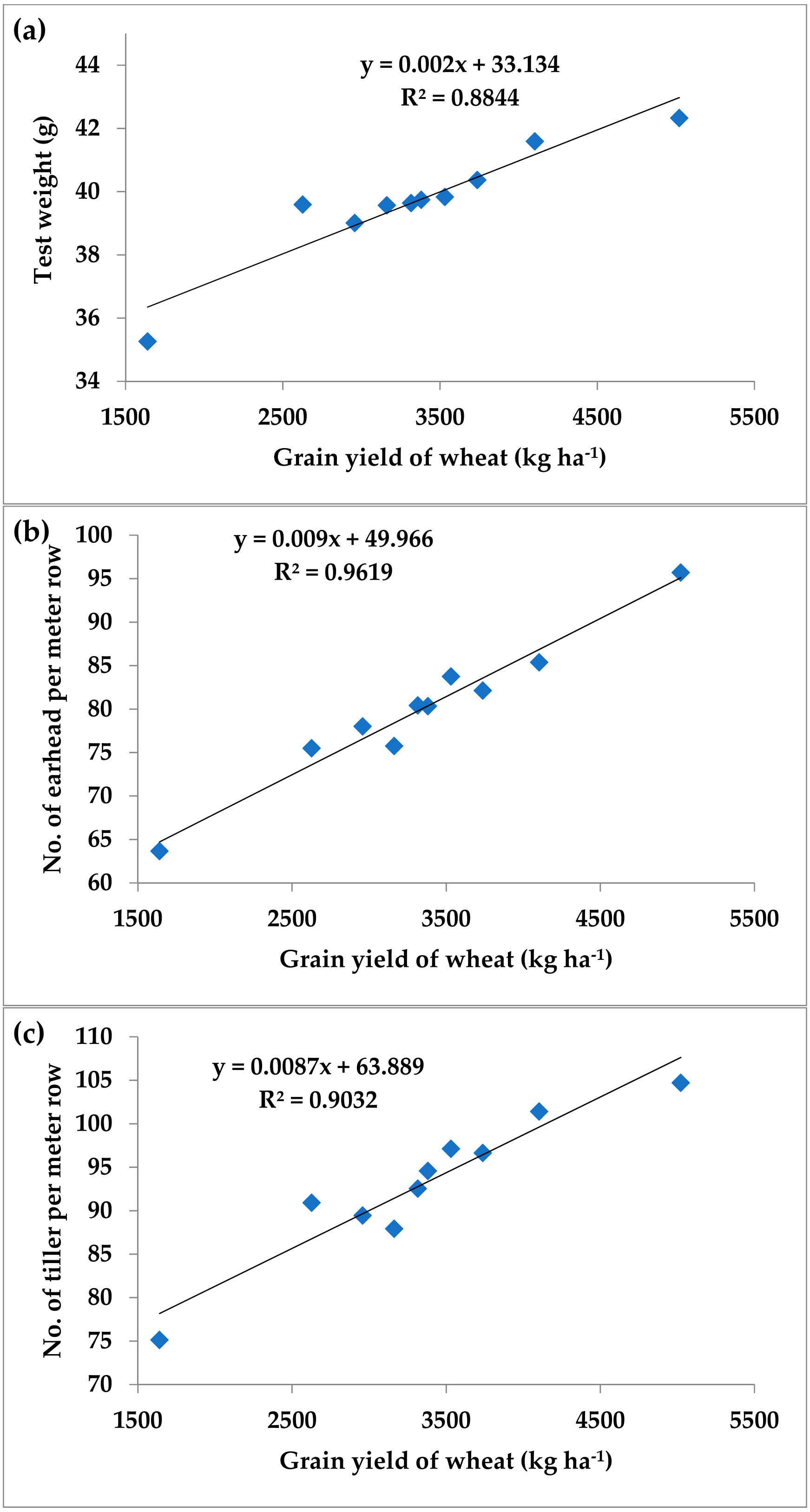

Figure 5. *Cont.*

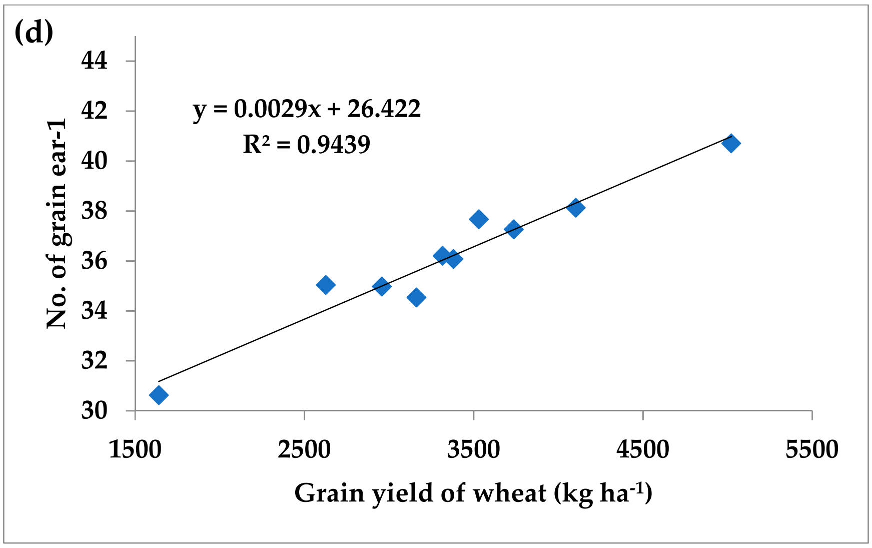

Figure 5. (**a**–**d**) Relationship between wheat grain yield and other growth and yield parameters (**a**) grain yield and test weight, (**b**) grain yield and number of ear head, (**c**) grain yield and number of tillers, and (**d**) grain yield and number of number of grains per ear of wheat.

4. Conclusions

Despite the indiscriminate use of inorganic fertilizers in India in the last few decades, farmers are shifting fertilizer use based on the cropping system. Here, we found that certain BMP options have the potential to sustain crop productivity and profitability. Results showed that judicious (75% RDF) application of inorganic fertilizers and manures (75% RDF + 10 t ha^{-1} FYM) had the potential to substitute inorganic fertilizers by 25% under this agro-climatic condition, which can help in increasing the profitability of farmers and reducing the amount of money the Government spends for importing and manufacturing synthetic fertilizers. Results suggested that the combined application of manure, fertilizers, and bio-inoculants is necessary to maintain the nutrient availability processes that contribute to sustainable soil health and crop productivity.

We also found that certain BMPs (RDF, INM, use of microbes) have the potential to sustain wheat productivity (+25%) in 75% NPK. Results suggested that we can achieve the same yield as 100% NPK by the application of 75% NPK + 10 t ha^{-1} FYM. Overall, the results suggested that innovative BMPs strategies need to be adopted and applied to attain sustainable development goals (SDG-1, SDG-2, and SDG-13) under changing climatic scenarios.

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