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Sustaining Soil Productivity by Integrated Plant Nutrient Management in Wheat Based Cropping System Under Rainfed Conditions

Mohiuddin Dilshad[a*], Mohammad Iqbal Lone[b], Ghulam Jilani[b], Muhammad Azim Malik[b], Muhammad Yousaf[b], Rizwan Khalid[a] and Fakhra Shamim[b]
[a]Soil Fertility Survey and Soil Testing Institute, Rawalpindi, Pakistan
[b]PMAS Arid Agriculture University, Rawalpindi, Pakistan

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Abstract. The study of the use of organic (FYM) and inorganic (NPK) nutrient sources with biofertiliser on wheat-fallow and wheat-maize cropping system under rainfed environment revealed significant increase in biometric parameters of wheat during winter and summer seasons of two years. During both the seasons, application of ½ NPK + ½ FYM + Biopower (brand) produced the highest grain yield (3684 kg/ha) and (3781 kg/ha) of wheat with the maximum N uptake of 357 kg/ha, P uptake of 51 kg/ha and K uptake of 215 kg/ha. Wheat-maize cropping system was found to be profitable economically with integrated use of mineral and organic and/or Biopower under rainfed conditions of Pakistan.

Keywords: integrated plant nutrient management, wheat-maize cropping, wheat-fallow cropping, rainfed area, biofertiliser, farm yard manure

Introduction

Growing concerns about the environmental consequences of use of mineral fertilizers and their future cost perspectives emphasize the need to develop new agricultural technologies that are sustainable both economically and ecologically. Use of chemical fertilizers alone does not sustain productivity under continuous intensive cropping, whereas inclusion of organic materials improves physical soil properties (Benbi *et al*., 1998), builds up soil fertility and increases crop yield (Yaduvanshi, 2003). Organic materials hold great promise due to their local availability as a source of multiple nutrients and ability to improve soil characteristics. According to several authors the improvement of fertility and quality of soil, especially under low input agricultural systems, requires the input of organic materials (Soumare *et al*., 2003; Ouedraogo *et al*., 2001). The effect of organic nutrients on crop yield is long term and not immediate. However, the use of biofertilisers along with organic/inorganic materials effectively stimulates the supply and the release of nutrients from the nutrient sources. Combination of both N sources with effective microorganisms (EM) increased the NPK concentrations in cotton crop (Khaliq *et al*., 2006). Wu *et al*. (2005) observed that half the amount of biofertiliser application had similar effects when compared with organic fertiliser and chemical fertiliser treatments.

Hence, the present experiment was carried out to evaluate the integrated use of organic and mineral fertilisers with biofertiliser 'Biopower' on the yield of wheat.

Materials and Methods

A field experiment pertaining to wheat based cropping system was conducted at the research farm of Soil Science and SWC Department of Arid Agriculture University, Rawalpindi. Split-plot design was used for two cropping system (CS) treatments in main plots and nine integrated plant nutrient management (IPNM) practices in subplots. All treatments were applied with three replications. The sub-plot size was 6 m x 4 m (24 m^2). The experiment was conducted in winter 2004-05 (Rabi season) with *Triticum aestivum* cv. Chakwal 97 as test crop followed by *Zea mays* cv. A gaiti 2002 in one main plot in summer of 2005 (Kharif season), while the second main plot remained fallow. All treatments of subplots were applied at the same rate to wheat and maize. The same experiment was repeated in winter 2005-06 and in summer 2006 on the same crops with identical treatments. National Institute for Biotechnology and Genetic Engineering (NIBGE), Faisalabad, Pakistan has developed a

*Author for correspondence; E-mail: mohiuddindilshad@yahoo.com

microbial inoculum 'Biopower'. The biofertiliser 'Biopower' was used for seed inoculation containing N-fixing bacteria, belonging to genus *Azotobacter, Azospirillum*, *Azoarcus* and *Zoogloea*. Fallow plots were kept weed-free by repeated cultivation immediately followed by planking. There were two treatments of cropping systems: wheat-fallow (CS_1) and wheat-maize (CS_2). There were nine treatments of integrated plant nutrient management practices. These included: control (without NPK fertilizer, FYM or biofertiliser); half of recommended NPK; full dose of recommended NPK (120-90-60); FYM @ 20 t/ha; FYM on N requirement basis + make-up dose of P/K fertilizer; ½ NPK + FYM @ 10 t/ha; ½ NPK + Biopower; ½ FYM + Biopower; and ½ NPK + ½ FYM + Biopower. The experimental site was located in the subtropical subhumid Pothwar plateau, Pakistan at an altitude of 513 m extending over latitude 32° 10 to 34° 9 N and longitude 71° 10 to 73° 55 E with 1.82 million hectares area. Fig. 1 and 2 present the data on mean monthly rainfall and temperature during the experimental period..

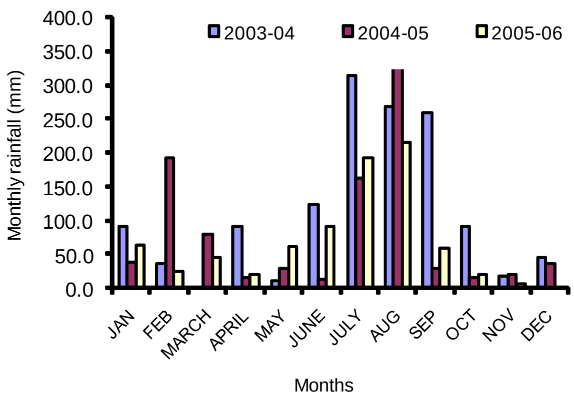

Fig. 1. Monthly rainfall during the study (2004-2006).

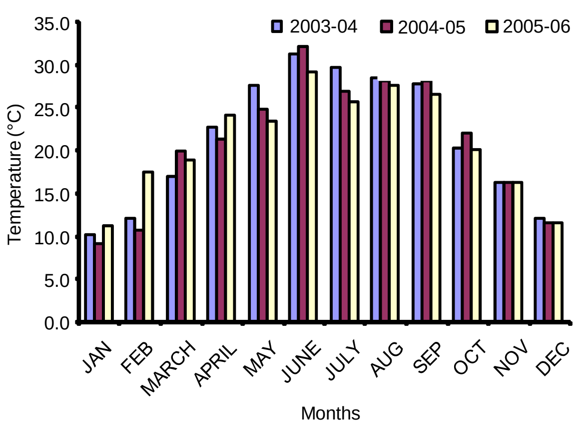

Fig. 2. Mean monthly temperature (°C) during the study (2004-2006).

Chemical analysis. Composite soil sample were collected from the experimental field at two depths (0-15 cm and 15-30 cm) before sowing. One soil sample was collected for each treatment from the subplot before sowing and after harvest of wheat. Soil samples were analyzed for various physical and chemical characteristics. Soil texture was determined by hydrometer method as described by Koehler *et al.* (1984) and pH in soil water suspension (1:10) was determined with pH meter (McLean, 1984). Organic carbon was determined by the method given by Nelson and Sommers (1982). Total nitrogen was determined by Kjeldahl digestion method (AOAC, 1982). Available phosphorus was determined by Spectronic 601 as described by Soltanpur and Schwabe (1977). Ammonium acetate-extractable potassium was determined by flame photometer (PFP, Jenway). Data for yield components and yield was recorded at physiological maturity of wheat. Plant and grain samples from individual treatments were analyzed for total nitrogen by Kjeldahl digestion method; phosphorus was determined by AB-DTPA extractable-P method and total K concentration, by flame photometer (Ryan *et al*., 2001).

Statistical and economic analysis. Growth, yield and soil parameters were recorded and then analyzed statistically according to standard statistical procedures described by Sokal and Rohlf (1997). Data showing significant difference at P=0.05 was put to comparison of treatment means by Duncan's multiple range test. All the data was processed using MSTAT software for statistical analysis. For economic analysis, after considering the cost of fertilizer N, P, K, farmyard manure and biofertilizer 'Biopower' application, income from seed yield was used for economic analysis (CIMMYT, 1988) using the formula:

Value cost ratio (VCR) = value of increased yield obtained/cost of mineral/organic sources.

Results and Discussion

Composite soil sample analysis before the start of the experiment showed that the soil was sandy loam in texture with reaction of 7.8 and ECe of 0.25 dS/m. It had low soil organic carbon of 0.32 g/100 g. The total soil nitrogen, available P and extractable K were estimated as 152, 3.45 and 80 µg/g, respectively, showing low fertility status of soil (Table 1).

Table 1. Physical and chemical properties of composite soil samples before the start of experiment

Soil series : Rawal; Soil order : Inceptisol; Parent material : Loess

Parameter	Soil depth	
	0-15 cm	15-30 cm
Clay (%)	16	17
Silt (%)	39	40
Sand (%)	45	43
Soil texture	Sandy loam	Sandy loam
Soil pH	7.80	7.91
EC_e (dS/m)	0.25	0.21
Bulk density (g/cc)	1.40	1.53
Soil moisture (g/100 g)	8.82	9.2
Total N (µg/g)	152	154
Organic C (g/100 g)	0.32	0.33
Available P (µg/g)	3.45	3.55
Extractable K (µg/g)	80	85

Yield and yield components of wheat. ***Plant height.*** The height of a plant is an expression of inherited biological and environmental factors. During 2004-05, the application of ½ NPK + ½ FYM + Biopower (T_9) produced maximum average plant height of 108.9 cm followed by 106.4 cm due to treatment of ½ NPK + ½ FYM(T_6). The recommended NPK treatment (T_3) produced 104.6 cm of plant height, which was statistically at par with the treatment (T_6) and (T_8). The results during 2005-06 showed that application of ½ NPK + ½ FYM + Biopower (T_9) caused the highest plant height of 111.8 cm followed by 110.1 cm in T_3, which were at par with the other, statistically. The plant height due to T_3 and T_6 were also statistically at par (Table 2). Maximum plant height by T_9 (½ NPK + ½ FYM + Biopower) was due to the improved availability of plant nutrients through Biopower. Rashid *et al*. (1998) and Ahmed *et al*. (1998) also reported that Integrated plant nutrient management (IPNM) produced higher plant height for wheat crop in rainfed areas. Chatha *et al*., (2006) also estimated that combined use of mineral and organic fertilizers resulted in higher plant height of wheat and maize in rainfed conditions. Many earlier researchers had also recorded that combined use of organic and chemical fertilizer to soil increased efficiency of chemical fertilizer and crop yield significantly (Bhatti, 2006; Jadoon *et al*., 2004; Nawaz *et al*., 2000).

Biological yield. During the first year (2004-05), application of ½ NPK + ½ FYM + Biopower (T_9)

Table 2. Effect of integrated use of organic and mineral fertilisers and/or biopower on plant height of wheat during 2004-06

Treatments	Plant height (cm)					
	2004-05			2005-06		
	CS_1	CS_2	Mean	CS_1	CS_2	Mean
T_1 Control	96.7^{g}	92.9^{h}	94.8^{G}	84.5	82.1	83.3^{F}
T_2 NPK (60-45-30) kg/ha	98.5^{fg}	96.8^{g}	97.7^{F}	96.2	95.8	96.0^{E}
T_3 NPK(120-90-60) kg/ha	103.3^{cde}	105.9^{bc}	104.6^{BC}	111.6	108.6	110.1^{AB}
T_4 Full FYM @ 20 t/ha	100.2^{ef}	101.2^{def}	100.7^{E}	105.0	102.3	103.6^{CD}
T_5 FYM*	103.6^{cd}	103.5^{cd}	103.5^{CD}	107.3	104.4	106.1^{CD}
T_6 ½ NPK + ½ FYM	106.4^{cd}	106.5^{bc}	106.4^{B}	109.6	105.0	107.3^{BC}
T_7 ½ NPK + Biopower	101.3^{def}	102.7^{de}	102.0^{DE}	101.5	103.7	102.6^{D}
T_8 ½ FYM + Biopower	103.3^{cde}	103.8^{cd}	103.6^{CD}	105.7	104.7	105.2^{CD}
T_9 ½ NPK + ½ FYM + BP	107^{b}	110.9^{a}	108.9^{A}	112.6	111.1	111.8^{A}
Mean	102.2^{Y}	102.7^{X}	-	103.8 ns	101.9 ns	-
Analysis of variance	P-value	LSD	SE	P-value	LSD	SE
Treatment (T)	< 0.001	1.995	0.6941	< 0.001	3.467	1.206
Cropping system (CS)	ns			0.0253		
T x CS	0.02	2.821	0.9817	ns		
CV (± %)	1.66	-	-	2.87	-	-

CS = cropping system; biofertiliser biopower (seed inoculation at sowing); NPK @ 120-90-60 kg/ha; FYM (farm yard manure), @ 20 t/ha; FYM* = N equivalent + P make up dose; data are average of three replications; means followed by the same superscripts are not significantly different (P < 0.05; DMR test) from each other.

produced the highest biological yield of 9698 kg/ha followed by 8899 kg/ha by treatment of ½ NPK + ½ FYM; difference between these treatments was significant (Table 3). Mineral fertilizer NPK treatment (T_3) yielded 8622 kg/ha, which was significantly lower to both the T_9 and the T_6 treatments. Application of FYM with P make-up dose produced biological yield of 7518 kg/ha, which was significantly higher than the T_4 that gave 7140 kg/ha. The ½ FYM + Biopower treatment (T_8) gave biological yield of 7206 kg/ha, which was statistically at par with the T_4. Biopower with ½ NPK produced a biological yield of 6969 kg/ha that was significantly lower than the T_8.

The results during 2005-06 showed that the highest biological yield of 9381 kg/ha was produced by T_9, which was statistically at par with the biological yield of 9335 kg/ha by T_6 and 8753 kg/ha due to NPK fertilisers (T_3). Application of FYM (T_4 and T_5) produced biological yield of 6725 kg/ha and 6308 kg/ha, respectively, which were statistically at par with one other.

Significant interaction between integrated nutrient management practices and cropping system (Table 3) was observed during 2004-05, while this interaction was nonsignificant during 2005-06. Higher biological yield was produced in CS_2 than CS_1 during 2004-05 and 2005-06. However, yield of 2005-06 was lower than that of 2004-05 with significant difference between the two cropping systems for the first year and the second year of wheat. It may be due to the low rainfall received during the second crop year (Fig. 1). This is evident from the integrated use of organic and mineral fertilisers and/or Biopower showing better performance regarding the biological yield of wheat. Integrated plant nutrient management had advantage over the sole application of mineral and organic and/or biofertilisers. Ahmed *et al*. (1998) reported that IPNM produced higher biological yield of wheat in rainfed areas. Highest biological yield produced by T_9 (½ NPK + ½ FYM + Biopower) may be due to better availability of plant nutrients (Hafeez *et al*., 2002). Khaliq *et al*. (2006) also reported higher growth and yield of cotton by integrated use of organic and inorganic nutrient sources with the effective microorganisms.

Grain yield. Grain yield in wheat *Triticum aestivum* L. is the result of a number of complex morphological and physiological processes affecting each other. During 2004-05, application of ½ NPK + ½ FYM + Biopower (T_9) produced the highest grain yield of 3684 kg/ha followed by the grain yield of 3492 kg/ha

Table 3. Effect of integrated use of organic and mineral fertilisers and/or biopower on biological yield of wheat during 2004-06

Treatments	Yield (kg/ha)					
	2004-05			2005-06		
	CS_1	CS_2	Mean	CS_1	CS_2	Mean
T_1 Control	4290^{i}	4255^{i}	4273^{H}	4200 ns	4106 ns	4153^{D}
T_2 NPK (60-45-30) kg/ha	6149^{h}	6200^{h}	6175^{G}	6066	6160	6113^{C}
T_3 NPK(120-90-60) kg/ha	8565^{c}	8679^{c}	8622^{C}	8580	8926	8753^{A}
T_4 Full FYM @ 20 t/ha	7199^{e}	7140^{e}	7170^{E}	6351	6264	6308^{BC}
T_5 FYM*	7505^{d}	7531^{d}	7518^{D}	6637	6812	6725^{BC}
T_6 ½ NPK + ½ FYM	8789^{b}	9010^{b}	8899^{B}	9290	9380	933^{5A}
T_7 ½ NPK + Biopower (BP)	6819^{g}	7119^{g}	6969^{F}	6575	6575	6575^{BC}
T_8 ½ FYM + BP	7176^{f}	7236^{g}	7206^{E}	7040	6776	6908^{B}
T_9 ½ NPK + ½ FYM + BP	9641^{a}	9755^{a}	9698^{A}	9226	9535	9381^{A}
		7348^{Y}	7436^{X}		7094	7151
Analysis of variances	P-value	LSD	SE	P-value	LSD	SE
Treatment (T)	< 0.001	109.0	37.92	< 0.001	588.8	186.9
Cropping system (CS)	0.0014			ns		
T x CS	0.0418			ns		
CV ($\pm$ %)	1.26			6.43		

CS = cropping system; biofertiliser Biopower (seed inoculation at sowing); NPK @ 120-90-60 kg/ha; FYM (farm yard manure), @ 20 t/ha; FYM* = (N equivalent + P make up dose); data are average of three replications; means followed by the same superscripts are not significantly different ($P < 0.05$; DMR test) from each other.

by the treatment T_6 (½ NPK + ½ FYM), while the use of the recommended NPK dose produced 3292 kg/ha grain yield which were significant. The difference between the highest and the lowest grain yield obtained was 1938 kg/ha. There was significant difference between CS_1 and CS_2 for the average of all the nine treatments (Table 4).

The results during 2005-06 showed that application of ½ NPK + ½ FYM + Biopower (T_9) caused the highest grain yield of 3781 kg/ha, which was statistically significant to all the nine treatments. The application of ½ NPK + ½ FYM produced significantly lower grain yield of 3611 kg/ha than T_9, while T_3 produced significantly lower grain yield of 3424 kg/ha than T_6. The grain yield produced during 2005-06 was higher than that produced during 2004-05, depicting nonsignificant difference between the two cropping systems for the first year and the second year of wheat. There was no effect of cropping system on grain yield of wheat during both the years; however, lower values of grain yield were recorded in 2004-05.

A nonsignificant interaction between the integrated nutrient management practices and the cropping system (Table 4) was observed in both the years. The highest grain yield was observed when ½ NPK + ½ FYM + Biopower were applied in CS_1 and CS_2. However, during 2005-06, CS_1 produced higher grain yield than CS_2. The reason might be that after the harvest of wheat in 2004-05, the field was kept fallow (CS_1), while in CS_2, maize was grown which might have depleted the soil of nutrients and moisture. The results showed that integrated use of organic and mineral fertilisers and/or biofertilisers showed better performance regarding grain yield of wheat. Both FYM treatments (T_4 and T_5) showed significant increase in grain yield. Results of previous studies indicated that use of organic sources as FYM produced equivalent or more plant biomass and grain yield of wheat as the application of inorganic fertilizers alone (Alam and Shah, 2003; Bakhtiar *et al.*, 2002; Khanum *et al.*, 2001). Chatha *et al.* (2006) also reported that the combined use of mineral and organic fertiliser produced higher grain yield of wheat crop in rainfed areas. Biofertilser 'Biopower' treatments (T_7 and T_8) showed significant increase in grain yield over T_3 depicting Biopower response (Hafeez *et al.*, 2002). The highest grain yield in IPNM treatment T_9 may be due to better availability of plant nutrients, while mineral fertilizers released nutrients readily to soil (Ahmad *et al.*, 2002). Increase in grain yield due to IPNM can be attributed to improvement of organic matter content (Singh and Swarup,

Table 4. Effect of integrated use of organic and mineral fertilisers and/or biopower on grain yield of wheat during 2004-2006

Treatments	Yield (kg/ha)					
	2004-05			2005-06		
	CS_1	CS_2	Mean	CS_1	CS_2	Mean
T_1 Control	1654 ns	1636 ns	1646^{H}	1580 ns	1466 ns	1523^{I}
T_2 NPK (60-45-30) kg/ha	2388	2408	2399^{G}	2333	2314	2324^{H}
T_3 NPK(120-90-60) kg/ha	3266	3317	3292^{C}	3429	3418	3424^{C}
T_4 Full FYM @ 20 t/ha	2830	2804	2818^{E}	2930	3017	2974^{E}
T_5 FYM*	2974	2936	2956^{D}	3173	3145	3159^{D}
T_6 ½ NPK + ½ FYM	3450	3533	3492^{B}	3625	3597	3611^{B}
T_7 ½ NPK + Biopower	2638	2771	2705^{F}	2695	2624	2660^{G}
T_8 ½ FYM + Biopower	2826	2837	2832^{E}	2858	2765	2812^{F}
T_9 ½ NPK + ½ FYM + BP	3675	3692	3684^{A}	3793	3768	3781^{A}
Mean	2856	2881		2935	2901	
Analysis of variances	P-value	LSD	SE	P-value	LSD	SE
Treatment (T)	< 0.001	55	19	< 0.001	66	23
Cropping system (CS)	0.0519			0.0357		
T x CS	0.068 ns			0.165 ns		
CV (± %)	1.64			1.93		

CS = cropping system; biofertilizer Biopower (seed inoculation at sowing); NPK @ 120-90-60 kg/ha; FYM (farm yard manure), @ 20 t/ha; FYM* = N equivalent + P make up dose; data are average of three replications; means followed by the same superscripts are not significantly different (P < 0.05; DMR test) from each other.

2001) and consequently improvement of physical properties particularly water holding capacity of soil (Hati *et al*., 2007). Khaliq *et al*. (2006) also recorded higher growth and yield of cotton by integrated use of organic and inorganic nutrient sources with effective microorganisms. Ahmad *et al*. (2008); Bhatti (2006) and Wu *et al*. (2005) also documented that combined use of organic and mineral fertilisers produced better grain yield.

NPK uptake. The uptake of macronutrients like N, P and K is the direct indication of the growth and the biomass production. During 2004-05, application of ½ NPK + ½ FYM + Biopower (T_9) recorded maximum N uptake of 357 kg/ha followed by 313 kg/ha by recommended dose of NPK fertiliser treatment (T_3). Maximum P uptake of 51 kg/ha was recorded by T_9 followed by P uptake of 49 kg/ha in mineral fertiliser treatment (T_3). Maximum K uptake of 215 kg/ha was recorded by T_9 followed by K uptake of 195 kg/ha by mineral fertilisers treatment (T_3) as depicted in Table 5.

During 2005-06, application of ½ NPK + ½ FYM + Biopower (T_9) recorded maximum N uptake of 367 kg/ha followed by N uptake of 344 kg/ha by the recommended dose of NPK fertiliser treatment (T_3). Maximum P uptake of 55 kg/ha was recorded by T_9 followed by P uptake of 53 kg/ha by T_3. Maximum K uptake of 210 kg/ha was recorded by T_9 followed by K uptake of 207 kg/ha by mineral fertiliser treatment (T_3).

The results showed that integrated use of organic and mineral fertilizers and/or biofertiliser rendered better performance regarding grain yield of wheat. Integrated plant nutrient management had advantage over the sole application of mineral and organic and/or biofertiliser. During 2004-05, application of ½ NPK + ½ FYM + Biopower (T_9) recorded 14, 4 and 10% increase in uptake of N, P and K, respectively, by wheat over mineral fertiliser treatment (T_3), while during 2005-06, application of ½ NPK + ½ FYM + Biopower (T_9) recorded 6.5, 3.8 and 1.5% increase in uptake of N, P and K, respectively by wheat over mineral fertiliser treatment (T_3). Integrated plant nutrient treatment, especially with Biopower, improved NPK uptake over mineral fertilisers (Hafeez *et al*., 2002; Bakhsh *et al*., 2001).

The results of this experiment revealed that full dose of mineral NPK fertilisers caused maximum uptake of N, P and K nutrients by both the wheat and the maize plants in both the growing seasons. Biofertiliser treatments, especially those with Biopower, improved NPK uptake over half the dose of NPK. This was due to the fact that Biopower contained four N-fixing bacteria, which resulted in increased availability of nutrients to wheat plants. Microbial inoculums not only increased the nutritional assimilation of wheat plants (total N, P and K) but also improved soil properties, which lead to better vegetative growth and crop yield (Ahmad *et al*., 2008).

The economic analysis. The economic analysis of the cropping systems revealed that wheat-maize cropping system was profitable with the integrated use of mineral, organic and/or biofertiliser under rainfed conditions. The results indicated that organic sources

Table 5. Effect of integrated plant nutrient management on NPK uptake (kg/ha) of wheat

Treatments	NPK uptake (kg/ha)					
	2004-05			2005-06		
	N	P	K	N	P	K
T_1 Control	77	15	66	67	17	62
T_2 NPK (60-45-30) kg/ha	134	25	112	131	27	110
T_3 NPK(120-90-60) kg/ha	313	49	195	344	53	207
T_4 Full FYM @ 20 t/ha	221	37	160	205	34	145
T_5 FYM*	237	43	174	222	39	157
T_6 ½ NPK + ½ FYM	299	45	194	329	49	206
T_7 ½ NPK + Biopower	200	30	148	200	28	139
T_8 ½ FYM + Biopower	209	31	153	217	30	146
T_9 ½ NPK + ½ FYM + Biopower	357	51	215	367	55	210

CS = cropping system; biofertiliser biopower (seed inoculation at sowing); NPK @ 120-90-60 kg/ha; FYM (farm yard manure), @ 20 t/ha; FYM* = N equivalent + P make up dose; data are average of three replications ($P < 0.05$; DMR test).

Table 6. Value cost ratio (VCR) due to integrated plant nutrient management on seed yield of wheat

Treatments	Value cost ratio			
	2004-05		2005-06	
	CS_1	CS_2	CS_1	CS_2
T_1 Control	-	-	-	-
T_2 NPK (60-45-30) kg/ha	1.84	1.94	1.89	2.13
T_3 NPK(120-90-60) kg/ha	2.02	2.11	2.32	2.45
T_4 Full FYM @ 20 t/ha	1.18	1.07	1.35	1.55
T_5 FYM*	1.28	1.26	1.54	1.62
T_6 ½ NPK + ½ FYM	2.00	2.11	2.28	2.37
T_7 ½ NPK + Biopower (BP)	2.35	2.71	2.67	2.77
T_8 ½ FYM + Biopower	2.25	2.31	2.46	2.50
T_9 ½ NPK + ½ FYM + BP	2.20	2.24	2.41	2.51

Prices of mineral and organic/biofertilisers in 2004-06 for VCR

Urea	(50 kg bag)	Rs.468.0	(US $ 7.8)
Diammonium phosphate	(50 kg bag)		(US $13.35)
Triple super phosphate	(50 kg bag)	Rs. 801.0	(US $13.35)
Sulphate of potash		Rs.996.0	(US $16.6)
Farmyard maure		Rs.1200.0	(US $ 20)
Biofertilizer Biopower	(1.0 kg packet)	Rs.100.0	(US $1.6)

(US $1.0 = Rupees 60 during 2004-2006)

CS = cropping system; biofertiliser Biopower (seed inoculation at sowing); NPK @ 120-90-60 kg/ha; FYM (farm yard manure), @ 20 t/ha; FYM* = N equivalent + P make up dose.

alone or their integrated use may improve yield but cannot compete mineral sources for sustaining crop productivity (Table 6). There is no scope for reducing the consumption of chemical fertilisers but due to their increasing cost and environmental concerns, chemical fertilisers may not be used since integrated use of fertilisers is showing a profitable VCR (CIMMYT, 1988). The VCR values of 2.20 and 2.41 were calculated for CS_1 while 2.24 and 2.51 for CS_2 were calculated in 2004-2005 and 2005-06, respectively, in T_9. The VCR estimated for IPNM in T_9 showed that integrated use of organic and inorganic fertiliser sources had better net profit for wheat yield for the farmer under rainfed conditions. Thus, IPNM may prove more viable and sustainable for wheat based cropping systems in rainfed Pothowar area of Punjab province of Pakistan.

Conclusion

The investigations presented in this study indicate distinct benefits of IPNM over the use of mineral fertilisers. The results of this study showed that integrated use of NPK (60-45-30) kg/ha and farmyard manure @ 10 t/ha with biofertiliser 'Biopower' as in T_9, was most appropriate and economical for better yield of wheat in wheat based cropping systems of rainfed areas. The results confirm that besides increasing the crop yield, IPNM saved mineral fertilisation which had potential effects on sustainable agricultural production in less fertile soils of rainfed Pothwar region of Pakistan. The high concentration of minerals in wheat plants demonstrated more efficient use of the applied mineral nutrients by IPNM in both the cropping systems. However, more intensive and systematic studies are required to provide better understanding of the usefulness of IPNM in making crop production more profitable and income generating activity for small farmers of rainfed Pothwar region of Pakistan. Integrated plant nutrient approach is going to be the mainstay in the next millennium.

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