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Integrated plant nutrient management and cropping system for restoring crop productivity of an eroded land

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Abstract

Crop productivity of eroded lands is very poor due to removal of top fertile soil losing organic matter and plant nutrients, with consequent exposure of the sub-soil with poor fertility status. Crop productivity of such lands needs to be restored in order to help farmers feed many mouths because of increased population and high land pressure. A field experiment was laid out at Thana, Malakand Agency for three years, during 2003-2004 to 2005-2006 to study the effect of integrated plant nutrient management on the yield of wheat. The fertilizer treatments consisted of farmer's practice: T_1 (60-45-0 kg N-P_2O_5-K_2O ha^{-1}), recommended fertilizer rate: T_2 (120-90-60 kg N-P_2O_5-K_2O ha^{-1} + 5 kg Zn ha^{-1}), and combined application of organic and inorganic sources of plant nutrients: T_3 (FYM @ 20 t ha^{-1} plus 60-90-60 kg N-P_2O_5-K_2O ha^{-1} + 5 kg Zn ha^{-1}). The results showed that the combined application of FYM with NPK Zn increased the grain yield significantly over the other two treatments with an increase of 58-88% over the farmer's practice and 18-28% over the recommended dose. As regards straw yields, T_2 and T_3 increased the yields significantly over farmer's practice (T_1). However, T_2 and T_3 were at par with each other. Mungbean-wheat system increased the yield of wheat during 2005-2006 by 24% over maize-wheat system. Bulk density was considerably decreased in T_3 and water holding capacity increased over a period of time. Organic matter content was improved, by T_3 followed by T_2. Similarly soil P and Zn contents were increased considerably in T_2 and T_3. It could be concluded from these results that the crop productivity of eroded lands can be restored and the soil fertility status improved with integrated plant nutrient management practices.

Key words: Erosion, organic, inorganic, fertilizers, productivity.

Introduction

Due to enhanced population pressure, pressure on land has been increased considerably in Pakistan. This increased land pressure has caused deforestation, overgrazing of exposed land and faulty cultivation of steep slopes. These factors have caused land degradation in many areas of Pakistan especially in NWFP. It has been reported that soil loss by erosion in some areas of Malakand Agency, NWFP, is bout 104 t ha^{-1} yr^{-1} (Ahmad, 1990). In a study by Khan *et al*. (2001), water erosion caused 7 t ha^{-1} soil loss during summer season.

Soil erosion causes several damages to the physico-chemical characteristics of soil such as loss of organic matter, loss of soil fertility, decreased infiltration rate and water holding capacity, and exposure of subsoil with higher clay content and poor soil fertility. A recent study by Khan and Bhatti (2000) showed that the soil loss by erosion under bare conditions was about 2 t ha^{-1} in one wheat crop season. Bhatti *et al*. (1997) reported a loss of about 48 kg ha^{-1} P, 24 kg ha^{-1} of profile nitrate N and 18 kg ha^{-1} organic matter in eroded lands. This indicates that valuable nutrients are lost every year resulting in low soil fertility.

As regards extent of soil erosion in Pakistan, about 15.22 million hectares of land is affected by various types of soil erosion (Mian and Javed, 1989). Low and erratic moisture availability and soil erosion are the major soil related problems of the rain-fed agricultural lands of NWFP. The land under moderate to severe soil erosion in NWFP is 25 % of the rain-fed cultivated land. These lands can be improved through integrated plant nutrient management, and moisture conservation practices. By improving crop productivity of these lands, crop yields can be significantly increased.

Bhatti *et al*. (1998a) found that there was a deficiency of available P (2.68 mg kg^{-1}) and K (48 mg kg^{-1}) in a large eroded field on AB-DTPA extractable basis and the field was low in organic matter (1.2 to 6.6 g kg^{1}). Bhatti *et al*. (1998b) reported in another study that AB-DTPA extractable P was either low or medium in 18 barani sites out of 38 sites tested. Out of 12 fields tested from Swat/Malakand, 6 were either low or medium in available P. All of the sites tested were low in organic matter.

Imbalanced fertilization practiced over a long period of time and replacement of recycling of organic materials and application of organic manures in this part of the country raised concerns about the potential long-term adverse impacts on soil productivity and environmental quality. The poor and marginal farmers often use sub optional rates of NPK fertilizers due to scarcity of resources available to them. Decline in soil organic matter is generally one of the causes of yield stagnation, particularly where imbalanced use of N fertilizers is practiced, irrespective of cropping system (Swamp *et al*., 2000). Balanced application

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of plant nutrients have been proved to enhance crop yield and organic matter content of soil also (Bakhsh *et al*., 1994; Bhatti *et al*., 1995; Gumani *et al*., 1996; Manna *et al*., 2005).

Addition of FYM with inorganic fertilizers to soil has been reported to increase the efficiency of applied fertilizers (More, 1994; Ahmad *et al*., 1998; Ahmad, 1999; Nawaz *et al*., 2000; Jadoon *et al*., 2003). Moreover, addition of FYM with inorganic fertilizers improves organic matter content of soil (Ahmad, 1999; Swarup, 2001) and consequently water holding capacity of soil (Hati *et al*., 2006).

Nutrient replenishment by merely adding chemical fertilizers is often not economically feasible. Even in the technical sense, it may not be in balance with the supply of organic matter. Moreover, nutrient replenishment by chemical fertilizers is not affordable by many farmers. Use of on-farm sources of nutrients needs to be explored in order to obtain a satisfactory level of sustainable crop yields and profitable returns which can be achieved through combined application of organic and inorganic fertilizers. Ghosh *et al*. (2004) showed that total system productivity was the highest in cereal-legume cropping system. Ali *et al*. (2006) reported that bulk density was reduced in cereal-legume inter cropping while organic matter, N, P and K contents of soil were increased in intercropped plots over mono-cropping. As horizontal expansion of area is not possible, the marginal lands such as eroded lands can be managed to restore their crop productivity. With this view, a study was carried out for 3 years on an eroded field at Thana, Malakand Agency to restore crop productivity of land through integrated plant nutrient management (IPNM).

Materials and Methods

A field survey was conducted in the Malakand Agency for selection of site for field experiments during 2003. One eroded field was selected. The geo position of the field was 34^0-36′-51″ N and 72^0-05′-28″ E. It was situated on Nall road 3 km from Thana town. Month wise rainfall data collected at Agriculture Research Station Mingora, Swat for three years are given below:

Field Experiments

Field experiments were started on wheat during 2003-2004, and continued on wheat during 2004-2005 and 2005-2006 in the same layout according to the plan. The experiment consisted of two factors i.e. cropping systems and fertilizer treatments. Cropping systems were wheat-maize-wheat and wheat-mungbean-wheat. Fertilizer treatments were 60-45 kg N- P_2O_5 ha^{-1} (T_1), 120-90-60-5 kg N-P_2O_5-K_2O-Zn ha^{-1} (T_2), and 60-90-60-5 kg N-P_2O_5-K_2O-Zn ha^{-1} + 20 t farm yard manure (T_3). Split plot experimental design was used with three replications. Cropping systems were assigned to main plots and fertilizer treatments to sub-plots.

Farm yard manure (FYM) @ 20 t ha^{-1} was applied to T_3 plots about one month before sowing of wheat crop during all the three rabi seasons. In case of farmer's practice (T_1) and combined application of FYM and NPK Zn (T_3), all the fertilizers were applied at the time of sowing and well incorporated into the soil. In case of NPK Zn treatment, (T_2) half N plus all P, K and Zn were applied at sowing and the remaining half N after about one month. Wheat variety used was Daman-98 during 2003-2004 and Fakhar-e-Sarhad during 2004-2005 and 2005-2006. Sowing of wheat was done in November each year. Crop was harvested from a net area of 1 m^2 in duplicate from each treatment plot in May each year and threshed. Grain yield was recorded in kg ha^{-1}. During kharif 2004 and 2005, maize and mungbean crops were grown according to the plan (data not shown).

Soil Analysis

Composite soil sample was collected from the experimental site before starting the experiment and was analyzed for various physical and chemical properties according to the standard procedures. After harvest of wheat each year, soil samples were collected from each treatment plot and were analyzed for bulk density by core method (Blake and Hartage, 1986), available soil water by pressure

Rainfall data at Agriculture Research Station (North) Mingora Swat from June 2003 May 2006.

Sr. No.	Month	Rainfall (mm)	Month	Rainfall (mm)	Month	Rainfall (mm)
1	June, 2003	122.1	June		June	11.3
2	July	161.6	July	167.8	July	147
3	August	168.0	August	96.3	August	91.4
4	September	81.3	September	47.3	September	66.4
5	October	8.5	October	171.1	October	41.4
6	November	73.0	November	13.8	November	33.3
7	December	56.9	December	67.3	December	15.2
8	January, 2004	108.0	January, 2005	114.7	January, 2006	175.2
9	February	79.3	February	216.2	February	66
10	March	11.0	March	133.9	March	100.3
11	April	83.0	April	78.6	April	36.2
12	May	48.0	May	89.1	May	10.2

membrane apparatus (Cassel and Nelson, 1986), organic matter (Neslon and Sommers, 1982), AB-DTPA extractable P, K, Zn, Cu, Fe and Mn (Sultanpour, 1985).

Statistical Procedures

The data obtained on wheat yields were statistically analyzed using Split-Plot design with three replications. Treatment means were compared using Least Significant Difference (LSD) test of significance according to Steel and Torrie (1980). The combined analysis of wheat data was done for two years 2004-2005 and 2005-2006 according to Gomez and Gomez (1976).

Results and Discussion

Characterization of soils of the experimental sites

Soil samples from the experimental site were collected at the depth of 0-30, 31-60 and 61-90 cm. Data on the analysis of soil for different soil properties (Table 1) shows that soil was alkaline in nature in the surface soil. The soil was normal as regards salinity/sodicity. Soil surface of the experimental site was highly calcareous. With marginal organic matter (1.10%), available P, (3.98 mg kg^{-1}) and K (88 mg kg^{-1}) where as available Zn content was low in soil. Bhatti *et al*. (1998c) also reported low organic matter content and deficiencies of P, K and Zn in an eroded field in Malakand Agency and in other rain-fed areas of NWFP (Bhatti *et al*., 1998 a, b). One of the most frequent places where zinc deficiencies are found is on fields where the surface soil has been removed (Viets, 1951; Berger, 1972). Texture of soil in the surface soil was loam while clay loam in the sub-soil.

Soil of the experimental site was classified according to the U.S.A. classification system as clayey, mixed, hyperthermic, Udic Haplustepts with Burhan soil series.

Grain yield of wheat

Yield data collected from various fertilizer treatments at Thana during 2003-2004 showed that the treatment differences were highly significant ($P<0.01$). Comparison of treatment means showed that the differences among various treatments were significant ($P<0.05$) (Table 2). The significantly highest yield of 3997 kg ha^{-1} was obtained from treatment receiving FYM in combination with NPK Zn which gave an increase of 58% over T_1 (farmer's practice) and 23% over T_2 (NPK Zn). This was followed by the treatment receiving NPK Zn (T_2) which gave an increase of 28% over the farmer's practice (T_1). The significantly lowest yield of 2536 kg ha^{-1} was obtained from the farmer's practice. Adding FYM and reducing N by 60 kg ha^{-1} produced the highest grain yield. The results showed that the IPNM can restore the crop productivity of degraded lands. Jadoon (2004) also recorded the highest grain yield of maize with the combined application of FYM with inorganic fertilizers at Mansehra.

Data on grain yield collected from various treatment plots during 2004-2005 showed that the effect of fertilizer treatments was highly significant while the effect of cropping systems and their interaction with fertilizer treatments were non-significant. Comparing the treatment means with one another, it was found that the treatment with FYM (T_3) produced the highest yield of 3933 kg ha^{-1} but was at par with NPK Zn treatment (Table 3). Both the treatments gave significantly higher yields than farmer's practice (T_1). T_3 and T_2 gave an increase of 88 and 59% over T_1, respectively, while T_3 gave an increase of 18% over T_2. It seems from these results that combination of FYM with half rate of N and recommended levels of P, K and Zn proved better than the other treatments.

The data collected on the grain yield of wheat as influenced by cropping systems and fertilizer treatments during 2005-2006 showed that the effects of treatments were significant ($P<0.05$) while the effects of cropping systems were non-significant. Though the results for cropping systems were non-significant, mungbean-wheat system increased the grain yield of wheat by about 24% (Table 4). As regards effects of treatments, T_3 produced the highest yield of 5004 kg ha^{-1} being significantly different from the other two treatments which were at par with each other. However, T_3 increased the yield by 28% over T_1 and 17% over T_2 while T_2 registered an increase of 9 % over T_1. The significant response of T_3 was due to the effect of FYM on some physical and chemical properties of the soils.

Combined analysis of the grain yield of wheat over two years i.e. rabi 2004-2005 and rabi 2005-2006 showed that the results were significant ($P<0.01$) only for treatments. All the three treatments differed significantly from one another and T_3 gave the significantly highest grain yield of 4469 kg ha^{-1} (Table 5). T_3 gave an increase of 49% over T_1 and 18% over T_2, while T_2 increased the yield by 27% over T_1. As regards cropping systems, mungbean-wheat system increased the yield by 14% over wheat-maize system.

Effect of years was significant ($P<0.01$). Wheat yield during 2005-2006 was 41% greater than 2004-2005 (Table 6). This was due to more rainfall during 2004-2005 which enhanced vegetative growth and adversely affected grain yield.

Though the interactions between treatments and years were non-significant, all the treatments gave higher yields during 2005-2006 than during 2004-2005.

Straw yield of Wheat

Yield data collected during 2003-2004 regarding straw as influenced by various fertilizer treatments showed that the treatment effects were highly significant ($P<0.01$). Regarding comparison of treatment means, it was found that the treatment receiving NPK Zn alone and the one with FYM plus NPK Zn, were comparable with each other (Table 7). However, both of these treatments (T_2 & T_3) increased the yields significantly over control (Table-5). As regards increase in yield, T_2 registered an increase of 38% over T_3 and 53% over T_1.

Data collected on straw yield obtained from various treatments during 2004-2005 showed that the effect of fertilizer treatments was highly significant ($P<0.01$) while the effect of cropping systems and interactions between fertilizer treatments and cropping systems were non-significant. Comparing the fertilizer treatments with one another, it was found that all the three treatments were significantly different from one another (Table 8). However, the treatment with FYM (T_3) produced significantly highest yield followed by NPK Zn (T_2) treatment. The lowest yield of 6382 kg ha^{-1} was obtained from farmer's practice. The treatment T_3 and T_2 increased the yields over farmer's practice by 102 and 67% respectively; while T_3 gave an increase of 21% over T_2. It seems that the combination of FYM with half N and recommended levels of P, K and Zn proved better than the other treatments.

Data on straw yield of wheat as influenced by cropping systems and fertilizer treatments during 2005-2006 showed that the results were significant ($P<0.01$) for fertilizer treatments while non-significant for cropping system. Though the cropping systems were non-significant, mungbean-wheat system increased the yield by 26% over maize-wheat system (Table 9). As regards treatments, T_3 and T_2 were at par with each other and were significantly different from T_1. T_3 gave an increase of about 35% over T_1 and 10% over T_2, while T_2 gave 22% increase over T_1.

Combined analysis of the straw yield over two years i.e. rabi 2004-2005 and 2005-2006 showed that the effects of treatments were significant ($P<0.01$). Interactions between years and cropping systems, and years and treatments were also significant. ($P<0.05$). All the three treatments differed significantly from one another. T_3 increased the yield by 63% over T_1 and 16% over T_2, while T_2 increased the yield by 41% over T_1 (Table 10). As regards cropping systems, though non-significant, mungbean-wheat system increased the straw yield by 8% over maize-wheat system.

Effect of years on the straw yield of wheat was non-significant. However, there was an increase of 2% during 2005-2006 over 2004-2005 (Table 11).

The results showed that the treatments with FYM (T_3) increased the grain yield during all the three years of experimentation over the other treatments followed by inorganic fertilizers NPK Zn (T_2). It can be visualized from these results that combination of FYM with inorganic fertilizers has restored the crop productivity of eroded land. This was followed by NPK Zn (T_2) which was the result of balanced application of inorganic fertilizers. Similar results have been reported by many workers that addition of FYM along with chemical fertilizers increases the crop yields significantly (More, 1994; Ahmad *et al*., 1998; Nawaz *et al*., 2000; Bakhsh *et al*., 2001; Jadoon *et al*., 2003; Bhatti *et al*., 2005). Bakhsh *et al*. (2001) reported an increase of 4.7 kg grains of wheat per kg NPK ha^{-1} in the presence of FYM application under irrigated conditions.

Balanced application of plant nutrients in T_2 increased the yields significantly over farmer's practice. Effect of balanced application of inorganic fertilizers on crop yields have also been demonstrated by many workers (Gurmani *et al*., 1996; Bakhsh *et al*., 1999).

Though the results between the two cropping systems were non-significant, the yields of wheat after mungbean were considerably higher than after maize. Bakhsh *et al*. (2001) also reported an increase of 5.3 kg ha^{-1} wheat grain per kg NPK ha^{-1} after mungbean crop.

Increases in grain yield due to integrated plant nutrient management can be attributed to the improvement of organic matter content (Swarup, 2001) and consequently improvement of physical properties particularly water holding capacity of soil (Hati *et al*., 2006) after three years. Organic matter content had significant correlation with available water content (r=0.50, 0.57 and 0.62 during 2003-2004, 2004-2005 and 2006, respectively). Available water content in turn had significant relationship with grain yield (r=0.54, 0.58 and 0.55 during 2003-2004, 2004-2005 and 2005-2006, respectively). Available water content of the soil was increased from 16.95 g g^{-1} in T_1 to 18.89 g g^{-1} in T_3 (Table 13). Moreover soil fertility status of the soil was also improved in T_3 and build up of soil fertility was observed (Table 13).

Similarly, balanced application of plant nutrients would have increased the biomass production resulting in increased organic matter and biological activity, which consequently contributed to grain yield.

Economics of fertilizer use

Economics of fertilizer use was calculated for wheat during each year using fertilizer and wheat prices during each respective year. Economic analysis of wheat yields obtained from different fertilizer treatments (Table 12) shows that T_3 with FYM gave the highest net return during all the three years. It ranged from Rs. 45677 in 2003-2004 to Rs. 84096 in 2005-2006. It can be visualized from these results that the net return per unit area increased consistently from all the three treatments over years. This indicates the restoration of crop productivity of these eroded lands making it more profitable and sustainable over time particularly in T_3 where FYM is used.

Table 1. Soil analysis of experimental site.

					ABDTPA Extractable (mg kg^{-1})					
Depth (cm)	pH	ECe dS m^{-1}	Lime %	O.M. %	P	K	Zn	Cu	Fe	Mn
0-30	7.80	0.1236	17.25	1.10	3.98	88.00	0.30	1.952	7.458	9.00
31-60	7.66	0.1195	16.96	0.64	1.06	71.2	0.148	0.558	13.14	4.948
61-90	7.88	0.1120	15.01	0.40	1.38	68.0	0.186	0.502	14.36	4.342

Table 2. Effect of various fertilizer treatments on the grain yield of wheat during 2003-2004.

Sr. No.	Treatment					Yield	Increase over	
	N	P_2O_5	K_2O	Zn	FYM		T_1	T_2
	---------------- kg ha^{-1} ----------------				t ha^{-1}	kg ha^{-1}	------kg ha^{-1}------	
1	60	45	0	0	0	2536 c	-	-
2	120	90	60	5	0	3241 b	705 (28)	-
3	60	90	60	5	20	3997 a	1461 (58)	756 (23)

Table 3. Effect of cropping systems and fertilizer treatments on the grain yield of wheat (kg ha^{-1}) during 2004-2005.

Cropping system	Fertilizer Treatment			Mean	% Increase
	T_1	T_2	T_3		
Wheat-Maize-Wheat	1993	3353	3912	3086	-
Wheat-Mungbean-Wheat	2198	3311	3955	3155	2
Mean	2096b	3332a	3933a		
Increase over T_1	-	59	88		
Increase over T_2	-	-	18		

Means followed by similar letter(s) do not differ significantly from one another.
**Values in parentheses refer to % increase.

Table 4. Grain yield of wheat (kg ha^{-1}) during rabi 2005-2006.

Cropping System	Treatments			Mean	% increase
	T_1	T_2	T_3		
Maize-Wheat	3560	3933	4292	3928 a	-
M. Bean-Wheat	4242	4608	5717	4856 a	24
Mean	3901 b	4271 b	5004 a		
% increase over T_1	-	9	28		
% increase overT_2	-	-	17		

Table 5. Interaction between cropping systems and treatments of grain yield (kg ha^{-1}) of wheat during different years i.e. 2004-05 and 2005-2006 as affected by various treatments.

Treatments	Cropping systems				
	Maize-Wheat (S_1)	Mungbean–wheat (S_2)	Treatments Mean	% increase over	
				T_1	T_2
T_1	2776	3220	2998 c	-	-
T_2	3643	3960	3802 b	27	-
T_3	4102	4836	4469 a	49	18
Cropping system Mean	3507 a	4005 a			
% increase	-	14			

Table 6. Grain yield (kg ha^{-1}) of wheat during different years i.e. 2004-05 and 2005-2006 as affected by various cropping systems and treatments.

Cropping system	Treatment	Years		Cropping system Mean
		Rabi 2004-05	Rabi 2005-06	
Maize-wheat (S_1)	T_1	1993	3560	3507 a
	T_2	3353	3933	
	T_3	3912	4292	
Mungbean-wheat (S_2)	T_1		4242	4005 a
	T_2		4608	
	T_3		5717	
	Year wise Means	3121 b	4392 a	
% increase		-	41	

Table 7. Straw yield of wheat as influenced by various fertilizer treatments during 2003-2004.

Sr. No.	Treatment					Yield	Increase over	
	N	P_2O_5	K_2O	Zn	FYM		T_1	T_2
	---------------- kg ha^{-1} ----------------				t ha^{-1}	kg ha^{-1}	------kg ha^{-1}------	
1	60	45	0	0	0	5864 b	-	-
2	120	90	60	5	0	8121 a	2257 (38)	-
3	60	90	60	5	20	9000 a	3136(53)	879(11)

*Means followed by similar letter(s) do not differ significantly from one another.
**Values in parentheses refer to % increase.

Table 8. Effect of fertilizer and cropping systems on the straw yield of wheat (kg ha^{-1}).

Cropping system	Fertilizer Treatment			Mean
	T_1	T_2	T_3	
Wheat-Maize-Wheat	6262	11075	13808	10382
Wheat-Mungbean-Wheat	6502	10192	11950	9548
Mean	6382c	10634b	12879a	
Increase over T_1	-	67	102	
Increase over T_2	-	-	21	

Table 9. Straw yield of wheat (kg ha^{-1}) during rabi 2005-2006.

Cropping System	Treatments			Mean	% increase
	T_1	T_2	T_3		
Maize-Wheat	7265	9375	10292	8977 a	-
M. Bean-Wheat	9800	11458	12663	11310 a	26
Mean	8532 b	10420 a	11480 a		
% increase over T_1	-	22	35		
% increase over T_2	-	-	10		

Table 10. Interaction between cropping system and treatments of straw yield (kg ha^{-1}) of wheat at different years i.e. 2004-05 and 2005-2006 as affected by various treatments.

Treatments	Cropping systems		Treatments Mean	% increase over	
				T_1	T_2
T_1	6763	8151	7457 c	-	-
T_2	10225	10825	10525 b	41	-
T_3	12050	12307	12178 a	63	16
Cropping system Mean	9679 a	10428 a			
% increase	-	8			

Table 11. Straw yield (kg ha $^{-1}$) of wheat at different years i.e 2004-05 and 2005-2006 as affected by various cropping systems and treatments.

Cropping system	Treatment	Years		Cropping system Mean
		Year 2004-05	Year 2005-06	
Maize-wheat (S_1)	T_1	6262	7265	9679 a
	T_2	11075	9375	
	T_3	13808	10292	
Mungbean-wheat (S_2)	T_1	6502	9800	10428 a
	T_2	10192	11458	
	T_3	11950	12663	
	Years Means	9965 a	10142 a	
	% increase	-	2	

Straw yield from all the three treatments were significantly higher during rabi 2005-2006 than during 2004-2005.

Table 12. Economic analysis of fertilizer use on wheat at Thana.

Years	Treatments	1 Grain Yield Kg ha^{-1}	2 Value of Grain yield Rs ha^{-1}	3 Straw yield Kg ha^{-1}	4 Value of Straw yield Rs ha^{-1}	5 (2+4) Total value Rs ha^{-1}	6 Cost of fertilizers Rs ha^{-1}	7(5-6) Net Return Rs ha^{-1}	8(7/6) Cost: value
2003-04	T1	2536	22190	5864	14074	36264	2436	33828	13.89
	T2	3241	28359	8121	19490	47849	6993	40856	5.84
	T3	3997	34974	9000	21600	56574	10897	45677	4.19
2004-05	T1	2096	20960	6382	17870	38830	2771	36059	13.01
	T2	3332	33320	10634	29775	63095	8112	54983	6.78
	T3	3933	39330	12879	36061	75391	11891	63500	5.34
2005-06	T1	3901	41448	8532	32422	73870	3015	70855	23.50
	T2	4271	45379	10420	39596	84975	9021	75954	8.42
	T3	5004	53168	11480	43624	96792	12696	84096	6.62

T_1 = (60-45-0 kg N-P_2O_5-K_2O ha^{-1})
T_2 = (120-90-60 kg N-P_2O_5-K_2O ha^{-1} + 5 kg Zn ha^{-1})
T_3 = (FYM @20 t ha^{-1} plus 60-90-60 kg N-P_2O_5-K_2O-Zn ha^{-1})

Table 13. Changes in soil properties over time at different locations.

Soil properties at the end of each year		Year	T_1	T_2	T_3
Physical	Bulk Density (g cm^{-3})	1st year	1.35	1.33	1.47
		2nd year	1.30	1.22	1.17
		3rd year	1.19	1.21	1.06
	WHC Available water (g kg^{-1})	1st year	153.1	151.0	167.5
		2nd year	150.1	158.4	165.0
		3rd year	169.5	172.1	188.9
Chemical	Organic Matter (g kg^{-1})	Initial	11.0	1.10	11.0
		1st year	15.5	19.1	21.7
		2nd year	09.3	12.1	13.8
		3rd year	12.6	13.1	17.3
Soil Fertility	P	Initial	3.98	3.98	3.98
		1st year	5.01	10.69	27.75
AB-DTPA Ext. (mg kg^{-1})		2nd year	5.22	9.08	22.75
		3rd year	7.17	13.29	39.04
	K	Initial	88.00	88.00	88.00
		1st year	74.57	75.70	128.20
		2nd year	66.42	86.39	163.20
		3rd year	80.93	110.30	338.5
	Zn	Initial	0.30	0.30	0.30
		1st year	0.68	1.94	3.69
		2nd year	0.45	2.49	2.61
		3rd year	0.47	1.94	2.57
	Cu	Initial	1.95	1.95	1.95
		1st year	1.76	2.25	2.15
		2nd year	1.97	1.85	2.18
		3rd year	0.59	0.85	1.18
	Fe	Initial	7.46	7.46	7.46
		1st year	5.53	5.93	7.61
		2nd year	10.43	13.26	13.94
		3rd year	3.28	3.42	5.02
	Mn	Initial	9.00	9.00	9.00
		1st year	11.32	13.43	13.72
		2nd year	0.93	1.21	1.38
		3rd year	3.37	3.37	6.45

T_1 = (60-45-0 kg N-P_2O_5-K_2O ha^{-1})
T_2 = (120-90-60 kg N-P_2O_5-K_2O ha^{-1} + 5 kg Zn ha^{-1})
T_3 = (FYM @20 t ha^{-1} plus 60-90-60 kg N-P_2O_5-K_2O-Zn ha^{-1})

Changes in soil properties over time

Looking at overall changes in some physical and chemical properties of soil over time (Table 13), it is clear that the physical properties viz. bulk density and water holding capacity were affected by combined application of FYM with inorganic fertilizers i.e. IPNM, over a period of time. Bulk density was reduced and water holding capacity was increased. This effect was due to increased organic matter content through addition of FYM and higher biomass production. These physical properties are very important in dry-land agriculture. This can be explained through their correlation with organic matter content of soil, organic matter available water (r-0.50, 0.58, 0.62 during 2003-2004, 2004-2005 and 2005-2006). Hati *et al*. (2006) observed the lowest bulk density in the surface soil in NPK + FYM treatment. Conservation of moisture by FYM application has been reported by many workers (NFDC, 1998; Jadoon *et al*., 2003; Hati *et al*., 2006). The higher yields would have been due to these properties increasing the fertilizer use efficiency by proliferation of roots and more storage of water reducing runoff.

Available P, K and Zn contents were increased to the adequate levels in T_3 followed by T_2 over T_1 as well as the initial levels of these nutrients. Initial levels of P and K were marginal and initial levels of Zn were deficient. Levels of these were increased over a period of time due to their residual/cumulative effect through addition of these nutrients. There was also an additional effect of FYM addition through releasing organic acids which would have solubilized soil P (Ahmad, 1999) and chelated Zn (Bhatti *et al*., 1982; Barak and Helmke, 1993). These results are supported by the work of other scientists (Patra *et al*., 2000; Yadav *et al*., 2000; Swarup, 2001). Masto *et al*. (2006) reported that applying farm yard manure (FYM) plus NPK fertilizer significantly increased soil organic carbon, microbial biomass, dehydrogenase and phosphatase activities.

There was also an evident effect of treatments on Cu, Fe and Mn contents of soil. This effect was variable during different years. The positive effect during some periods of time would have been due to the chelating effect of organic acids released from FYM as well as higher biomass production.

Effect of cropping systems was also evident on some soil properties. This effect was due to the addition of organic matter through incorporation of crop residues in mungbean-wheat system (NFDC, 1998; Bhatti, 2000; Ali *et al*., 2006).

Similar crop effects on microbial activity have been reported by Manajaiah *et al*. (2000); cropping system with legumes showed relatively higher microbial biomass than other systems.

Conclusions

Under a continuous wheat-mungbean cropping system, the crop yields may be increased by reducing 50% N dose and applying complete doses of PK Zn along with 20 t ha^{-1} FYM to wheat and complete doses of PK Zn to mungbean. This management strategy will improve the sustainability of crop yields. This practice will also improve the physical condition of soil and its fertility status with regard to P and Zn. In the long term, it will become more economical and will also have impact on environment through providing cover during monsoon rains and reducing soil erosion.

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