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Response of irrigated and N- fertilized wheat to legume-cereal and cereal-cereal rotation

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Abstract

A four-year field experiment was conducted during 1998-2002 under irrigated condition at the Research Farm of Nuclear Institute for Food and Agriculture (NIFA), Peshawar, to study the response of wheat to two crop rotations viz., i) wheat following maize, and ii) wheat following soybean and to fertilizer N application. Wheat after maize or soybean was fertilized with 0, 60 and 120 kg N ha^{-1}. The main objective of the research project was to improve the productivity, profitability and sustainability of wheat through legume N management. Including soybean in rotation significantly increased the grain and straw yield of the following wheat in each season in both fertilized and unfertilized N treatments as compared to wheat following maize. On an average, soybean improved the grain yield of wheat by 44.9% (741.7 kg ha^{-1}) in unfertilized, and 14.5 -14.7% (496.4-419.0 kg ha^{-1}) in fertilized N treatments. The yield obtained in soybean-wheat rotation treatment in the absence of N-fertilizer was statistically equal to the yield of 60 kg N fertilizer treatment in maize-wheat rotation. Straw yield increased in similar pattern. The N uptake by wheat straw and grain was increased significantly in each year by soybean rotation and maximum increase was recorded in the absence of N fertilizer. The economic analysis of wheat yield data indicated that an increase in net return of Rs. 8055 ha^{-1} in soybean-wheat rotation was obtained in control (no-N fertilizer). The results further indicated that soybean based rotation reduced the fertilizer N requirement of subsequent wheat by 50%. These results suggest that inclusion of soybean in cropping system maintains soil fertility and enhances wheat crop productivity.

Key words: Crop rotation, soybean/ maize, nitrogen fertilizer, wheat yield

Introduction

Wheat (*Triticum aestivum L.)* is the major staple food crop of Pakistan. It is cultivated on 8.447 m ha of land in Pakistan with 7.338 m ha in irrigated area (MINFAL, 2006). With the population growth rate at around 2.4%, the demand for wheat grain will increase many folds in the years to come. To meet such food demand for increasing population, there is a dire need to increase wheat production accordingly in the country. Higher production can only be realized either through expansion of cultivated area or increasing production per unit area. There seems little scope in the expansion of cultivated area in the light of current population growth. The agricultural lands and water resources are rather declining rapidly to meet the residential demand of people. Thus, the only choice available with us is to enhance production per unit area. The average wheat grain yield remained static at around 2.3 t ha^{-1} in irrigated areas for last many years (MINFAL, 2006). Nutritional stress, including widespread nutrient deficiencies (Rashid, 1994) and low and unbalanced use of fertilizers (NFDC, 1997) are the major limiting factors causing low crop production in Pakistan. Among the plant nutrients, nitrogen deficiency is one of the major yield limiting factors for cereals (Shah *et al.,* 2003), hence nitrogen fertilizer application is an essential input for crop productivity in most areas of the world (Zapata and Cleenput, 1986; Ahmad, 1998; Idris and Mohammad, 2001). With wheat, the most commonly grown cereal, the soil must supply around 30 kg N ha^{-1} in a plant available form (usually as nitrate) for each ton of grain produced (Evans and Herridge, 1986). The problem faced by farmers everywhere is that the capacity of their soils to supply the required quantities of N (30 to 80 kg ha^{-1}) declines rapidly. With continued cereal cropping, the N supplied from the break down of organic matter must be supplemented from other sources (Herridge and Doyle, 1988; McDonald, 1992).

To satisfy the required level of plant nutrients, the farmers are indispensably inclined to use the commercial fertilizers. But during the last few years, the price of fertilizers has shown unprecedented hike and their availability at proper time has been a matter of serious concern (Kabir, 1999). The results are failure to obtain the targeted production and hence the national average yields of major crops are below the demonstrated production potential (Kabir, 1999). It is in such system that the inclusion of legumes in cropping system can play an increasing important role to maintain soil fertility and sustain crop productivity. The ability of legumes to fix

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atmospheric nitrogen, their nodulated roots and plant residues left after harvesting represent a valuable source of organic N (Rowland, 1987). In contrast to earlier findings (Clarke, 1984; Evans and Herridge, 1986), there are now clear evidences that legumes contribute to the soil organic N pool and to subsequent crops production (Herridge and Bergersen, 1988; Giller, 2001).

Research has shown that the yield of cereals grown after legumes are generally increased often as much as 80% compared with cereals grown after cereals. Understanding the N benefits of legume in rotations is important, if they are to be managed for optimum cereal yields and fertilizer N recommendation. Keeping in view the importance of nitrogen fertilizer and legumes value in crop rotation, a long-term field experiment was conducted at the Research Farm of Nuclear Institute for Food and Agriculture (NIFA), Peshawar with the objective to evaluate the effect of legumes based crop rotation system on subsequent wheat productivity and fertilizer N management under irrigated conditions.

Materials and Methods

Site characterization

The experimental site was situated at the Research Farm of Nuclear Institute for Food and Agriculture (NIFA), Tarnab (longitude $71^0 50$, latitude $34^0 01$), Peshawar, Pakistan. The site is located at the altitude of 400 m above sea level in the Peshawar valley of NWFP and has cool climate in winter and warm to hot in the summer. Mean annual rainfall ranged from 380-550 mm during the experimental period of 1998-2002 with slightly summer dominance. Soil of the experimental site was clay loam [Order: *Inceptisols*, Sub order: *Ustepts*, Soil great group: *Haplustepts*, Soil Sub group: *Udic Haplustepts*, Family: *Fine, mixed*, *hyperthermic, Udic Haplustepts, Taru* Soil Series (US Soil Taxonomy)]. The site had been used for various experimental research programmes during the last 22 years. This site was used for potato experiment to evaluate the influence of nitrification inhibitors on N fertilizer use efficiency and crop yield for four years before the establishment of this experiment. Before commencing this experiment, a general maize crop was grown across the site receiving no fertilizer to remove any of the residual fertilizer applied to previous potato experiment. In the following season, the site was sown to wheat to obtain uniform fertility gradient across the site. Before the establishment of experiment, composite soil samples were collected at various depths viz. 0-15, 15-30, 30-60, 60-90, and 90-120 cm and were analyzed for various soil physico-chemical properties (Table 1). Soil texture was determined by the Bouyocous Hydrometer method of Moodie, *et al.* (1954). The proportion of sand in the soil profile ranged between 18 and 20%, silt between 40 and 48%, and clay between 32 and 40%.

The soil organic C, total N and total mineral N were determined according to the methods of Nelson and Sommers (1982), Bremner and Mulvaney (1982) and Keeney and Nelson (1982), respectively. The amount of soil organic C in the surface 0-15 cm was 0.94 %, which gradually decreased to 0.44 % in the lower 90-120 cm depth. The amount of soil total N was 0.061 % in the 0-15 cm to 0.033% in the 90-120 cm depth. The total mineral N was 13.0 $\mu g\ g^{-1}$ soils in the 0-15 cm and 5 $\mu g\ g^{-1}$ in the 90-120 cm depth. Soil pH was determined in soil-water suspension (1:5) with the help of pH meter (McLean, 1982). Soil EC (electrical conductivity) was determined in soil-water suspension (1:5) using the Electrical Conductivity Meter (Rhoades, 1982). The soil was alkaline in reaction (pH 8.2), non-saline (EC 0.5 dS m^{-1}), moderately calcareous, having field capacity of 0.26 $cm^3\ cm^{-3}$ and bulk density 1.62 g cm^{-3}.

Trial description

The response of wheat to fertilizer N and crop rotations viz., i) wheat following maize, and ii) wheat following soybean), was assessed in field experiment conducted at the Research Farm of NIFA, Tarnab, Peshawar for four years (1998/99 through 2001/02). The site was planted to wheat in the first season (1997/98) to obtain uniform fertility gradient across the site. In the following 1998 summer, seven treatments were arranged in a randomized complete block design with four replications. The treatment plot size was 4 x 6 m^2. Three treatments were assigned to maize (+N) and three to soybean (-N). In the following 1998/99 winter, wheat was planted in all treatment plots receiving different N levels as detailed below:

Sr. No	Summer	Winter
1.	Maize + N	Wheat 0 N
2.	Maize + N	Wheat 60 N
3.	Maize + N	Wheat 120 N
4.	Soybean 0 N	Wheat 0 N
5.	Soybean 0 N	Wheat 60 N
6.	Soybean 0 N	Wheat 120 N

This sequence of cropping continued for 4 consecutive summers and 4 winter seasons. Maize was fertilized with 150 kg N ha^{-1} in the first season and with 120 kg N ha^{-1} in the remaining three seasons as urea, half at sowing and half at tasselling stage. Soybean did not receive any N fertilizer in any season. However, its seeds were inoculated with *Bradyrhizobium Japonicum* obtained from NifTAL in each season just before sowing, using the seed pelleting

Table 1. Some properties of soil of the experimental site

Depth (cm)	Organic C %	Total N %	NH_4-N µg g^{-1}	NO_3-N µg g^{-1}	Mineral N µg g^{-1}	Soil moisture %	EC (1:2.5) dS m^{-1}	pH (1:2.5)	Sand %	Silt %	Clay %	Soil texture
00-15	0.94	0.061	4.5	8.5	13.0	14.1	0.5	8.2	20	46	34	Clay loam
16-30	0.90	0.059	4.3	5.6	9.9	15.4	0.5	8.2	20	40	40	Clay loam
31-60	0.67	0.047	3.5	4.4	7.9	10.5	0.5	8.2	18	46	36	Silty clay loam
61-90	0.54	0.040	0	5.4	5.4	19.9	0.5	8.2	20	48	32	Silty clay loam
91-120	0.44	0.033	0	5.0	5.0	19.9	0.5	8.2	18	48	34	Silty clay loam

technique (Vincent, 1970). Both maize and soybean were fertilized with P at 90 kg P_2O_5 ha^{-1} in each season as basal dose in the form of Triple Super Phosphate. Cultivars sown were Azam (maize), and Kharif-93 (soybean) in 1998/1999, and Swat-84 (soybean) in 2000/ 2001. Seeds were sown by hand to about 5-cm depths in rows 60 cm apart. Wheat after maize or after soybean was fertilized with 0, 60, and 120 kg N ha^{-1} as urea in each season, half at sowing and half at boot stage. Triple Super Phosphate at 90 kg P_2O_5 ha^{-1} was applied to all plots as basal dose to ensure that this element is not limiting crop yield. Wheat cultivar sown was Fakhar-e- Sarhad during all years. The seeds were sown by hand to about 5-cm depth in rows 30 cm apart. All crops were irrigated with tube well water when needed. Weeds in each crop were controlled manually or by chemical. Wheat straw and grain yields were recorded from central four rows at crop maturity. The data were analyzed statistically and the means were compared using the computer MSTAT C programme based on the principle of Steel and Torrie (1980).

Results and Discussion

The effect of involving soybean and maize in the cropping system and fertilizer nitrogen was evaluated on the following wheat crop productivity in a field experiment from 1997/98 to 2001/02 under irrigated condition. The results obtained are presented and discussed in the following sections:

Wheat grain yield

The grain yield of wheat responded significantly to the rotation and fertilizer N in each year (Table 2). The grain yield of wheat increased significantly by soybean rotation in each year. On average, the grain yield in the soybean-wheat treatment increased by 44.9% (741.7 kg ha^{-1}) in the absence of N- fertilizer, 14.7 % (419.0 kg ha^{-1}) and 14.5% (496.4 kg ha^{-1}) in the presence of 60.0 and 120.0 kg N levels respectively over maize – wheat rotation. The year wise data showed that maximum increase in yield by soybean-wheat rotation over maize – wheat rotation was recorded in absence of N fertilizer. The yield obtained in soybean-wheat rotation treatment in absence of N-fertilizer was statistically equal to the yield of 60 kg N fertilizer treatment in maize-wheat rotation. The results indicated that legume (soybean) inclusion in rotation supplied up to 60 kg N ha^{-1} to subsequent wheat crop.

Wheat straw yield

The straw yield of wheat also responded to the previous soybean in all the four years (Table 2). The average of four year data showed that wheat straw yield in the soybean-wheat treatment increased by 32.51% (1038 kg ha^{-1}) in the absence of N- fertilizer, 11.0% (576.5 kg ha^{-1}) and 8.8% (568.3 kg ha^{-1}) in the presence of 60.0 and 120.0 kg N levels, respectively, over maize-wheat rotation. The individual year results indicated that wheat crop also responded significantly to the previous soybean and maximum increase in straw yield was recorded in the absence of N fertilizer. These results suggested that legume rotation had a significant effect on wheat productivity.

N uptake by wheat

The results obtained on the effect of involving soybean in the cropping system for four years on N uptake by wheat are presented in Table 3. The results showed that soybean in rotation substantially improved the N uptake by wheat. It was observed that the average grain N uptake was improved by 19.8% (12.3 kg ha^{-1}) in the presence of 120 kg N, 17.26% (8.7 kg ha^{-1}) in the presence of 60 kg N and 50.0% (14.3 kg ha^{-1}) in the absence of fertilizer N. Such increases in straw N by soybean were 9.1% (3.9 kg ha^{-1}) in the presence of 120 kg N, 12.7% (4.4 kg ha^{-1}) in the presence of 60 kg N, and 35.5% (7.5 kg ha^{-1}) in the absence of fertilizer N. The N uptake by wheat straw and grain was increased significantly in each year by soybean based rotation and maximum increase was recorded in absence of N fertilizer.

Economic analysis

The maximum value of Rs. 8055/- (Rupees eight thousand and fifty five) was obtained in control (No-N fertilizer). While increased of Rs. 4525/- and 5087/- was recorded in treatment receiving 60 and 120 kg N ha^{-1},

Table 2. Rotation and fertilizer N effect on wheat yield during 4 years at NIFA

Treatment	Grain yield (kg ha^{-1})			Straw yield (kg ha^{-1})		
	0 kg N ha^{-1}	60 kg N ha^{-1}	120 kg N ha^{-1}	0 kg N ha^{-1}	60 kg N ha^{-1}	120 kg N ha^{-1}
			1998-1999			
WM*	1125 d	2300 c	3175 b	1712 c	4087 b	5875 a
WS**	2000 c	2900 b	4000 a	2537 c	4650 b	5962 a
			1999-2000			
WM	1632 e	2587 d	3333 b	3628 d	5469 c	6580 ab
WS	2413 d	2934 c	3663 a	5191 c	5920 bc	7275 a
			2000-2001			
WM	1494 d	3309 b	3707 a	4106 b	6491 a	6693 a
WS	2249 c	3899 a	4121 a	4901 b	7366 a	7629 a
			2001-2002			
WM	2361 d	3194 bc	3472 ab	3333 d	4861 bc	6667 a
WS	2917 c	3333 bc	3889 a	4305 c	5278 b	7222 a
			Average (1998/99-2001/2002)			
WM	1653.0	2847.5	3266.5	3194.7	5227.0	6453.7
WS	2994.7	3266.5	3421.7	4233.5	5803.5	7022.0

*Wheat after Maize
**Wheat after Soybean

Table 3. Rotation and N fertilizer effect on N uptake of wheat yield during 4 years at NIFA

Treatment	Grain N yield (kg ha^{-1})			Straw N yield (kg ha^{-1})		
	0 kg N ha^{-1}	60 kg N ha^{-1}	120 kg N ha^{-1}	0 kg N ha^{-1}	60 kg N ha^{-1}	120 kg N ha^{-1}
			1998-1999			
WM*	18.2 d	38.9 c	54.9 b	7.0 e	17.2 c	22.9 ab
WS**	38.0 c	51.9 b	79.6 a	12.7 d	20.5 bc	26.2 a
			1999-2000			
WM	26.7 e	42.4 d	60.6 b	21.0 e	34.4 cd	44.1 b
WS	41.3 d	51.6 c	68.9 a	32.2 d	37.3 c	48.7 a
			2000-2001			
WM	25.8 d	59.2 b	67.5 b	30.4 b	47.4 a	50.8 a
WS	39.8 c	71.3 ab	77.9 a	36.3 b	56.0 a	56.4 a
			2001-2002			
WM	43.9 d	61.0 bc	65.3 ab	26.0 d	38.9 bc	52.7 a
WS	52.5 c	61.7 b	71.2 a	33.1 c	41.7 b	54.9 a
			Average (1998/99-2001/2002)			
WM	28.6	50.4	62.1	21.1	34.5	42.6
WS	42.9	59.1	74.4	28.6	38.9	46.5

*Wheat after Maize
**Wheat after Soybean

respectively (Table-4). It is thus evident that legume based rotation is more beneficial and is the key to enhance wheat productivity in the region

Discussion

Wheat responded considerably to the previous soybean during four years of rotation experiment at the Research Station, NIFA. When wheat was grown after soybean (S:W), yields were increased compared with wheat grown after maize (M:W). The average increase in grain yield of S:W over M:W was 44.9% (741.7 kg ha^{-1}) in N unfertilized and 14.5-14.7 % (496.4 - 419.0 kg ha^{-1}) in the N fertilized wheat. The straw yields of wheat responded similarly to the previous soybean in all four years of the experiment. It was observed that the effect of soybean was much higher in the N limiting system. The rotational benefits of soybean are consistent with results published/reported elsewhere. More recently, Shah *et al.* (2003) reported 36% increase in wheat yields following mung bean in four years long rotation experiment in the rain-fed Swat valley of NWFP. In a field experiment in Peshawar valley, rain-fed wheat responded to

Table 4. Economic value of net increases in wheat yields by previous soybean cropping during 4 years at NIFA

Treatment	Net increase in wheat yield		Value of increased wheat yield		Total value of increased yield (Rs. ha^{-1})
	Grain	Straw	Grain	Straw	
	(kg ha^{-1})		(Rs. ha^{-1})		
Soybean effect in 0 N treatment	741.7	1038.8	5562.7	2493	8055.7
Soybean effect in 60 N treatment	419.0	576.5	3142.0	1383	4525.0
Soybean effect in 120 N treatment	496.5	568.3	3723.7	1364	5087.7

Price of wheat used was Rs. 7.50 per kg for grain and Rs.2.40 per kg for straw as was the market price during the experimental period (1999-2002)

both lentil and chickpea when involved in rotation with it (Mohammad *et al*., 2003).

This experiment was conducted on fine-textured soil (silty clay), low in organic matter and deficient in nitrogen. With the long term intensive continuous cereal cropping without legume rotation resulted in general decline in soil N fertility and structural degradation of the surface soil. With continuous cereal cropping, the soil surface becomes crusted and so dense that germination and root growth are impeded (Reeves, 1991). To maintain soil fertility and surface structural condition in an intensive cropping system, stubble/ organic matter must be retained. However, due to energy crises, the farmers in our country usually use the crop stubble, residues and animal dung for fuel. In such situations, legumes incorporation in the cropping system can play an increasingly important role. Legume has a highly beneficial effect on soil structure, by increasing the stability of aggregates through improved soil organic matter content (Ryan *et al.,* 1993). Leguminous crops add appreciable amount of residue (leaves and roots) to soil as compared to cereal and thus enhance the soil N, organic matter status and soil structure, which contribute to yield improvement. Many studies have verified (Rowland *et al.,* 1988; Evans *et al.,* 1991) that N is a key factor in the response of cereals following legumes compared with cereals following non-legumes. Chalk (1998) reviewed and reported that many studies have shown that cereals derive both yield and N benefits from rotations with grain legumes compared with cereal monoculture. The yield advantage may be entirely due to N or to other factors, or to a combination of both. The cereal in the legume-cereal rotation may benefit from the transfer of biologically fixed N, and from mineral N spared under the antecedent. Difference in rotational effect amongst the crop legume species appears to be minor. However, effects of legumes were strongly correlated with the amounts of nitrate in top 120 cm of soil profiles, which in turn appeared to be influenced by nodulation and general vigour of the legume (Ahlawat *et al*., 1981; Marcellos, 1984). Results from legume-based experiments in a number of countries have been published (Marcellos, 1984; Jessop and Mahoney, 1985). In most cases, wheat following grain legumes yielded more than wheat following wheat, irrespective of the species of legume. The contribution of the legume is often quantified in terms of yield improvement in the absence of fertilizer N and in the amount of fertilizer N required in the cereal-cereal sequence to match production in the legume-cereal sequence. Reported yield responses to previous legume crops are mainly in the range of 1-2 t ha^{-1}, representing 50-80% increase over yields in the cereal-cereal sequences (Herridge *et al.,* 1995; Peoples *et al.,* 1995). These responses are equivalent to applications of 40-100 kg N ha^{-1} as fertilizer[1] (Ahlawat *et al.,* 1981; Schultz, 1995; Dalal *et al.,* 1998). Similarly, in our experiments, the responses at zero N-level in soybean treatment are statistically equivalent to the treatments receiving 60 kg N ha^{-1} as fertilizer in maize-wheat system. The grain yield of the following wheat increased by 44.9% (741.7 kg ha^{-1}) and straw by 32.51% (1038.8 kg ha^{-1}) in the non N-fertilized.

Like the yield, the N uptake by wheat was improved in soybean treatments than those following maize. Over all, maximum increase in N uptake in grain (14.3 kg ha^{-1}) was recorded in non- N fertilized treatments as compared to 8.7 kg ha^{-1} in 60 kg N ha^{-1} and 12.3 kg ha^{-1} in 120 kg N treatment in all four years. The results suggested that soybean increase the uptake at all levels of applied N but the response was clearly indicated in the non-N fertilized like the grain yield data. The experiments conducted elsewhere confirm our results. The results of many trials conducted at several locations in Australia have shown 2% increase in grain protein of wheat following field pea (P:W) than wheat following wheat (W:W) in the absence of nitrogen fertilizer (Rowland *et al.*, 1993). The N uptake was depending on the yield of crop. Chalk (1998) reviewed and reported that many studies have shown that cereals derive both yield and N benefits from rotations with grain legumes compared with cereal monoculture. The yield advantage may be entirely due to N or to other factors, or to a combination of both. The cereal in the legume-cereal rotation may benefit from the transfer of biologically fixed N and from mineral N spared under the antecedent.

Conclusion

Wheat responded significantly to the previous soybean in each year. On average, soybean increased the grain yield of the following wheat by 44.9% (741.7 kg ha^{-1}) in the non N-fertilized and 14.5-14.7% (496.5- 419.0 kg ha^{-1}) in the N-fertilized treatment. The N uptake by wheat was improved in soybean treatments than those following maize. Over all, maximum increase in N uptake in grain (14.3 kg ha^{-1}) was recorded in non- N fertilized treatments as compared to 8.7 kg in 60 kg N ha^{-1} and 12.3 kg in 120 kg N treatment in all four years. The economic analysis of wheat yield data indicated that an increase in net return value of Rs. 8055 ha^{-1} (Rupees eight thousand and fifty five) in soybean-wheat rotation was obtained in control (No-N fertilizer).

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