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Nitrogen, Yield and Economic Benefits of Summer Legumes for Wheat Production in Rainfed Northern Pakistan

[1]S. Ali, [2]G.D. Schwenke, [3]M.B. Peoples, [2]J.F. Scott, [2]D.F. Herridge
[1]University of Arid Agriculture, Rawalpindi, Pakistan
[2]NSW Agriculture, RMB 944, Tamworth, NSW, Australia 2340
[3]CSIRO Plant Industry, P.O. Box 1600, Canberra, ACT, Australia, 2601

Abstract: The objectives of the reported research were to compare, using gross margin, dominance and marginal analysis, summer legume-wheat (*Triticum aestivum*) and fodder maize (*Zea mays*)-wheat systems in northern Pothwar, Pakistan. Legume species were soybean, mungbean and black gram. Data on legume shoot and grain yields of dry matter (DM) and nitrogen (N) and N_2 fixation, using natural ^{15}N abundance, were combined with grain yields of subsequent wheat crops for inclusion in the economic analyses. Mean grain yields for the three legumes were 2.7 (soybean), 0.4 (mungbean) and 1.1 t ha^{-1} (black gram). Maize not fertilized with N produced 7.2—8.9 t ha^{-1}, compared with 5.8—13.2 t ha^{-1} when fertilized. Estimates of the proportion of legume N derived from the atmosphere (%Ndfa) were 31—64 % for soybean, 37—44 % for mungbean and 42—48% for black gram. Both legume rotation and fertilizer N significantly improved the yields of following wheat crop. In the absence of fertilizer N, increases were 15—70% for DM and 14—67% for grain yield, relative to maize. When the wheat was fertilized with N, the legume benefits disappeared. Responses of the wheat to fertilizer N, irrespective of prior crop, were large, ranging from 75 to 276%. Gross margin analysis indicated the black gram/N-fertilized wheat and soybean/N-fertilized wheat sequences to be the most profitable, with the large variation in gross margins (Pakistani Rs. 2861 to Rs. 115500) reflecting the wide range of yields and grain prices. Dominance analysis confirmed the economic benefits of black gram-based sequences, particularly at low to intermediate levels of input. These results highlight the need for thorough economic, as well as biological, analysis of cropping options.

Key words: Nitrogen fixation, summer legumes, fertilizer N, N benefit, gross margin, economic analysis, dominance analysis, marginal analysis

Introduction

The benefits of legumes to soil nitrogen (N) fertility and cereal yields have been widely reported for a large number of agricultural production systems (Toomsan *et al.*, 1995; Felton *et al.*, 1998; Schulz *et al.*, 1999; Ahmad *et al.*, 2001). Economic analysis of these systems has, by contrast, received scant attention (Armstrong *et al.*, 1998). This is surprising because farmers would be more likely to adopt legumes in rotation with cereals if they were convinced of the economic advantage of doing so. The advantage would come through the value of the legume grain or fodder and through the benefits to cereal production on the same land, i.e. higher cereal yields coupled with reduced fertilizer N requirements.

In the Pothwar region of the northern Punjab, Pakistan, low soil N fertility has been recognized as a key factor contributing to inefficient water use and sub-optimal cereal yields (Khan *et al.*, 1989; Ahmad *et al.*, 1996). About 70% of the 1 million ha of the cultivated Pothwar are cropped to cereals, principally wheat (*Triticum aestivum*). Chickpea (*Cicer arietinum*) is widely grown in the southern, drier part of the Pothwar, with small areas of groundnut (*Arachis hypogaea*), mungbean (*Vigna radiata*), black gram or mashbean (*Vigna mungo*) and soybean (*Glycine max*) grown in the wetter, more northerly parts (Agricultural Statistics of Pakistan, 1995). The most common sequences of crops are winter wheat-summer maize (*Zea mays*) in the north and wheat or chickpea with a summer fallow in the drier south. Current management by farmers is at very low level of technology (Khan *et al.*, 1989). Farmers do not apply fertilizer N at the rates required for high levels of cereal productivity due to high costs, uncertainty of returns and lack of clear guidelines (Annual Report ARI Tarnab, 1991).

Development and adoption of summer crop legumes in set rotations with winter wheat or as intercrops with summer maize may enhance the soil N fertility, reduce fertilizer N inputs and improve overall productivity and profitability, provided N_2 fixation levels of the legumes were high. Such data are currently not available for this region, in contrast to other regions, nor are data available on the economic impacts of the legumes. The objectives of the reported research were to compare, using gross margin, dominance and marginal analysis, summer legume-wheat and fodder maize-wheat systems in the northern Pothwar. Legume species were soybean, mungbean and black gram. Data from three experimental sites on legume shoot and grain yields of dry matter (DM) and N and N_2 fixation were combined with grain yields of subsequent wheat crops for inclusion in the economic analyses.

Materials and Methods

Sites and experiments: Two of the field experiments commenced in July 1997, one at the University of Arid Agriculture Rawalpindi (UAAR) (33°38'N, 73°04'E), the second in a farmer's field near Fatehjang) (33°35'N, 72°46'E). A third rotation experiment commenced in July 1998 at the National Agricultural Research Center (NARC), Islamabad (33°42'N, 73°10'E). The climate of the region is warm temperate. Average annual rainfall ranged from 950 mm at Fatehjang to 1200 mm at NARC, with a summer dominance (70% between July and September). Soils at the three sites were either silty clay loams or silty loams (Typic Ustochrepts). General characteristics of surface soil at the sites are given in Table 1.

Table 1: Surface soil (0-10 cm) properties at the three experiment sites in the Pothwar region of northern Pakistan

Property	UAAR	Fatehjang	NARC
Texture	Silty clay loam	Silty clay loam	Silty loam
Bulk density (Mg m^{-3})	1.60	1.37	1.54
pH (water)	7.2	7.6	7.4
EC (dS m^{-1})	0.33	0.55	0.60
Organic C (%)	0.66	0.59	0.66
Olsen P (mg kg^{-1})	7.8	4.0	4.5

At each site, the summer crops soybean (cultivar NARC-1), mungbean (NM-92), black gram (NARC-2), and fodder maize (Neelam), were sown at rates of 100, 20, 20 and 35 kg ha^{-1}, respectively. Sowing dates were 21st July 1997 (UAAR), 2nd August 1997 (Fatehjang) and 21st July 1998 (NARC). Basic plot size was 5 x 5 m^2. Experimental design was a randomized complete block with four replications. Maize plots were either unfertilized (UAAR and Fatehjang) or fertilized with 100 kg N ha^{-1} as urea at sowing (all sites). The three legume species were inoculated at sowing with effective brady rhizobia, supplied by Dr M. Aslam, NARC, Islamabad.

Table 2: Input costs and output prices used in the economic analyses of cropping sequences at the three experimental sites in the Pothwar region of northern Pakistan

Factors	Cost/Price unit^{-1} (Rs)[a]	Cost/Price ha^{-1}(Rs)[a]
Input		
Seed (kg)		
Soybean	16	1600
Mungbean	24	480
Black gram	34	512
Maize	6	210
Wheat	9.5	950
Fertilizer (kg)		
Urea (50kg ha^{-1})	7	763
Urea (100kg ha^{-1})	7	1522
Labour (hr)		
Fertilizer application	12.5	375
Planting	12.5	375
Harvest (< 2.5t ha^{-1})	12.5	1298
Harvest (> 2.5t ha^{-1})	12.5	1665
Output		
Grain (kg)[b]		
Soybean	15.2	
Mungbean	23.2	
Black gram	33.2	
Wheat	6.7	
Straw (kg)		
Maize		11860[c]
Wheat	4	

[a] US$1 = Rs. 64
[b] Field price, i.e. gross price less threshing and bagging costs
[c] Value of maize fodder

About two weeks after grain harvest of the summer crops, all plots were sown with wheat (Inqalab-91) at a rate of 100 kg ha^{-1} (sowing dates: 6th November 1997 (UAAR), 7th November 1997 (Fatehjang) and 11th November 1998 (NARC)). The plots were split for N fertilizer at 0 and 100 kg N ha^{-1} (UAAR and Fatehjang), or 0, 50 and 100 kg N ha^{-1} (NARC), applied as urea at sowing.

Phosphorus was added to all plots (both summer and winter) at sowing as single superphosphate (35kg P ha^{-1}). Weeds were controlled by hand hoeing. Plant populations, estimated 4—6 weeks after sowing, were reasonably uniform across the three sites, averaging 11 plants m^{-2} for maize and 19 (soybean), 30 (mungbean) and 29 plants m^{-2} (black gram). Wheat plant populations were 170 m^{-2} (UAAR) and 67 m^{-2} (NARC) with no treatment effects. There were no wheat population data for Fatehjang.

At estimated maximum biomass of the summer crops (late pod-fill stage in the legumes), whole shoots were harvested from a 1 m^2 quadrat in each plot, oven dried at 80°C to a constant mass, then weighed, finely ground (< 0.1 mm), and analyzed for total N and $\delta^{15}N$ using an automated N and C analyzer / mass spectrometer (ANCA-SL/20-20 stable isotope mass spectrometer, Europa Scientific, Crewe, UK). Maize samples were used as the non-fixing reference plant in N_2-fixation calculations. Grain yield and N were determined from harvested 1 m^2 quadrats. Wheat biomass and grain yield was assessed at crop maturity from two 1 m^2 quadrats in each plot. Harvest dates were: 2nd May 1998 (UAAR), 28th April 1998 (Fatehjang) and 30th April 1999 (NARC)).

In the determinations of N_2 fixation, shoot ^{15}N values were expressed with reference to air N_2 as follows:

$$\delta^{15}N = 1000\ (R_{sample} - R_{air}) / R_{air} \qquad (1)$$

where R is the ratio mass 29/mass 28. The proportion of plant N derived from atmosphere (%Ndfa) was then calculated:

$$\%Ndfa = 100\ (x-y) / (x-z) \qquad (2)$$

where 'x' is the $\delta^{15}N$ of shoots of the maize deriving all N from the soil; 'y' is the $\delta^{15}N$ of sampled legume shoots; and 'z' is the $\delta^{15}N$ of the legumes receiving all N from N_2 fixation. The value for 'z' used for all three species was -2.50 ‰ (Peoples *et al.*, 1989).

Statistical analysis: Field experiment data were analyzed by analysis of variance using S-Plus. Any spatial auto-correlations in the data were accounted for as replicate effects then removed from the residuals as random components. Log transformations were conducted on non–normal data where necessary.

Economic analysis: Gross margin, dominance and marginal analyses were used to determine the profitability of different summer crop-wheat sequences. Briefly, the gross margin was defined as gross income less the variable costs incurred in achieving that income. Variable costs were those that were directly attributable to the enterprise, e.g. for seed, fertilizer. The gross margin was not equivalent to gross profit because it did not include fixed or overhead costs such as depreciation, interest payments or permanent labour, all of which had to be met regardless of enterprise size (Scott, 2001). For this study, gross margins were calculated for each season using all estimated input costs and output income. Cumulative gross margins were then calculated by summing gross margins for each treatment across the two seasons.

Dominance analysis, an initial examination of costs and benefits, was used to eliminate less optimal and identify the most optimal treatments for farmers (CIMMYT, 1988). Tonye and Titi-Nwel (1995) used dominance analysis to evaluate methods of alley cropping under a maize/groundnut cropping system in Cameroon, Africa. To undertake dominance analysis, the treatments were first listed in order of increasing variable costs. Any treatment that had net benefits less than, or equal to, those of a treatment with lower variable costs was dominated. Therefore, dominated treatments had less net benefits per unit increase in extra costs than other treatments and would return less benefit for the investment. The net benefit curve was then derived to illustrate the most economic treatments.

Marginal analysis uses budgets to compare, amongst treatments, variable costs with the net benefits of those treatments (CIMMYT, 1988). This enables farmers to relate additional costs to the increased net benefits. We calculated the marginal rates of return for the dominant treatments. Thus, the marginal rate of return indicates what the farmer would have gained, given the results obtained in the trial, in return for their extra investment when changing from one practice to an other.

All input costs and output prices used in the economic calculations are summarized in Table 2. It was assumed that seed, fertilizer spreading and harvesting were undertaken by family labour. Therefore it was necessary to estimate the opportunity cost of the labour (CIMMYT, 1988). Estimated labour required for fertilizer application and seed broadcasting was 5 hours ha^{-1} per 6-person family. Harvesting was assumed to take 17.3 hours ha^{-1} per 6-person family for a crop yielding 3 t ha^{-1} or less, and 22.2 hours ha^{-1} per 6-person family for a crop yielding more than 3 t ha^{-1}. The wage rate used was Rs. 12.5 hour^{-1}, based on a Rs. 100 wage for an 8-hour day (US$1 = Rs. 64). The prices used for the crops were current field prices, i.e. the price received for the crop less any harvest (threshing and bagging) and sale costs.

Results and Discussion

Yields of legumes and maize: Shoot biomass yields were highest at UAAR site and similar at the other two sites, reflecting to a large extent July-October rainfall (UAAR – 1070 mm; Fatehjang – 770 mm; NARC – 890 mm) (Table 3). Of the legumes, soybean consistently produced the largest crops (average of 5.5 t ha^{-1} shoot DM and 98 kg ha^{-1} shoot N), compared with 3.1 and 3.6 t DM ha^{-1} and 52 and 62 kg N ha^{-1} for mungbean and black gram, respectively. Maize responded to fertilizer N at UAAR site.

Soybean grain yields were also much greater than those of the mungbean and black gram. Averages for the three sites were 2.7

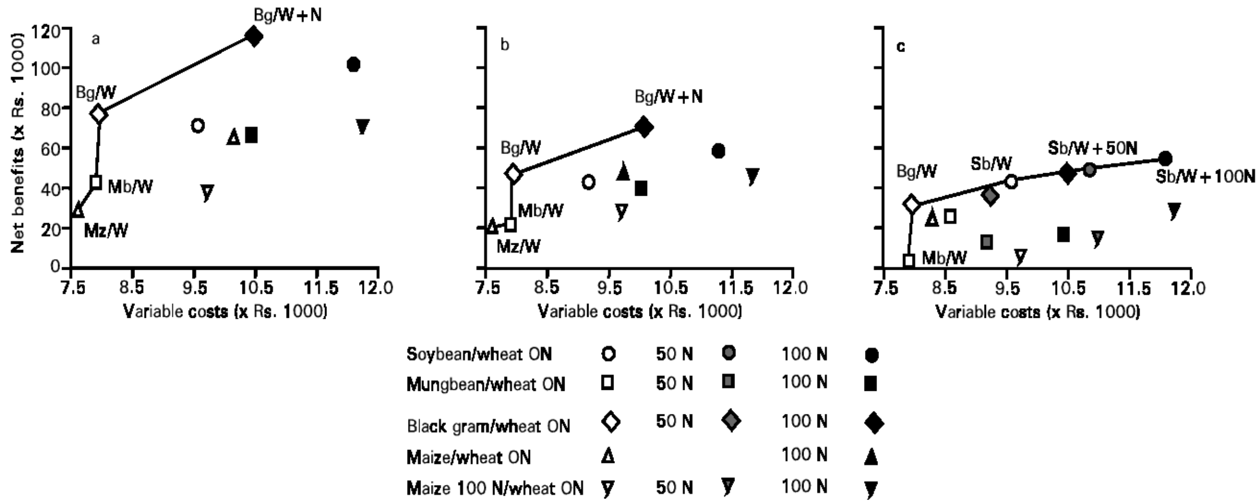

Fig. 1: Net benefit curves for rotation x N rate treatments from (a) UAAR - 97, (b) Fatehjang - 97, and © NARC - 98 field experiments in the Pothwar region of the Punjab, Pakistan. Dominating treatments are joined by a solid line and labeled on the graph.

Table 3: Shoot, grain and N_2 fixation data for soybean (Sb), mungbean (Mb) black gram (Bg) and maize (Mz) shoot at 3 experimental sites in the Pothwar region of the Punjab, Pakistan (UAAR, Fatehjang and NARC). Standard errors of difference between means (S.E.D.) are shown

Crop	Shoot DM (t ha^{-1})	Shoot N (kg ha^{-1})	Grain yield (t ha^{-1})	Grain N (kg ha^{-1})	δ^{15}N ($^0/_{00}$)	%Ndfa
UAAR - 97						
Sb	6.7	96	3.3	222	-0.28	31.00
Mb	4.4	73	0.7	28	-0.47	37.00
Bg	4.8	76	1.5	61	-0.81	48.00
MzON	8.9	56	n.d.	n.d.	0.72	
Mz+N	13.2	121	n.d.	n.d.	1.56	
S.E.D.	0.6	16	0.3	9	0.18	5.7
Fatehjang-97						
Sb	3.6	37	1.9	114	-1.19	64.00
Mb	2.4	45	0.3	11	-0.49	44.00
Bg	2.9	51	0.9	33	-0.39	42.00
MzON	7.2	62	n.d.	n.d.	1.10	
Mz+N	7.4	93	n.d.	n.d.	2.63	
S.E.D.	1.6	17	0.7	14	0.31	11.00
NARC - 98						
Sb	6.2	161	3.0	189	-0.52	n.c.
Mb	2.5	37	0.1	5	0.10	n.c.
Bg	3.2	59	1.0	38	-0.78	n.c.
Mz+N	5.8	36	n.d.	n.d.	4.11	
S.E.D.	0.8	21	0.4	15	0.17	

n.d. not determined, n.c. not calculated because the non N_2-fixing maize had been supplied with fertilizer N and therefore could not be used as the reference in the %Ndfa calculation

Table 4: Prior crop [soybean (Sb), mungbean (Mb), black gram (Bg) and maize (Mz)] and N fertilizer effects on wheat dry matter and grain yield at 3 experimental sites in the Pothwar region of the Punjab, Pakistan (UAAR, Fatehjang and NARC). Standard errors of difference between means (S.E.D.) for the interaction of prior crop and fertilizer N are shown

N rate (kg ha^{-1})	Shoot DM (t ha^{-1}) following					Grain yield (t ha^{-1}) following				
	Sb	Mb	Bg	MzON	Mz+N	Sb	Mb	Bg	MzON	Mz+N
UAAR - 97										
0	5.7	6.5	6.9	4.7	7.3	2.4	2.8	2.8	2.1	3.0
100	12.2	11.9	14.8	12.0	13.8	5.2	4.9	6.2	5.1	6.0
S.E.D.	1.14					0.49				
Fatehjang - 97										
0	3.4	3.1	2.3	2.0	3.8	1.5	1.2	1.3	0.9	1.4
100	5.1	5.2	6.6	5.7	5.5	1.9	2.2	2.2	2.4	2.3
S.E.D.	1.06					0.45				
NARC - 98										
0	3.2	3.4	3.0	n.d.	2.3	1.2	1.2	0.9	n.d.	0.6
50	5.9	7.0	5.3	n.d.	5.7	2.3	2.8	2.0	n.d.	2.2
100	8.4	8.6	9.0	n.d.	10.4	3.2	3.5	3.6	n.d.	4.4
S.E.D.	0.98					0.55				

n.d. not determined

Table 5: Estimated income, costs and gross margins of different crop sequences at 3 experimental sites, UAAR, Fatehjang and NARC, in the Pothwar region of the Punjab, Pakistan. All values are expressed as Pakistani rupees (US$1 = Rs.64). Where appropriate, values rounded off to 4 significant figures

Crop sequence	Income	Costs	Gross margin
UAAR - 97			
Sb/W	80050	9363	70690
Sb/W+100N	112970	11630	101340
Mb/W	50040	7876	42160
Mb/W+100N	76400	10140	66260
Bg/W	84340	7908	76430
Bg/W+100N	125170	10170	115000
Mz/W	35620	7606	28010
Mz/W+100N	73760	9870	63890
Mz+N/W	47790	7500	38290
Mz+N/W+100N	82270	11760	70510
Fatehjang - 97			
Sb/W	52100	8996	43100
Sb/W+100N	68860	10890	58970
Mb/W	30020	7876	22140
Mb/W+100N	49600	9776	39830
Bg/W	54680	7908	46770
Bg/W+100N	79590	9805	69780
Mz/W	28170	7606	20560
Mz/W+100N	56240	9503	46740
Mz+N/W	38850	9500	29350
Mz+N/W+100N	58160	11400	46760
NARC - 98			
Sb/W	52590	9363	43230
Sb/W+50N	59980	10500	49480
Sb/W+100N	66350	11620	54730
Mb/W	10740	7876	2861
Mb/W+50N	21740	9014	12740
Mb/W+100N	26780	10140	16640
Bg/W	39191	7908	31280
Bg/W+50N	46370	9046	37320
Bg/W+100N	57250	10170	47080
Mz+N/W	15620	9500	6120
Mz+N/W+50N	26700	10640	16060
Mz+N/W+100N	41060	11760	29300

Table 6: Marginal analysis of dominant treatments (crop sequences) at 3 experimental sites, UAAR, Fatehjang and NARC, in the Pothwar region of the Punjab, Pakistan. All monetary values are expressed as Pakistani rupees (US$1 = Rs.64). Where appropriate, values rounded off to 4 significant figures

Crop sequence	Marginal costs (Rs)	Marginal net benefit (Rs)	Marginal rate of return (%)
UAAR - 97			
Mz/W	-	-	-
Mb/W	270	14150	5241
Bg/W	32	34270	107090
Bg/W+100N	2264	38560	1703
Fatehjang - 97			
Mz/W	-	-	-
Mb/W	270	1582	586
Bg/W	32	24630	76970
Bg/W+100N	1897	23010	1213
NARC - 98			
Mb/W	-	-	-
Bg/W	32	28420	88810
Sb/W	1455	11950	821
Sb/W+50N	1138	6245	549
Sb/W+100N	1123	5253	468

(soybean), 0.4 (mungbean) and 1.1 t ha^{-1} (black gram). Grain N data showed even larger species effects, with average grain N yields of 175 kg ha^{-1} (soybean) 15 kg ha^{-1} (mungbean) and 44 kg ha^{-1} (blackgram).

Legume N_2 fixation: The low natural ^{15}N abundance values for both N_2-fixing legumes and reference maize crops at the three sites produced %Ndfa estimates of 31—64% for soybean, 37—44% for mungbean and 42—48% for black gram (Table 3). Soybean %Ndfa values were similar to those from farmer crop surveys in northwest Thailand (range 45—74%) (A. Bhromsiri and M.B. Peoples, unpublished data), and the Hill and Terai regions of Nepal (mean of 62%) (Maskey *et al.*, 2001). They were substantially higher than for soybean in a local farmer crop survey (mean of 16%) (Ali *et al.*, 1997), most likely reflecting effective nodulation and N_2 fixation of the experimental crops. Although inoculation of chickpea is commonplace in the Pothwar, most farmers in the region do not inoculate summer legumes, and, particularly in the case of soybean, apply moderate to high rates of fertilizer N. Whereas mungbean and black gram nodulate readily with naturalized populations of rhizobia in the soil, soybean, a relatively new crop in the Pothwar, requires specific rhizobia (M. Aslam, personal communication; Ahmad *et al.*, 2001).

Mungbean and black gram %Ndfa values were similar to those from farmer crop surveys of the same species in the North West Frontier Province of Pakistan (mean of 47%) (Shah *et al.*, 1997) and the Hill and Terai regions of Nepal (black gram mean of 47%) (Maskey *et al.*, 2001). They were also similar to the values of 28—38% for mungbean and 40—44% for irrigated black gram in the middle Punjab reported by Ahmad *et al.* (2001), but less than those from a local Pothwar survey of 12 mungbean and black gram crops (range 45—90%, mean of 77%) (Ali *et al.*, 1997).

Yields of following wheat: For the 0N wheat, shoot DM and grain yields were substantially greater following the three legumes than following the 0N maize (Table 4). Increases were 15—70% for DM and 14—67% for grain yield, which were consistent with many published studies on legume effects on cereal crop yields (Peoples and Herridge, 1990; Dalal *et al.*, 1998; Ahmad *et al.*, 2001). There were residual benefits for the wheat of the fertilizer N applied to the previous maize crops at UAAR and Fatehjang, but not at NARC. The benefits were similar in magnitude to the legume benefits.

When the wheat was fertilized with N, the legume benefits disappeared. Responses to fertilizer N, irrespective of prior crop, were large. Wheat shoot DM increased by an average of 92% and 93% at Fatehjang and UAAR (N rates of 100kg ha^{-1}) and by 100% (50N) and 205% (100N) at NARC. Grain yield responded similarly with average increases of 109% at UAAR, 75% at Fatehjang and 138% and 276% for 50N and 100N treatments at NARC, respectively. It would appear from the magnitude of the N responses that the three sites were very deficient in plant-available N.

Such a result confirms previous reports. A number of surveys and fertilizer trials in the barani areas of northern Pakistan during the past two decades indicate that N has been and continues to be a major limitation to cereal yield. In one study, involving about 8,000 soil samples, 95% were deficient in plant-available N (Khan *et al.*, 1989). Results of 200 trials in the northern Punjab showed that the low average yields (0.9 t ha^{-1}) of wheat not fertilized with N could be increased to > 2.0 t ha^{-1} with inputs of 120 kg fertilizer N ha^{-1} (Annual Report ARI, Tarnab, 1991).

Economic analysis:

Gross margin analysis: Gross margins, as well as incomes and costs, are shown in Rs. per hectare, and are cumulative over the two seasons of cropping (i.e. UAAR and Fatehjang - summer 1997 and winter 1997/8; NARC - summer 1998 and winter 1998/9) (Table 5). For UAAR and Fatehjang, the sequences involving black gram and soybean and N-fertilized wheat returned the highest gross margins, followed by the same species but with unfertilized wheat. Absolute values of the gross margins from Fatehjang were less than those from UAAR because of the lower yields of both legumes and maize and the following wheat (Tables 3 and 4). Results were similar at NARC, although sequences involving soybean provided substantially greater gross margins than the black gram-wheat sequences.

The gross margins, ranging from Rs. 2861 ha^{-1} to > Rs. 110000 ha^{-1} reflected the yields of the various crops (Tables 3 and 4) and their prices (Table 2). Interestingly, effects on the gross margins of N fertilizer and replacing cereals with legumes were similar in this study to an economic study of crop sequences in eastern Australia (Armstrong *et al.*, 1998).

In the latter, winter pulse-wheat sequences had gross margins that were between 10 and 480% greater than the wheat-wheat sequences.

Gross margins do not necessarily indicate the best return on the investment, since each treatment has different costs, stemming from the cost differences in the pulse crops and the differences in N costs. In order to select the treatments providing the best return per rupee invested, the cost and income data (Table 5) were subjected to dominance and marginal analysis.

Dominance and marginal analysis: Dominant treatments, in order of increasing costs, were maize/wheat 0N, mungbean/wheat 0N, black gram/wheat0N and black gram/wheat 100N at both UAAR and Fatehjang (Fig. 1). The soybean-wheat sequences were the best of the dominated treatments, featuring at the intermediate (Rs. 9000—9500) and high-cost levels (RS. 11000—12000).

The marginal costs, income (net benefit) and rate of return figures in Table 6 provide an economic analysis of the return on investment as income is increased amongst the dominant treatments. For example, the mungbean/wheat0N treatment cost Rs. 270 more than the maize/wheat0N treatment, but the income from the former was an extra Rs. 14152, giving a marginal return of 5241%. The very high marginal rate of return associated with replacing mungbean with black gram reflected the substantially greater yields of black gram (Table 3) and the marginally higher price for the grain (Table 2).

Thus, in the UAAR and Fatehjang experiments, the best economic treatment at low variable cost structure (i.e. < Rs. 8000 ha^{-1}) was black gram/wheat without additional nitrogen. The marginal rate of return was high from fertilizing the wheat in that same crop sequence (Fig. 1 and Table 6).

Results of the dominance analysis were similar at NARC site with the mungbean/wheat0N and black gram/wheat0N featuring at low variable costs (Fig. 1c). With increasing costs, the soybean/N fertilized wheat as well as the black gram/N fertilized wheat featured. There appears to be economic advantages in extending the variable cost structure right through to the highest rate of fertilizer N on the wheat (i.e. 100 kg ha) in the soybean/wheat sequence. Marginal rates of return were 549% for moving from fertilizer N rates of 0N to 50N and 468% for moving from 50N to 100N (Table 6).

It should be noted that this economic analysis did not account for extra costs that may vary from farm to farm, e.g. family labour and/or delivery costs associated with getting the urea to the farm. There may also be grazing benefits for farm livestock from grazing weeds during the growing phase of the crop - livestock are commonly used in this area for weed control.

Results of the reported experiments confirm the beneficial effects of legumes on grain yields of following wheat crops in the northern Pothwar region of the Punjab, Pakistan.

However, the legume benefits disappeared when the wheat was fertilized with N. Thus, the region's farmers may consider that the legumes should only be used when fertilizer N is not or cannot be applied to wheat. They may also consider that the maize/wheat sequences are equal to the mungbean/wheat or soybean/wheat sequences when fertilizer N is available. Economic analysis of the data showed, however, that the sequences involving black gram and soybean were far more profitable than the maize/wheat sequences. The best economic option at a low level of input, i.e. < Rs. 8000, was black gram/wheat without N. At higher input levels, marginal analysis indicated that supplying the wheat with fertilizer N (cost about Rs. 2000) would have been justified with marginal rates of return of 1213 and 1703% at UAAR and Fatehjang, respectively. Taken together, these results highlight the need for thorough economic, as well as biological, analysis of cropping options.

Acknowledgments

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