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RESEARCH ARTICLE

Recycling of legume residues for nitrogen economy and higher productivity in maize (*Zea mays*)–wheat (*Triticum aestivum*) cropping system

A. R. Sharma · U. K. Behera

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Abstract Contribution of legumes towards N economy in cereal-based cropping systems is well-known but there has been a gradual decline in the cultivation of grain legumes, threatening sustainability of maize (*Zea mays*)–wheat (*Triticum aestivum*) cropping system in north-western India. A study was made to evaluate and quantify the effect of different grain legumes on productivity, profitability, N economy and soil fertility in maize–wheat cropping system at New Delhi during 2002–2004. Five legumes, viz. blackgram (*Vigna mungo*), greengram (*Vigna radiata*), cowpea (*Vigna unguiculata*), groundnut (*Arachis hypogaea*) and soybean (*Glycine max*) were either intercropped with maize or grown in sole cropping, and their residues were incorporated before the following crop of wheat, which was grown with varying rates of N, viz. 0, 40, 80 and 120 kg N ha^{-1}. Maize-equivalent productivity was significantly more with intercropped greengram (16.1–29.9%), cowpea (24.8%) and groundnut (11.1–16.6%) than in sole maize. Land equivalent ratio and other competitive functions were favourably influenced with intercropped maize + greengram and maize + cowpea. Addition of N through legume residues varied from 11.5–38.5 kg ha^{-1} in intercropped system and 17.5–83.5 kg ha^{-1} in sole cropping, which improved productivity of following wheat to a variable extent. Nitrogen economy in wheat was 21 kg ha^{-1} due to residue incorporation of intercropped greengram, cowpea and groundnut; and 49–56 kg N ha^{-1} of sole cropped greengram and groundnut. Residual soil fertility in terms of organic C and $KMnO_4$-N showed an improvement under maize-based intercropping systems followed by wheat, and the beneficial effect was more pronounced with sole cropping of legumes due to greater addition of residues. Apparent N balance as well as actual change in $KMnO_4$-N at the end of study was positive in most intercropped legumes as well as sole cropping systems, with greater improvement noticed under groundnut, soybean and greengram. Net returns were marginal with maize-based intercropping or sole cropping of legumes, but improved considerably with wheat, particularly when greengram, cowpea and groundnut were grown in the previous season. The studies suggested that inclusion of grain legumes, particularly greengram, cowpea and groundnut was beneficial for improving productivity, profitability, N economy and soil fertility in maize–wheat cropping system.

Keywords Economics · Grain yield · Intercropping · Legumes · Maize-equivalent · N balance · N fertilizer · Residue incorporation

A. R. Sharma (✉) · U. K. Behera
Division of Agronomy, Indian Agricultural Research Institute, New Delhi 110 012, India
e-mail: sharma.ar@rediffmail.com

Introduction

Legumes are widely recognized as builders of soil fertility and contribute substantial amounts of N for sustainability of cereal-based cropping systems. Inclusion of legumes increases soil fertility and consequently the productivity of succeeding cereal crops (Ghosh et al. 2007). Fodder or green manure legumes are more important N economizers than grain legumes (Gangwar and Sharma 1994; Mahapatra and Sharma 1995). The latter are often intercropped with wide-row spaced crops like maize not only for insurance against crop failures as in dryland conditions but also for higher overall productivity and nitrogen economy in the current and following crop. Intercropping is a major method of crop production in most countries of sub-tropical Asia, tropical Africa, and central and south America, which are characterized by smallholder farmers, limited land resources and low crop productivity. Although the area of monocropped cereals and oilseeds exceeds the area under intercropping in Latin America, the number of farmers growing intercrops is still greater than those producing in monocrop systems. Such systems with legumes are adopted for maximizing crop production through optimal use of land resources and obtaining higher economic returns (Reddy and Willey 1980; Mandal and Mahapatra 1990). Introduction of a grain legume in cereal-based cropping system aims at increased productivity and profitability to achieve food and nutritional security and sustainability (Paroda 1997; Swaminathan 1998).

Intercropped legumes benefit the associated cereal crop like maize by either transferring a part of fixed N_2 or sparing effect because of their less N requirement (Singh 1983; Subba Rao et al. 2001; Lupwayi and Kennedy 2007). These also provide a good canopy cover in the early stages to control soil loss through erosion especially on slopped lands and also to control weeds (Khola et al. 1999). The benefits of intercropped legumes vary according to the kind and purpose of crop grown (seed, fodder or green manure), maturity duration, planting geometry, and overall compatibility of the system. The productivity of the main crop of maize may or may not be affected but the overall productivity in terms of crop equivalent yield is generally higher in intercropping than in sole stand (Siddeswaran et al. 1989; Maitra et al. 2000). Most grain legumes shed their leaves towards maturity and the litter together with residues and roots contain varying amounts of biologically fixed atmospheric N_2 which is added to the soil, hence affecting the N economy and productivity of the following wheat crop. The inclusion of legumes and stover incorporation improves the productivity of soil and the grain yield of subsequent non-legume gradually increases owing to release of N and other growth promoting factors (Shivran and Ahlawat 2000). Generally, fertilizer recommendations are made based on the requirement of an individual crop without any regard to the previous crop and its management. However, response of wheat to N is invariably influenced by the previous legume, fertilizer applied and residue management. Although the beneficial effects of intercropped or sole cropped legumes are widely known, the contribution of legume litter and residues on N economy and productivity of following wheat are not adequately investigated. This study was planned to quantify the beneficial effect of grain legumes in sole and intercropped system with maize, and their residue incorporation on the following crop of wheat.

Materials and methods

Field experiments were conducted during 2002–2004 at the research farm of Indian Agricultural Research Institute, New Delhi located at 28.4° N, 77.1° E and 228 m above mean sea level. The soil of the experimental site was sandy loam with pH 7.7, 410 mg organic C kg^{-1} soil, 98.0 mg $KMnO_4$ oxidizable N kg^{-1} soil, 4.53 mg 0.5 N $NaHCO_3$ extractable P kg^{-1} soil, and 116 mg 1.0 N NH_4OAc exchangeable K kg^{-1} soil. Two experiments were conducted; in experiment 1, maize-based intercropping systems involving different grain legumes during summer/rainy season (June–October), followed by wheat during winter/dry season (November–April) during 2002–2003 and 2003–2004; while in experiment 2, the grain legumes were grown in pure stand (2003) followed by wheat during 2003–2004. In experiment 1, six treatments included maize cv. 'Ganga Safed 2' (85 days) intercropped with blackgram cv. 'T 9' (80 days), greengram cv. 'Pusa Vishal' (75 days), cowpea cv. 'No. 88' (95 days), groundnut cv. 'Punjab No. 1' (110 days), and soybean cv. 'Pusa 9702' (110 days) and sole maize. After harvest, the residues of grain legumes were incorporated and the main plot of maize (84 m^2) was sub-divided into four sub-plots (16.8 m^2) for the following wheat cv. 'HD 2687' (150 days) grown with varying rates of N, viz. 0, 40, 80 and 120 kg N ha^{-1}. In the second cropping cycle (2003–2004), the experiment was repeated in the same layout, but the varieties of cowpea and groundnut were replaced with 'V 578' (85 days) and 'JL 24' (105 days), respectively. In experiment 2, the sole crops of grain legumes, viz. greengram, blackgram, cowpea, groundnut and soybean were grown. Wheat was grown after the harvest and incorporation of residues of legume crops at different N rates, viz. 0, 40, 80 and 120 kg ha^{-1}. The varieties and plot size were the same as for experiment 1 during 2003–2004. The experimental design was a randomized block design for the summer season crops, and a split plot design for wheat keeping maize-based intercropping systems (experiment 1) and sole legumes (experiment 2) in main plots, and N rates in sub-plots with 4 replications throughout.

Field was initially ploughed twice in May after the harvest of previously-grown uniform crop of wheat and the main plots of 15.0 × 5.6 m were marked. In experiment 1, uniform dose of 60 kg N + 26.2 kg P and 33.3 kg K ha^{-1} was broadcast in each plot and mixed with cultivator. Maize was sown by end of June with inter-row spacing of 70 cm in both sole and intercropping system. Simultaneously, one row of legume crops was sown in between the two rows of maize in the intercropping system as additive series (Experiment 1). Plant to plant spacing was maintained at 20 cm for maize and 5–7 cm for legumes after thinning at 20 days of growth in both sole and intercropping systems. Top dressing of N @ 60 kg ha^{-1} was done to maize only in two equal splits at 25 and 40 days through hill placement. In experiment 2, legumes were sown in a thoroughly-prepared field by end of June at 35 cm inter-row spacing using a basal dose of 20 kg N + 26.2 kg P ha^{-1}. Thinning was done after 20 days to maintain optimum plant to plant spacing for different crops.

These crops were harvested at different intervals during September–October depending on their maturity. In case of greengram and cowpea, the pods were hand picked twice, groundnut pods were separated after pulling out the roots, and blackgram and soybean were threshed after sun-drying. The fallen leaf litter and residues of the legumes were returned to the respective plots for incorporation. The entire above-ground biomass of maize was removed in both experiments. Wheat was sown by mid-November in a well-prepared field without changing the layout at 20 cm row spacing using 100 kg seed ha^{-1} and uniform basal dose of 26.2 kg P and 33.3 kg K ha^{-1}. The varying rates of N were applied in the sub-plots as per treatments, with 50% at sowing and after first irrigation (25 days after sowing). The crops were irrigated as and when required, and recommended pest control measures were adopted.

Data were recorded on growth and yield performance of crops. Maize-equivalent yield (MEY) in intercropping systems was calculated based on the grain price of the crops as follows:

MEY of intercrop = (Grain yield of intercrop × grain price of intercrop) ÷ grain price of maize. The efficiency of intercropping systems was assessed based on different parameters, such as land equivalent ratio (Rao and Willey 1980), relative crowding coefficient, aggressivity, competitive ratio (Willey and Rao 1980) and area-time equivalent ratio (Allen and Obura 1983). These indices for an intercropping system with area allocation of 50:50 were calculated as follows:

$$\begin{aligned}
\text{Land equivalent ratio (LER)} &= (\mathrm{Yab} \div \mathrm{Yaa}) + (\mathrm{Yba} \div \mathrm{Ybb}) \\
\text{Relative crowding coefficient (RCC, Kab)} &= \mathrm{Yab} \div (\mathrm{Yaa} - \mathrm{Yab}) \\
\text{Aggressivity (Aab)} &= (\mathrm{Yab} \div \mathrm{Yaa}) - (\mathrm{Yba} \div \mathrm{Ybb}) \\
\text{Competitive ratio (CRa)} &= (\mathrm{Yab} \div \mathrm{Yaa}) \times (\mathrm{Ybb} \div \mathrm{Yba}) \\
\text{Area-time equivalent ratio (ATER)} &= [\{(\mathrm{Yab} \div \mathrm{Yaa}) \times \mathrm{ta}\} + \{(\mathrm{Yba} \div \mathrm{Ybb}) \times \mathrm{tb}\}] \div \mathrm{T}
\end{aligned}$$

where, Yaa, yield of sole crop ‘a’; Ybb, yield of sole crop ‘b’; Yab, yield of crop ‘a’ intercropped with crop ‘b’; Yba, yield of crop ‘b’ intercropped with crop ‘a’; ta, duration of crop ‘a’; tb, duration of crop ‘b’; and T, duration of intercropping system.

The saving of N through legumes was worked out based on the relative yields under varying N rates and through calculation of maximum yield (Ymax) and optimum yield (Yopt) based on Nmax and Nopt derivations from quadratic response equations as follows:

$$\text{Nmax} = -\,b \div 2c; \quad \text{Nopt} = \{(Px \div Py) - b\} \div 2c$$

where, b and c are the coefficients of the quadratic equations, and Px and Py are the cost of N fertilizer (Rs 11 kg^{-1}) and price of wheat grain (Rs 8,000 t^{-1}), respectively.

Amount of litter fall and residues of legumes incorporated were measured. Nitrogen content of grain and residues of maize, wheat and legumes was determined by Kjeldahl method (Prasad et al. 2006) to work out the N uptake and addition of N through legume residues. Organic C and $KMnO_4$ oxidizable N in soil was also determined at the termination of study in April 2004. Apparent N balance was determined based on the inputs (N added through fertilizer + N added through legume residues + estimated biological N_2 fixation) and outputs (N uptake by maize + legumes + wheat) for the two cropping cycles in experiment 1 and one cropping cycle in experiment 2. The approximate amounts of biological N_2 fixation by different legumes as reported by Subba Rao (1988) were considered: blackgram 50.0 kg, greengram 52.5 kg, cowpea 67.5 kg, groundnut 132.0 kg, and soybean 89.5 kg ha^{-1}. These values were halved for the intercropping system. Economic analysis of the data was done based the prevailing cost of inputs/operations and price of produce. The cost of cultivation for growing crops involved the expenditure towards land preparation, seed and sowing, fertilizers and their application, pest control, irrigation, harvesting and threshing, and rental value of land (Table 1). Gross returns were worked out based on the price of main produce (grain) and byproduct (stover) of the crop. Net returns were estimated by deducting total cost of cultivation from gross returns, and the net returns per Re invested by dividing the net returns with the cost of cultivation.

Table 1 Cost of cultivation of different crops (per ha basis)

Input/field operation	Maize	Wheat
Land preparation	1,500	1,100
Seed	800	1,600
Sowing	400	400
Fertilizers and their application	2,600	2,000
Thinning	300	0
Irrigations	1,000	2,000
Herbicides	700	400
Insecticides	800	0
Pesticide application	1,000	400
Harvesting, threshing etc.	1,400	1,600
Rental value of land	4,000	4,000
Total	14,500	13,500

The additional cost of cultivation of legumes in intercropping system was: blackgram Rs 1,300, greengram Rs 1,500, cowpea Rs 1,300, groundnut 2,600, and soybean 2,600; while in sole cropping, the total cost was: blackgram Rs 13,000, greengram Rs 13,000, cowpea Rs 13,000, groundnut Rs 15,000, and soybean Rs 15,000

(Rs 40 ≃ 1 US $)

Statistical analysis of the data was done using ANOVA technique and following MSTAT-C software. There was no residual effect of N rates applied to wheat on the following maize in the second cropping cycle (experiment 1); and therefore, these effects were ignored and not presented in the tables.

Results and discussion

Crop productivity

Grain yield of maize decreased due to intercropping with different legumes, and the mean decrease was more pronounced in 2002 (19.1%) than in 2003 (9.4%) (Table 2). In 2002, the yield was significantly lower when cowpea, groundnut and soybean were intercropped with maize, but not with blackgram and greengram. On the other hand, in 2003 the decrease in yield of maize due to intercropping with all legumes remained the same as with sole cropping. These discrepancies occurred due to variation in weather conditions and change in the varieties of intercrops in the two years. In 2002, the crops experienced extreme weather (dry spell and high temperature) till mid-August, which affected the

Table 2 Yield performance of maize and grain legumes in intercropping system (Experiment 1)

Treatment	2002			2003		
	Grain yield of maize (t ha^{-1})	Yield of intercrops[a] (t ha^{-1})	Total maize equivalent grain yield (t ha^{-1})	Grain yield of maize (t ha^{-1})	Yield of intercrops (t ha^{-1})	Total maize equivalent grain yield (t ha^{-1})
Sole maize	2.79		2.79	2.78		2.78
Maize + blackgram	2.54	0.23 (0.62)	3.16	2.55	0.12 (0.32)	2.87
Maize + greengram	2.48	0.28 (0.76)	3.24	2.58	0.38 (1.03)	3.61
Maize + cowpea	2.04	0.21 (0.57)	2.61	2.61	0.32 (0.86)	3.47
Maize + groundnut	2.04	0.42 (1.16)	3.20	2.44	0.29 (0.80)	3.24
Maize + soybean	2.28	0.35 (0.70)	2.98	2.41	0.30 (0.60)	3.01
SE	0.144		0.137	0.143		0.133
CD ($P = 0.05$)	0.434		0.413	NS		0.401

[a] Data in parentheses indicate maize-equivalent yield of intercrops

performance of maize as well as intercrops. Further, prolific foliage growth of cowpea cv. 'No. 88' and longer duration of groundnut cv. 'Punjab No. 1' resulted in greater competition for resources with maize. In 2003, growing of cowpea cv. 'V 579' and groundnut cv. 'JL 24' proved to be more compatible with maize, causing no adverse effect on its performance. Similarly, maize yields were not much affected due to intercropping with blackgram, greengram and soybean due to better compatibility of their varieties. The yield of maize in an intercropping system with legumes may increase (Patra et al. 1999, 2000; Shivay et al. 1999) or decrease (Allen and Obura 1983; Siddeswaran et al. 1989; Maitra et al. 2000), depending on the planting geometry, competitive ability, kind of crops grown, weather conditions etc.

Total maize equivalent yield (MEY) under different intercropping systems improved compared with sole cropping of maize. The maximum increase in MEY was under maize + greengram (16.1%), followed by maize + groundnut (14.7%) in 2002; while in 2003, the trend was maize + greengram (29.9%), followed by maize + cowpea (24.8%) and maize + groundnut (16.6%). Better compatibility of short-statured early-maturing grain legumes with tall-growing maize resulted in not only their better performance without causing little or no competition with maize plants but led to higher overall productivity. Patra et al. (1999) also reported higher maize-equivalent yield when intercropped with groundnut and greengram in 1:1 ratio compared with normally-spaced sole maize. Therefore, selection of appropriate crops and their suitable varieties is an important consideration for success of intercropping system.

Comparison of performance of grain legumes in intercropping and sole cropping systems in 2003 revealed that yields decreased by more than half despite being grown in 50% area under intercropping (Tables 2 and 3). The highest productivity in sole cropping was obtained with soybean and groundnut (1.5–1.6 t ha^{-1}), followed by greengram and cowpea (1.1–1.2 t ha^{-1}), while blackgram performed miserably (0.4 t ha^{-1}). In intercropping system, the yields of greengram and cowpea were 29.6–30.6% of that in sole cropping, while in case of groundnut and soybean, it was only 18.9–19.7%. Decreased productivity of legumes under intercropping was due to the shading effect, the former crops (greengram and cowpea) were more tolerant to reduced light which led to a lower decrease in their productivity. Slow initial growth and longer duration of groundnut and soybean was also responsible for their poor performance in intercropping system.

Incorporation of residues of different legumes in intercropping and sole cropping systems added variable amounts of N (Table 3), which led to a significant influence on the productivity of following wheat (Tables 4 and 5). Addition of residues and N was much higher with groundnut and soybean than other intercrops. Further, the addition was 2–3 times more in sole cropping than in intercropped systems. The stover of all legumes was rich in N (0.91–1.70%), having relatively narrow C:N ratio (<25:1), which resulted in quick N mineralization. The critical N content of organic materials for net

Table 3 Addition of legume residues and nitrogen in intercropping and sole cropping systems

Legumes	Intercropping system (Experiment 1)				Sole cropping (Experiment 2)		
	2002		2003		2003		
	Residues added (t ha^{-1})	N added (kg ha^{-1})	Residues added (t ha^{-1})	N added (kg ha^{-1})	Seed yield (t ha^{-1})	Residues added (t ha^{-1})	N added (kg ha^{-1})
Blackgram	0.92	11.5	1.07	13.4	0.39	1.40	17.5
Greengram	1.12	13.0	1.08	12.6	1.24	2.72	31.6
Cowpea	1.33	12.1	1.24	11.3	1.08	3.17	28.8
Groundnut	1.66	28.3	2.26	38.5	1.47	4.92	83.8
Soybean	1.75	21.7	2.36	29.3	1.58	4.84	60.0
SE	0.092	1.05	0.089	0.99	0.081	0.276	2.77
CD ($P = 0.05$)	0.284	3.23	0.274	3.04	0.249	0.860	8.55

Table 4 Effect of intercropped grain legumes with maize and their residue management on productivity of succeeding wheat (Experiment 1)

Treatment	2002–2003		2003–2004	
	Grain yield (t ha^{-1})	Stover yield (t ha^{-1})	Grain yield (t ha^{-1})	Stover yield (t ha^{-1})
Intercropping systems				
Sole maize	4.16	5.65	3.79	6.08
Maize + blackgram	4.30	5.96	3.91	6.09
Maize + greengram	4.42	6.08	4.02	6.00
Maize + cowpea	4.47	6.15	4.03	6.36
Maize + groundnut	4.41	6.35	3.92	6.45
Maize + soybean	4.35	6.50	3.96	6.22
SE	0.080	0.197	0.078	0.228
CD ($P = 0.05$)	0.241	0.594	0.214	NS
N rates to wheat (kg ha^{-1})				
0	3.31	4.94	3.36	5.72
40	4.15	6.14	3.86	6.17
80	4.77	6.48	4.16	6.52
120	5.18	6.89	4.38	6.39
SE	0.063	0.115	0.064	0.116
CD ($P = 0.05$)	0.179	0.327	0.182	0.329

mineralization is about 1.7–1.8% (Sharma et al. 1998). Enhanced nutrient availability, particularly of N, resulted in improvement in productivity of wheat; the mean increase being relatively small (0.18–0.23 t ha^{-1}) under maize-based intercropping system than under sole cropping of legumes (0.36 t ha^{-1}). The beneficial effect of blackgram was lower due to less addition of residue N, while other legumes were equally effective in increasing the wheat yield. Such beneficial effects of residue incorporation of legumes have been reported widely (Banik and Bagchi 1994; Shivakumar and Mishra 2001; Shivran and Ahlawat 2000), attributed to decomposition of their biomass and thereby increased nutrient availability (Collins et al. 1992; Pawar and Jadhav 1995) and better soil physical condition (Hulugalle et al. 1996).

Mean effect of N rates on wheat yield was significant up to 120 kg N ha^{-1} under maize-based intercropping but only up to 90 kg N ha^{-1} under sole cropping of legumes. There was a differential response of wheat to N rates under intercropping and sole cropping systems. Based on the yield data of 2 years in intercropping system, the response to N was quadratic (Fig. 1), indicating that beneficial

Table 5 Performance of wheat as affected by residue incorporation of preceding legumes and direct N application in 2003–2004 (Experiment 2)

Treatment	Grain yield (t ha^{-1})	Stover yield (t ha^{-1})	N uptake (kg ha^{-1})		
			Grain	Straw	Total
Sole cropping of legumes					
Blackgram	4.02	6.36	81.2	24.9	106.1
Greengram	4.28	6.49	86.7	26.0	112.7
Cowpea	4.10	6.57	84.9	26.5	113.4
Groundnut	4.22	6.75	81.8	27.9	109.7
Soybean	4.14	6.40	82.0	26.6	108.5
SE	0.118	0.245	1.54	0.81	2.07
CD ($P = 0.05$)	NS	NS	4.75	2.49	6.39
N rates to wheat (kg ha^{-1})					
0	3.63	5.96	67.6	23.2	90.8
40	4.09	6.48	80.2	25.7	105.9
80	4.37	6.70	91.4	28.0	119.4
120	4.51	6.91	94.0	28.6	122.6
SE	0.068	0.166	1.46	0.53	2.02
CD ($P = 0.05$)	0.194	0.474	4.17	1.52	5.77

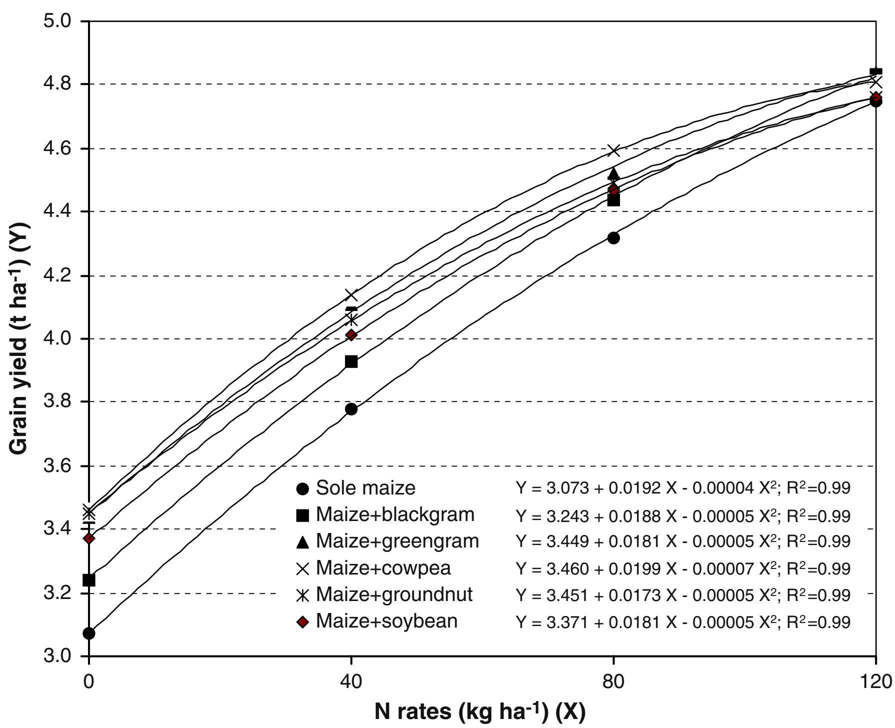

Fig. 1 Response of wheat to varying N rates grown after different intercropped grain legumes with maize (based on mean of 2002–2003 and 2003–2004 (experiment 1)

effect of different legumes was more discernible when N fertilizer rate was zero or low, and decreased with increasing rates. The maximum yields were obtained when residues of intercropped greengram, cowpea or groundnut were incorporated. On the other hand, sole cropping of legumes and incorporation of their residues brought about large differences in wheat yields at varying N rates (Fig. 2). The best performance of wheat was achieved when greengram residues were incorporated, followed by groundnut. The effect of cowpea and soybean was similar, and comparatively lower than greengram and groundnut.

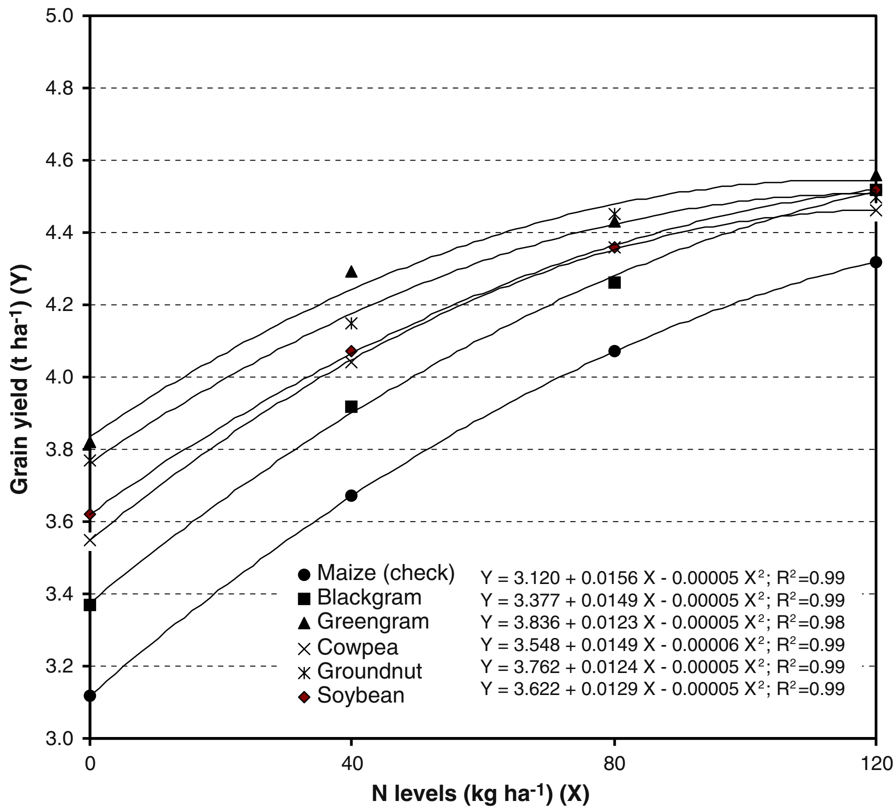

Fig. 2 Response of wheat to varying N rates grown after different grain legumes in sole cropping during 2003–2004 (experiment 2)

Table 6 Yield maximizing (Nmax) and optimizing rates of N (Nopt), and corresponding wheat yields under different legumes

Treatment	N rate (kg ha^{-1})		Wheat yield (t ha^{-1}) at			N rate required to obtain Y_0 (kg ha^{-1})
	Nopt	Nmax	No N (Y_0)	Nopt (Yopt)	Nmax (Ymax)	
Intercropping systems (Experiment 1, 2002–2003 and 2003–2004)						
Sole maize	223	240	3.07	4.91	4.92	0.0
Maize + blackgram	174	188	3.24	5.00	5.01	9.0
Maize + greengram	167	181	3.44	5.08	5.09	20.8
Maize + cowpea	132	142	3.46	4.87	4.87	21.2
Maize + groundnut	159	173	3.45	4.94	4.95	20.9
Maize + soybean	167	181	3.37	4.99	5.01	16.2
Sole cropping (Experiment 2, 2003–2004)						
Sole maize	142	156	3.12	4.33	4.34	0.0
Blackgram	135	149	3.38	4.48	4.49	17.7
Greengram	109	123	3.84	4.58	4.59	56.4
Cowpea	113	124	3.55	4.47	4.47	30.6
Groundnut	110	124	3.76	4.52	4.53	48.8
Soybean	115	129	3.62	4.44	4.45	36.5

Based on the quadratic response equations, the yield maximizing dose of N was higher than the highest dose of N tested in this study, particularly in the intercropping experiment (Table 6). Optimum dose of N was also higher than 120 kg N ha^{-1} under all intercropped legumes, but it was considerably reduced under sole legumes. Both the doses were much higher when the legumes were intercropped than in sole cropping, indicating greater contribution of N from residues under the latter system. Optimum N dose was 10–17 kg ha^{-1} lower than maximum doses but there were no differences between the corresponding yield levels. In general, inclusion of legumes either in intercropping system with maize or in sole cropping did not make much impact on the potential yield of following wheat compared with that after sole maize. Evidently, the N contribution from legume residues was maximum under no N, and the N dose required to obtain wheat yield equal to that without N (Y_0) indicated savings of N fertilizer under different legumes. The saving was about 21 kg N ha^{-1} due to intercropped greengram, cowpea and groundnut; while in case of sole cropping, it was 49–56 kg N ha^{-1} with groundnut and greengram, and 31–37 kg N ha^{-1} with cowpea and soybean. Kumar and Prasad (1999) reported a saving of 25 kg N ha^{-1} in wheat when grown after a grain legume. The nitrogen economy was effected not only due to direct N addition through legume residues and its subsequent mineralization but also due to enrichment of soil with fixed N_2 from root exudates (Pawar and Jadhav 1995).

Competitive functions

Land equivalent ratio (LER) was much higher for maize than for grain legumes (Table 7), indicating that maize was less adversely affected than legumes in the intercropping system. Further, the individual LER values were higher for both the crops when maize was intercropped with blackgram, greengram and cowpea. Accordingly, the total LER was maximum under maize + greengram and maize + cowpea. The greater value of LER under these intercropping systems indicated greater biological efficiency of crops grown in association, and was probably due to temporal and spatial complementarity effect (Singh and Arya 1999). Intercropping of soybean and groundnut with maize resulted in lower LER because of greater adverse effect on the performance of both these crops. The lower values of LER in these systems reflected relatively poor efficiency of the intercropped species due to competition for growth limiting factors. An apparently high value of LER under maize + blackgram, despite poor performance of blackgram may be misleading, which is a limitation in the interpretation of this parameter (Mead and Willey 1980). Relative crowding coefficient (RCC) was considerably higher (>1.0) for maize than for legume crops, indicating maize was a dominating crop and produced more than the expected yield. The highest value of combined RCC was recorded under maize + cowpea, followed by maize + greengram, indicating greater compatibility and definite yield advantage under these intercropping systems. Further, greater numerical values of aggressivity with maize + soybean and maize + groundnut indicated greater difference in competitive ability between the component crops, resulting in wide variations between the actual and expected yields (Maitra et al. 2000). Similarly, maize in these intercropping systems showed greater competitive ratio than with other legumes. In fact, opposite trends in the competitive ratio of the two crops indicate that an optimum competitive balance between the component crops, such as in maize + cowpea or maize + greengram

Table 7 Competitive functions and efficiency of maize-based intercropping systems in 2003 (Experiment 1)

Intercropping system	Land equivalent ratio (LER)			Relative crowding coefficient (RCC)			Aggressivity (A)		Competitive ratio (CR)		Area-time equivalent ratio (ATER)
	Maize (LERa)	Legume (LERb)	Combined	Maize (Kab)	Legume (Kba)	Combined (K)	Maize (Aab)	Legume (Aba)	Maize (CRa)	Legume (CRb)	
Maize + blackgram	0.92	0.31	1.23	11.09	0.44	4.88	0.61	−0.61	2.98	0.34	1.21
Maize + greengram	0.93	0.31	1.23	12.90	0.44	5.68	0.62	−0.62	3.03	0.33	1.22
Maize + cowpea	0.94	0.30	1.24	15.35	0.42	6.45	0.64	−0.64	3.17	0.32	1.24
Maize + groundnut	0.88	0.20	1.08	7.18	0.25	1.79	0.68	−0.68	4.46	0.22	0.88
Maize + soybean	0.87	0.19	1.06	6.51	0.23	1.49	0.68	−0.68	4.59	0.22	0.86

was likely to give maximum yield advantage (Willey and Rao 1980; Maitra et al. 2000). Similar to LER, the area time equivalent ratio was also higher (>1.0) with maize + cowpea, followed by maize + greengram, indicating greater temporal and spatial complementarity in these intercropping systems for improving productivity (Allen and Obura 1983; Mandal and Mahapatra 1990; Patra et al. 1999).

Nitrogen uptake

Uptake of N by maize (grain and stover) was the highest when it was grown in sole stand, and decreased to a varying extent under different intercropping systems (Table 8). The decrease was comparatively less with intercropped greengram and blackgram in 2002, and with cowpea, greengram and blackgram in 2003. This was because of the lower competition between these legumes and maize plants. Groundnut and soybean in both years, and cowpea in 2002 grew vigorously, competing for N and other resources for a longer period, thereby adversely affecting the growth and N uptake by maize. However, the total uptake of N in the intercropping systems (maize + legumes) was higher than sole maize. Intercropped legumes might have benefited the associated maize not only due to transfer of biologically fixed N_2 released in root exudates (Singh 1983; Subba Rao et al. 2001) but also by sparing effect of N (Lupwayi and Kennedy 2007). Accordingly, cereal-legume association proved to be more effective in increasing productivity and N utilization, leading to its higher uptake.

Nitrogen uptake by wheat was significantly higher when grown after incorporation of residues of intercropped grain legumes than after sole maize (Table 9). The increase in N uptake was even greater when higher amount of residues was added through sole cropping of legumes (Table 5). In general, cowpea was more effective in improving the N uptake in both intercropping as well as sole cropping system, while the effect of all other legumes was more or less similar. Evidently, the greater N availability in the soil as observed from the increased uptake by wheat was due to N added as a constituent of legume residues and some of the N was through biological fixation. The legume residues had a narrow C:N ratio (<25:1), which was within easy range of mineralization (Sharma et al. 1998). Thus, the mineralized N as well as fertilizer N were equally available to wheat plants, resulting in its prolonged availability due to reduced losses and formation of organo-mineral complexes (Buresh and De Datta 1991, Ladha et al. 2005). Mean effect of N fertilizer showed significant increase in N uptake by grain up to 120 kg N ha^{-1} in both years, while the effect on uptake by straw was evident up to 90 kg N ha^{-1} only. Nonetheless, the total N uptake of wheat increased significantly up to 120 kg N ha^{-1} when grown after intercropped maize (experiment 1) and up to 90 kg N ha^{-1} after sole legumes (experiment 2). This was due to greater addition of residue N with sole legumes than in intercropping system. Greater N harvest index at higher rates of N indicated efficient translocation of photosynthates to the developing grains. Apparent recovery of applied N fertilizer decreased with increasing rates, and was higher in 2002–2003 (42.9–49.3%) than in 2003–2004 (30.4–42.3%). This was due to abnormally high temperatures in March 2004, which hastened

Table 8 Nitrogen uptake of maize (kg ha^{-1}) as influenced by different intercropping systems (Experiment 1)

Treatment	2002			2003		
	Grain	Stover	Total	Grain	Stover	Total
Sole maize	45.2	38.9	84.2	45.1	37.2	82.3
Maize + blackgram	38.4	37.3	75.7	38.6	32.9	71.5
Maize + greengram	40.7	33.9	74.6	41.0	30.5	71.5
Maize + cowpea	33.7	27.8	61.4	43.1	34.7	77.8
Maize + groundnut	30.1	26.4	56.5	37.9	31.3	69.2
Maize + soybean	36.1	31.3	67.4	38.2	31.3	69.4
SE	2.52	2.80	3.91	2.04	1.95	3.39
CD ($P = 0.05$)	7.60	8.44	11.77	6.14	5.88	10.20

Table 9 Nitrogen uptake of wheat (kg ha^{-1}) as influenced by different intercropped grain legumes with maize and N application rates (Experiment 1)

Treatments	2002–2003			2003–2004		
	Grain	Stover	Total	Grain	Stover	Total
Intercropping systems						
Sole maize	81.2	21.5	102.6	73.9	23.1	97.0
Maize + blackgram	86.9	23.4	110.2	79.0	23.9	102.9
Maize + greengram	89.5	24.4	113.9	81.4	24.1	105.5
Maize + cowpea	92.5	24.8	117.3	83.4	25.6	109.1
Maize + groundnut	85.5	26.2	111.7	76.0	26.6	102.6
Maize + soybean	86.1	27.0	113.1	78.4	25.8	104.2
SE	2.22	0.83	2.62	2.18	0.78	1.94
CD ($P = 0.05$)	6.68	2.49	7.89	6.58	2.34	5.85
N rates to wheat (kg ha^{-1})						
0	65.5	19.3	84.9	60.3	21.8	82.0
40	81.6	23.0	104.6	75.0	24.0	99.0
80	92.8	27.2	120.1	87.3	27.4	114.7
120	107.8	28.5	136.4	92.2	26.3	118.5
SE	1.10	0.38	1.50	1.47	0.38	1.14
CD ($P = 0.05$)	3.12	1.08	4.25	4.18	1.08	3.24

Table 10 Residual soil fertility at wheat harvest and N balance in different cropping systems

Cropping systems	Organic C (mg kg^{-1} soil)	$KMnO_4$-N (mg kg^{-1} soil)	Total N inputs[a] (kg ha^{-1})	Total N outputs[b] (kg ha^{-1})	Apparent N balance (kg ha^{-1})	Actual change over initial $KMnO_4$-N (kg ha^{-1})
Intercropping systems (Experiment 1, 2002–2003 and 2003–2004)						
Sole maize – wheat	421	100	360.0	366.1	−6.1	+5.0
Maize + blackgram – wheat	402	102	409.9	371.3	+38.6	+9.7
Maize + greengram – wheat	432	110	411.9	387.6	+42.3	+25.8
Maize + cowpea – wheat	445	105	417.2	382.1	+35.1	+16.2
Maize + groundnut – wheat	452	105	492.8	371.2	+121.6	+16.6
Maize + soybean – wheat	440	108	455.8	396.4	+59.4	+21.5
Sole cropping (Experiment 2, 2003–2004)						
Blackgram – wheat	424	98	147.5	118.4	+29.1	−8.2
Greengram – wheat	445	110	164.1	154.3	+9.8	+18.3
Cowpea – wheat	450	112	176.3	145.3	+31.0	+23.5
Groundnut – wheat	462	119	295.8	174.3	+121.5	+38.6
Soybean – wheat	452	116	229.5	211.1	+18.4	+32.1

[a] Total N inputs included: N added through fertilizer + N added through legume residues + estimated amount of biologically fixed N_2 in soil

[b] Total outputs included: N uptake by maize + legumes + wheat

maturity (7–10 days) but reduced grain yields (9.51%) and also N uptake (7.11%) of wheat compared with that in 2002–2003. This late heat stress was widespread in the Indo-Gangetic plains in 2004 and reduced overall productivity of wheat by 7 million tonnes (ICAR 2007).

Residual soil fertility and N balance

After two cropping cycles of maize-based intercropping—wheat system, organic C showed a slight improvement over the initial values, particularly when legume residues were incorporated (Table 10).

A similar increase was noted under sole legumes—wheat system over a period of one cropping cycle. This increase was related to the amount of residues added, and was comparatively higher with groundnut, soybean and cowpea. $KMnO_4$-N also showed improvement under residue incorporation, and the increase was more conspicuous under sole than intercropped legumes. The added legume residues mineralized gradually and improved the N status of soil, a greater part of which was utilized by the wheat crop and some amount was left in relatively complex organic compounds.

Based on the total inputs and outputs, the apparent N balance in soil was negative in sole maize—wheat but positive in intercropped maize with legumes as well as sole legumes—wheat system (Table 10). The positive balance was higher when groundnut and soybean were grown in the intercropping system due to greater addition of N in their residues. The apparent N balance was also positive in all sole legume—wheat systems, maximum being under groundnut followed by cowpea. The actual change in $KMnO_4$-N over the initial status was positive in all cases but the magnitude was much different from the apparent N balance. These discrepancies may be because of the fact that the apparent N balance was based on total N (organic + inorganic), and did not consider the N inputs through irrigation and rainwater, root stubbles, actual amounts of N_2 fixed and also the various N losses from the system. The maximum increase in $KMnO_4$-N was under maize + greengram – wheat, followed by maize + soybean – wheat (experiment 1); and groundnut – wheat, followed by soybean – wheat system (experiment 2). Inclusion of blackgram in sole or intercropping system was ineffective in improving the $KMnO_4$-N status of soil due to small amount of N addition by its residues. Such improvements in organic C and $KMnO_4$-N might be significant due to continuous inclusion of legumes over many years, and thus help in improving productivity and sustainability in the long-run.

Economics

Total cost of cultivation was higher in maize-based intercropping system but the returns were considerably lower compared with wheat (Table 11). Higher cost in maize-based intercropping than sole maize was due to additional expenditure on legume seed,

Table 11 Economic analysis of different cropping systems

Cropping systems	Cost of cultivation ($\times 10^3$ Rs ha^{-1})		Gross returns ($\times 10^3$ Rs ha^{-1})		Net returns ($\times 10^3$ Rs ha^{-1})			Net returns Re^{-1} invested		
	Rainy season crops	Wheat	Rainy season crops	Wheat	Rainy season crops	Wheat	Total	Rainy season crops	Wheat	Total
Intercropping systems (Experiment 1, mean of 2002–2003 and 2003–2004)										
Sole maize	14.5	13.5	21.1	39.6	6.6	26.1	32.6	0.45	1.93	1.17
Maize + blackgram – wheat	15.8	13.5	21.2	40.8	5.4	27.3	32.7	0.34	2.02	1.12
Maize + greengram – wheat	16.0	13.5	23.5	41.6	7.5	28.1	35.6	0.47	2.08	1.21
Maize + cowpea – wheat	15.8	13.5	21.3	42.3	5.5	27.8	33.2	0.35	2.13	1.13
Maize + groundnut – wheat	17.1	13.5	21.3	42.0	4.2	28.5	32.6	0.24	2.11	1.07
Maize + soybean – wheat	17.1	13.5	21.0	41.8	3.9	28.3	32.2	0.23	2.09	1.05
Sole cropping (Experiment 2, 2003–2004)										
Blackgram – wheat	13.0	13.5	5.3	19.6	–7.7	27.4	19.6	–0.60	2.03	0.74
Greengram – wheat	13.0	13.5	16.7	33.2	3.7	29.4	33.2	0.29	2.18	1.25
Cowpea – wheat	13.0	13.5	14.6	29.9	1.6	28.3	29.9	0.12	2.09	1.13
Groundnut – wheat	15.0	13.5	20.3	34.8	5.3	29.5	34.8	0.35	2.19	1.22
Soybean – wheat	15.0	13.5	15.8	29.1	0.8	28.3	29.1	0.05	2.09	1.02

Price of produce t^{-1}: Maize grain, Rs 5,000, Maize stover, Rs 1,000, Wheat grain Rs 8,000, Wheat stover Rs 2,000, blackgram Rs 13,500, greengram Rs 13,500, cowpea, Rs 13,500, groundnut Rs 13,800, soybean Rs 10,000 (Rs 40 $\simeq$ 1 US \$)

sowing and harvesting/threshing. Wheat gave much higher yields ($>$4 t ha^{-1}) compared with maize ($<$3.0 t ha^{-1}), leading to higher returns. In fact, the net returns with maize-based intercropping system were only about one-fourth compared with wheat. The highest net returns were obtained with maize + greengram, followed by maize + cowpea. The differences in net returns of wheat after different maize-based intercropping systems were not large but the beneficial effect of legumes was discernible. The overall net returns of the system were maximum in case of maize + greengram − wheat, followed closely by maize + cowpea − wheat. The net returns per Re invested were $<$0.5 in all maize-based intercropping systems but $>$2.0 in case of wheat grown after different legumes.

In experiment 2, growing sole legumes gave much lower returns than maize. Groundnut was the more remunerative crop, followed by greengram, while blackgram cultivation resulted in negative returns due to its very low yields (0.39 t ha^{-1}). Poor returns from grain legumes due to their low productivity on account of non-suitability of varieties and non-remunerative prices have been the major factors, discouraging cultivation of pulses in India by the farmers. This has resulted in no increase in area and productivity of pulses in India during the last 3 decades (ICAR 2007). Wheat was a more remunerative crop because of reasonably good yields and remunerative prices. Accordingly, total net returns from the system were maximum in case of groundnut − wheat, followed by greengram − wheat. The net returns per Re invested were also higher with greengram and groundnut, and in wheat following these legumes, resulting in greater overall profitability of the system.

It was concluded that adoption of maize-based intercropping system with legumes such as greengram, cowpea and groundnut followed by wheat was beneficial for realizing higher productivity and profitability than sole maize or legume-based system. Nitrogen economy in wheat through incorporation of legume residues was 21 kg N ha^{-1} when grown in intercropping system and up to 49–56 kg N ha^{-1} in sole cropping. Such inclusion of legumes in cereal-based maize–wheat system may help in fertility restoration and sustained productivity in the long-run.

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