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PRODUCTIVITY AND PROFITABILITY OF THE TRANSGENIC COTTON–WHEAT PRODUCTION SYSTEM THROUGH PEANUT INTERCROPPING AND FYM ADDITION

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SUMMARY

The cotton–wheat production system (CWPS) occupies an important place in the agricultural economy of several South Asian countries. The instability of the CWPS has increased particularly during the post-transgenic hybrids phase mainly because of these hybrids calling for intensive crop management being cultivated under all situations, especially in resource-poor conditions leading to violent fluctuations during adverse years and thereby affecting the socio-economic status of these developing countries. A study was conducted to evaluate and quantify the effect of the two-tier intercropping of cotton and peanut with the substitution of a 25–50% recommended dose of nitrogen (RDN) of cotton by farmyard manure (FYM) on productivity, profitability and nitrogen economy in the CWPS at New Delhi during 2006–08. To quantify the residual effects of previous crops and their fertility levels, a succeeding crop of wheat was grown with varying rates of nitrogen, viz. 0, 50, 100 and 150 kg ha^{-1}. Wheat equivalent productivity was significantly more with the inclusion of peanut in the CWPS (21–26%) with a high net return (US$288) than a pure stand of cotton in the CWPS. The substitution of 25% RDN of cotton by FYM being on par with no substitution recorded a higher wheat equivalent yield, nitrogen, phosphorus and potassium uptake, net return and nitrogen use efficiencies. Nitrogen economy in wheat was 22 kg ha^{-1} due to inclusion of peanut in the CWPS and 13 kg ha^{-1} due to substitution of the 25% RDN of cotton by FYM. The study suggested that for the success of the CWPS in South Asian countries, escalating prices of N fertilizers with environmental issues and the instability of transgenic hybrids can be overcome by using wider rows of cotton by peanut intercrop with the integrated use of both organic and inorganic sources of nitrogen.

INTRODUCTION

Cotton–wheat is a long established crop production system of the north-western plains of India and Pakistan, and it occupies an important place in the agricultural economy of both the countries. While cotton is a cash crop, wheat provides the necessary food security. In India, the cotton–wheat production system (CWPS) is followed on 1.40 million hectares and on 2.62 million hectares in Pakistan. Next only to the rice–wheat cropping system, the CWPS occupies around 4.0 million hectares in the north-western states (Punjab, Haryana and Rajasthan) of India and adjoining areas of Punjab and Sindh provinces of Pakistan (Mayee *et al.*, 2008). The economy of the regions where it is cultivated is consistently influenced by its production and processing sectors, and by generating direct and indirect employment to more than 8 million people. There was a

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decline in the cotton productivity in the Indian cotton growing states and fluctuations in the area for almost a decade during the late nineties due to insect-pest infestation and uneven and erratic monsoon and improper irrigation water distribution (CICR, 2010). However, the introduction of Bt-cotton hybrids in 2005–06 in north India led to a considerable rise in area and productivity and restored the CWPS from a short period of slow growth (Mayee *et al.*, 2009). In 2007, Bt cotton occupied globally 15 million hectares, which comprised 43% of the total cotton area of 35 million hectares in eight countries, namely the USA, Mexico, China, Argentina, South Africa, Colombia, India and Brazil. With 6.2 million hectares under Bt cotton, India occupied the first position in terms of the area occupied, followed by China with 3.8 million hectares (ISAAA, 2008).

Among all the approaches of increasing the agricultural productivity, intercropping is one of the highly promising possibilities in most countries of sub-tropical Asia, tropical Africa and central and south America, which are characterized by smallholder farmers, limited land resource and low crop productivity (Singh and Ahlawat, 2011; Singh *et al.*, 2013). The intercropping system involves the growing of two or more crops simultaneously with a distinct row arrangement for the complementary use of natural resources and enhancing the productivity (Willey, 1979). Cotton is sown at wider row spacing (90–120 cm), hence provides sufficient space for the cultivation of a short-duration intercrop like peanut (Singh *et al.*, 2009). Intercropped legumes benefit the associated cotton crop by either transferring a part of fixed N_2 or sparing effect because of their less nitrogen (N) requirement and mitigation drought effect acts as live mulch for evaporation (Lupwayi and Kennedy, 2007; Subba Rao *et al.*, 2001). These also provide a good canopy cover in the early stages to control soil loss through erosion especially on light sandy loam soils and also to control weeds (Khola *et al.*, 1999). The productivity of the main crop of cotton may or may not be affected but the overall productivity in terms of cotton or wheat equivalent yield is generally higher in intercropping than in sole stand (Maitra *et al.*, 2000). This practice stabilizes the productivity besides enhancing the total returns (Blaise *et al.*, 2005).

Among the agronomic packages of any crop, N management is the most important factor deciding the crop performance and maintenance of soil fertility is important in sustaining cotton productivity and profitability (Karlen *et al.*, 1998). Since N is a costly input, efficient utilization of this resource through optimum synergistic combination is essential for higher productivity and input use efficiency of the CWPS (Rochester *et al.*, 2001). The integration of mineral fertilizers and organic manures such as farmyard manure (FYM) has proved a viable alternative for the CWPS across the globe (Mathur, 1997). High prices and low supply of nitrogenous fertilizers necessitate organic manure to substitute inorganic nitrogen for greater stability in the crop production (Behra *et al.*, 2007).

The fertilizer applied to the preceding cotton crop might leave some residual effect and thus modifies the nitrogen requirement of the wheat crop (Kairon *et al.*, 1996). The N removal by cotton alone is reported to be as high as 80–170 kg ha^{-1}. This high N input to the cropping system involving high costs for economical yields has led to the renewed interest in the use of FYM and increased involvement of legumes in the

CWPS. Looking at the prospects of a large area coming under Bt-cotton cultivation in the next few years in tropical countries, our objective was to study the nutrient requirement, economic and the agronomic efficiencies of the CWPS in order to develop appropriate production modules for the sub-optimum irrigated sub-tropical situation in the northern zone of India. The findings of this study provide new insights into the enhanced crop productivity and sustainability in transgenic cotton-based systems that include legumes and organic sources (Rochester and Peoples, 2005) in various parts of the world.

MATERIALS AND METHODS

Experimental site

This field experiment was conducted during 2006–08 at the Indian Agricultural Research Institute, New Delhi, situated at 28°35′N latitude and 77°12′E longitude at an altitude of about 228.61 m above mean sea level (Arabian sea). It has a semi-arid and sub-tropical climate with hot dry summers and severe cold winters. The soil of the experimental site was sandy loam (Typic Haplustept, Inceptisol) with pH 7.8, 490 mg organic C kg^{-1}soil, 96.4 mg $KMnO_4$ oxidizable N kg^{-1} soil, 5.9 mg 0.5 N $NaHCO_3$ extractable P kg^{-1} soil, and 122.7 mg 1.0 N NH_4OAc exchangeable K kg^{-1} soil in a 0–30 cm soil depth. The total precipitation during the study period was 629.5 mm (505.8 mm for the rainy season, during 2006) and 489.0 mm (457.0 mm for the rainy season, during 2007) while 50 years' average rainfall of the site is 650 mm and more than 80% generally occurs during the south-west monsoon season (July–September) with a mean annual evaporation of 850 mm. Mean monthly relative humidity in 2006 and 2007 ranged from 47.1 to 95.0%, and 31.0 to 95.0%, respectively during the period of experimentation. Water table remained below 3.5 m deep from ground surface during the crop growth period.

Treatments and crop culture

Two experiments were conducted; in experiment 1, the cotton-based intercropping system involving peanut during the summer/rainy season (June–November), followed by wheat during the winter/dry season (December–April) during 2006–07 and 2007–08. Peanut–wheat is another legume-based cropping system of cotton growing regions (ICAR, 2010); therefore, for comparison, in experiment 2, peanut was grown in pure stand followed by wheat during 2006–07 and 2007–08. In experiment 1, eight treatments comprising a combination of two cropping systems (sole cotton and cotton + peanut) and four fertility levels [control (0 N), 100% recommended dose of nitrogen (RDN) through urea, 75% RDN through urea + 25% N through FYM and 50% RDN through urea + 50% N through FYM] to cotton were laid out in a randomized block design with three replications. In the succeeding wheat crop of both experiments, the main plots were sub-divided into four plots to accommodate doses of N (0, 50, 100 and 150 kg ha^{-1}) to wheat in a split plot design. In cotton, 150 kg N ha^{-1} was used as RDN. In sole peanut (experiment 2), a uniform basal dose of 20 kg N + 26.2 kg P ha^{-1} was applied. The field was initially ploughed twice in May after the harvest of a previously grown uniform crop of wheat and the gross plots of 18.0 × 6.0 m were marked. Conventionally prepared FYM from cattle dung mixed with leftover crop residues and well composted in a pit for over 6 months was used. This well-decomposed FYM was uniformly incorporated into the soil 7 days before sowing as per treatments. FYM on a dry weight basis contained 178–5.0–2.0–5.0 g kg^{-1} organic C-N-P-K, respectively. Nonetheless, the application of different quantities of FYM resulted into variable amounts of nutrient addition and their release pattern might have caused changes in soil properties, hence crop growth and yields. Half N and full dose of P were applied at the time of sowing. Remaining N was topdressed in the form of urea at the square initiation stage of cotton at 60 days after sowing (DAS) along with second irrigation. A uniform dose of 26 kg P ha^{-1} through single super phosphate (SSP) was applied at sowing to all the treatments. Cotton 'RCH-134 Bt' (180 days) was sown by dibbling with 120 cm × 60 cm geometry on 17 June in 2006 and on 2 June in 2007. Five rows of non-Bt isogenic lines at the border as refugia crop were also planted. In intercropped cotton, three rows of peanut 'Punjab No. 1 (110 days)' were planted simultaneously in between two cotton rows with 30 cm × 10 cm geometry (additive series) without any extra doses of fertilizers. One day after the sowing of both crops, a pre-emergence weedicide 'pendimethalin' was applied in all the treatments. In the second cropping cycle (2007–08), the experiment was repeated in the different location with the same layout. Sole and intercropped peanuts were harvested in the last week of September in both the years while cotton was harvested manually in two pickings in the second and first fortnights of November, respectively, in both the years. There was no incidence of bollworms during the study period in Bt-cotton. After the cotton and peanut harvest, the field was irrigated and wheat 'Pusa Gold (120 days) was grown on 31 December in 2006 and on 7 December in 2007 applied in rows 22.5 cm apart using a seed rate of 125 kg ha^{-1}. N was applied through urea as per treatments in two equal splits at sowing and first irrigation (25 DAS). Other management practices were adopted as per recommendations of the crop under irrigated condition. Wheat in both experiments was harvested in the second and first fortnights of April, respectively, in both the years. The entire above-ground biomass of cotton, peanut and wheat was removed at harvest.

Sampling and analysis of soil and plants

Destructive soil samples (0–30 cm) were collected at 0 DAS and at harvesting of wheat. At day 0 (just before FYM mixing), the soil sample was taken immediately. At the harvest of all crops, five randomly selected plants from each plot were collected and sun dried. The sun-dried samples were transferred into a thermostatic drying oven and were dried at 65 °C (36–48 h) to obtain a constant dry weight. Different estimations on N use efficiencies were made according standard procedures given by Isafan (1990). 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 is given in Table 1. Net returns were estimated by deducting the total cost of cultivation from gross returns, and net return

Table 1. Cost of cultivation (US$ ha^{-1}) of different crops.

Input/field operation	Cotton	Peanut	Wheat
Land preparation	30	30	42
Seed	67	52	68
Sowing	8	8	8
Fertilizers and their application	66	32	60
Thinning and gap filling	6	2	0
Irrigations	20	20	40
Herbicides	14	8	8
Insecticides	30	20	0
Pesticide application	20	8	8
Harvesting, threshing etc.	50	20	32
Rental value of land	30	30	30
Total	341	230	296

The additional cost of peanut cultivation in the intercropping system was US$52 (₹50 = ~US$1).

per US dollar invested by dividing net return with the cost of cultivation. The saving of N through legumes was worked out based on the relative yields under varying N rates and through calculation of maximum yield (Y_{max}) and optimum yield (Y_{opt}) based on N_{max} and N_{opt} derivations from quadratic response equations as follows:

$$N_{max} = -b \div 2c; \quad N_{opt} = \{(P_x \div P_y) - b\} \div 2c,$$

where b and c are the coefficients of the quadratic equations, and P_x and P_y are the cost of N fertilizer (US$0.22 kg^{-1}) and the price of wheat grain (US$185 $tonne^{-1}$), respectively. Wheat equivalent yield was calculated as follows: {(seed cotton yield or peanut pod yield × market price of seed cotton or peanut pod) ÷ market price of wheat} + wheat grain yield.

Statistical analysis

The data collected on different parameters were subjected to appropriate statistical analysis following the procedure described by Cochran and Cox (1957). The significance of the difference between means was tested through the F test and the critical difference was worked out where the variance ratio was found significant for the treatment effect. The treatment effects were tested at the 5% probability level for their significance.

RESULTS

Crop productivity

The cropping system did not significantly influence seed cotton yield in both the years (Table 2). The application of RDN irrespective of its source significantly caused a perceptible variation in seed cotton yield in both the seasons. The substitution of 25% RDN through FYM being on par with 100% RDN through urea significantly increased the seed cotton yield over 50% RDN substitution through FYM and control.

Table 2. Yield performance of cotton, peanut and wheat in the intercropping system (experiment 1).

	Seed cotton yield (t ha^{-1})		Peanut pod yield (t ha^{-1})		Wheat equivalent yield (t ha^{-1})	
Treatment	2006	2007	2006	2007	2006–07	2007–08
Cropping system						
Sole cotton–wheat	2.94	2.24			9.00	7.66
Cotton + peanut–wheat	3.15	2.53	0.49	0.46	11.23	9.25
SEm±	0.08	0.10			0.74	0.52
CD ($p = 0.05$)	NS	NS			2.21	1.56
N dose (kg ha^{-1}) and source (% Urea N–% FYM-N)						
Control (0–0)	2.16	1.52	0.54	0.58	7.95	6.61
150 (100–0)	3.33	2.77	0.47	0.40	10.72	9.35
150 (75–25)	3.61	3.05	0.43	0.39	11.56	9.83
150 (50–50)	3.06	2.19	0.50	0.47	10.23	8.03
SEm±	0.11	0.14	0.02	0.04	1.04	0.74
CD ($p = 0.05$)	0.33	0.44	0.07	0.12	3.12	2.21
N applied to wheat (kg ha^{-1})						
0					7.49	6.66
50					8.29	7.55
100					8.83	7.90
150					8.51	7.78
SEm±					0.42	0.29
CD ($p = 0.05$)					1.14	0.84

Furthermore, a 50% RDN substitution through FYM also recorded a significantly higher yield over control. The trend was similar in both the seasons. Over the seasons, a 25% RDN substitution through FYM increased the seed cotton yield by 26.0% over a 50% RDN substitution through FYM and 81.0% over control.

The performance of peanut was drastically altered in intercropping with cotton when compared with its sole stand. Cotton receiving no N (control) showed superior performance of intercropped peanut in terms of pod yield as compared with a 25% RDN of cotton substitution through FYM-N. Furthermore, 100% RDN through urea also had poor performance of peanut than control in 2007. Peanut performance in 100% RDN through urea and 25% RDN of cotton substitution through FYM-N was on par in both the years.

The residual effect of the preceding crop(s) and their fertility levels had a significant effect on the grain yield of wheat (Figure 1). Wheat after cotton intercropped with peanut recorded a significantly higher grain yield (5–6%) than that after sole cotton in both the years. The application of RDN to cotton irrespective of its source being on par with each other had a significantly higher grain yield of wheat as compared with unfertilized control in both the years. N applied to wheat had a significant effect on grain yield. Wheat recorded a significantly higher grain yield with each successive increase in N dose up to 100 kg N ha^{-1}. The application of 150 kg N ha^{-1} to wheat, however, significantly decreased wheat yield but the significant yield reduction was not observed. A similar trend was observed for the system productivity expressed as wheat equivalent yield (Table 2).

Table 3. Yield performance of peanut and wheat in the peanut–wheat cropping system (experiment 2).

	Peanut pod yield (t ha^{-1})		Wheat grain yield (t ha^{-1})		Wheat equivalent yield (t ha^{-1})	
Treatment	2006	2007	2006–07	2007–08	2006–07	2007–08
Cropping system						
Sole peanut–wheat	1.05	1.08	3.33	3.83	4.62	5.50
N applied to wheat (kg ha^{-1})						
0			2.46	2.86	3.93	4.53
50			3.35	4.03	4.62	5.70
100			3.85	4.26	4.91	5.84
150			3.65	4.17	5.01	5.93
SEm±			0.086	0.234	0.69	0.516
CD ($p = 0.05$)			0.257	0.700	1.39	1.030

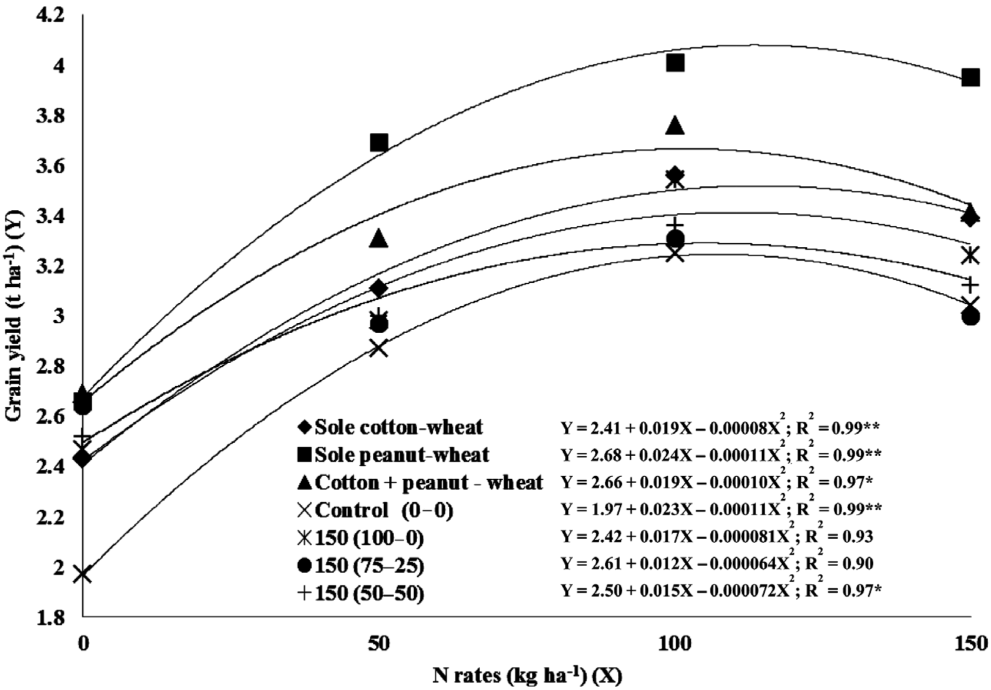

Figure 1. Response of wheat to varying N rates grown after cotton and peanut (mean data of two years of both experiments). The asterisks (* and **) are significance levels at 5 and 1%, respectively.

In the sole peanut–wheat production system (Table 3), wheat recorded a significantly higher grain yield with each successive increase in N dose up to 100 kg N ha^{-1} in both the years. Application of 150 kg N ha^{-1} to wheat did not significantly decrease wheat yield in both years. All the four N doses applied to wheat in 2006–07 did not significantly affect wheat equivalent yield but in 2007–08, 100 and 150 kg N ha^{-1} being on par with each other significantly produced higher wheat equivalent yield than 0 and 50 kg N ha^{-1}.

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Economics

Among rainy season crops, the total cost of cultivation was higher in cotton intercropped with peanut but net return and net return per US dollar invested were highest in this system (Table 4). Wheat grown after the peanut crop had a higher cost of cultivation with a higher net return as well. However, the net return per US dollar invested was higher in wheat grown after cotton intercropped with peanut. The cotton + peanut–wheat system maintained the highest cost of cultivation, net return, net return per US dollar invested and economic efficiency followed by the sole cotton–wheat system.

Among fertility levels applied to the cotton crop, a 50% RDN substitution by FYM had the highest cost of cotton cultivation followed by a 25% RDN substitution by FYM. The highest net return was observed with a 25% RDN substitution by FYM, followed by 100% RDN through urea. The net return per US dollar invested was higher with 100% RDN through urea. The cost of cultivation for wheat was higher in a 25% RDN substitution by FYM to cotton. Net return and net return per US dollar invested on wheat cultivation were higher in a 50% RDN substitution by FYM followed by a 25% RDN substitution by FYM. The total cost of the cultivation system was higher in 100% RDN through urea applied to cotton. The highest net return, net return per US dollar invested and economic efficiency of the cotton–wheat system were recorded in a 25% RDN substitution by FYM. Among N doses applied to wheat, 150 kg N ha^{-1} had the highest cost of wheat and total system cultivation. The highest net return, net return per US dollar invested and economic efficiency of wheat and total system were recorded in 100 kg N ha^{-1} followed by 150 kg N ha^{-1} applied to wheat.

Nitrogen use indices

The substitution of 25% RDN through FYM to cotton recorded the highest agronomic N use efficiency (ANUE) and apparent N recovery (ANR) followed by 100% RDN through urea, while a 50% RDN substitution recorded the least ANUE and ANR of cotton (Table 5). In wheat, a 50% RDN substitution by FYM recorded the highest ANUE and ANR followed by a 25% RDN substitution by FYM. Sole cotton maintained the highest N efficiency ratio (NER) and N harvest index (NHI) over other rainy season crops. Wheat followed by sole cotton recorded the highest NER, followed by cotton intercropped with peanut. The highest NHI of wheat was recorded in the cotton + peanut–wheat system. The highest NER of cotton and NHI of wheat were recorded in no N (control) treatment followed by a 50% RDN substitution through FYM and 100% RDN through urea, respectively. The highest NHI of cotton was recorded in a 50% RDN substitution by FYM. 100% RDN through urea and a 25% RDN substitution by FYM were equally effective in respect of NER of wheat. Among N doses applied to wheat, 50 kg N ha^{-1} maintained the highest ANUE and ANR, although these values were higher in wheat grown after sole peanut than cotton crop. NER and NHI of wheat grown after peanut were higher in 50 kg N ha^{-1} applied to wheat, but in wheat after cotton these values were higher in no N (0) and 100 kg N ha^{-1}, respectively.

Table 4. Economic analysis of different treatment (mean data of two years of both experiments).

Treatments	Cost of cultivation (US$ ha^{-1})			Net returns (US$ ha^{-1})			Net return US $$^{-1}$ invested			Economic efficiency
	Rainy season crops	Wheat	Total	Rainy season crops	Wheat	Total	Rainy season crops	Wheat	Total	(US$ ha^{-1} day^{-1})
Cropping systems										
Sole cotton–wheat	395	302	704	672	420	1092	0.034	0.028	0.031	3.0
Sole peanut–wheat	255	352	584	102	524	626	0.008	0.030	0.021	1.7
Cotton + peanut–wheat	416	270	720	930	450	1380	0.045	0.033	0.038	3.8
N dose (kg ha^{-1}) and source (% Urea N–% FYM-N)										
Control (0–0)	334	296	644	538	390	928	0.032	0.026	0.029	2.5
150 (100–0)	376	302	794	970	438	1162	0.052	0.029	0.029	3.9
150 (75–25)	444	306	702	1016	450	1466	0.046	0.029	0.042	4.0
150 (50–50)	502	304	742	698	462	1454	0.028	0.030	0.039	3.2
N applied to wheat (kg ha^{-1})										
0		284	696		304	1106		0.021	0.032	3.0
50		292	710		438	1242		0.030	0.035	3.4
100		286	716		488	1326		0.034	0.037	3.6
150		312	724		472	1274		0.030	0.035	3.5

FYM: farmyard manure; N: nitrogen

Price of produce per tonne; seed cotton US$402.0; cotton sticks US$12.5; peanut pods US$307.0; peanut haulm US$16.5; wheat grain US$185.0; wheat straw US$31.0 (₹50 = ~US$1).

Table 5. ANUE, ANR, NER, NHI of cotton, peanut and wheat (mean data of two years of both experiments).

	ANUE (kg economic yield kg N $^{-1}$)*			ANR (%)†			NER (kg DM kg N uptake^{-1})‡			NHI (%)§		
Treatment	Cotton	Peanut	Wheat	Cotton	Peanut	Wheat	Cotton	Peanut	Wheat	Cotton	Peanut	Wheat
Cropping system												
Sole cotton–wheat							46.2		10.8	38.0		76.5
Sole peanut–wheat								3.7	9.9		26.1	76.0
Cotton + peanut–wheat							44.1		10.6	33.5		80.0
N dose (kg ha^{-1}) and source (% Urea N–% FYM-N)												
Control (0–0)							55.8		9.9	35.3		80.0
150 (100–0)	8.2		1.3	69.3		4.5	41.7		10.7	32.9		79.5
150 (75–25)	9.5		1.5	83.3		6.0	40.0		10.7	37.6		79.0
150 (50–50)	5.3		1.9	40.0		9.0	50.0		10.4	42.6		75.0
N applied to wheat (kg ha^{-1})												
0								9.8	10.9		75.5	73.5
50		20.6	15.6		63.5	46.0		10.3	10.7		76.5	78.0
100		13.9	11.5		42.0	34.0		9.8	10.2		76.5	79.0
150		8.3	6.9		26.0	21.5		9.8	10.1		76.0	77.5

ANUE: agronomic N use efficiency; ANR: apparent N recovery; NER: N efficiency ratio; NHI: N harvest index; FYM: farmyard manure; N, nitrogen.

∗(Yield in treatment plot yield in control)/kg N applied.

†(N uptake in treatment plot − N uptake in control)/kg N applied.

‡(Dry matter yield/N accumulated at harvest).

§(N uptake by economic parts/N uptake by whole plant)*100.

Table 6. Yield maximizing (N_{max}) and optimizing rates of N (N_{opt}) and corresponding wheat yields under different treatments.

	N rate (kg ha^{-1})		Wheat yield (t ha^{-1}) at			
Treatment	N_{opt}	N_{max}	No N (Y_0)	N_{opt} (Y_{opt})	N_{max} (Y_{max})	Response (kg grain kg N^{-1})
Cropping system						
Sole cotton–wheat	111.1	118.7	2.41	3.53	3.54	10.1
Sole peanut–wheat	103.6	109.1	2.68	3.98	3.99	12.5
Cotton + peanut–wheat	89.0	95.0	2.66	3.55	3.56	10.0
N dose (kg ha^{-1}) and source (% Urea N–% FYM-N)						
Control (0–0)	99.1	104.5	1.97	3.16	3.17	12.0
150 (100–0)	97.5	104.9	2.42	3.30	3.31	9.0
150 (75–25)	84.4	93.7	2.61	3.16	3.17	6.5
150 (50–50)	95.8	104.2	2.50	3.27	3.28	8.0

N_{max}, yield maximizing rates of N; N_{opt}, yield optimizing rates of N; Y_{opt}, optimum yield; Y_{max}, maximum yield.

Response function

There was a differential response of wheat to N rates under the intercropping and the sole cropping systems with different fertility levels. Based on the yield data of two years in all cropping systems and fertility levels applied to cotton, the response to N was quadratic (Figure 1), indicating that the beneficial effect of peanut intercrop and cotton RDN substitution by FYM was more discernible when the N fertilizer rate was zero or low, and decreased with increasing rates. The response function of N fertilization in wheat grown after rainy season crops has worked out by quadratic equations between the grain yield of wheat and nitrogen doses applied to wheat (Table 6). The response functions showed the economic optimum dose of N for wheat and response in kg grain kg $^{-1}$ N was least when peanut was intercropped with cotton in the preceding *kharif* crop and was highest after sole cotton. The yield at the economic optimum dose of N was highest when the preceding *kharif* crop was sole peanut as compared with sole and intercropped cotton. The yield-maximizing dose of N was lower than the highest dose of N tested in study in all cropping systems and fertility levels applied to cotton. The optimum dose of N was also lower than 150 kg N ha^{-1} under all treatments. Both the doses were much lower when peanut was intercropped with cotton and a 25% RDN of cotton substitution through FYM, indicating a greater contribution of N from peanut and FYM residues. The optimum N dose was 5–10 kg ha^{-1} lower than maximum doses but there were no differences between the corresponding yield levels. Wheat yield at no N (Y_0) was highest when the preceding crop was peanut. Response at the optimum dose of N was also highest with sole peanut as a preceding *kharif* crop and no N was applied to cotton.

DISCUSSION

Crop productivity

Intercropped peanut did not significantly affect the seed cotton yield over sole cotton. This might be due to non-competitive environment between the main crop and intercrop in respect of available growth resources such as solar radiation, moisture and nutrients owing to different growth habits of companion crops in the system (Blaise *et al.*, 2005; Sharma and Behera, 2009). The cotton crop fertilized by the substitution of 25% RDN through FYM being on par with 100% RDN through urea had the highest seed cotton yield. This might be due to availability of more $KMnO_4$-N in soil and uptake by plant parts with these treatments. Higher plant growth parameters with combined application of organic (FYM) and inorganic (urea) sources of N might be due to an extended period of availability of nutrients from combined source compared with urea alone. This might have increased photosynthetic activities of plants, which ultimately helped to realize greater seed cotton yield (Das *et al.*, 2006).

The poor performance of peanut in intercropping than sole peanut was mainly attributed to lower plant population (45% base population in intercropping as compared with sole peanut). Furthermore, the shading effect of cotton (90 DAS onwards) and competition for resources particularly water and nutrients also contributed to lower yield. Cotton receiving no N showed superior performance of intercropped peanut in terms of pod yield as compared with a 25% RDN of cotton substitution through FYM N. This might be because up to 40 DAS, the cotton crop of N treatments did not offer N competition to intercropped peanut because of less N requirement of cotton (sparing effect) and high N requirement of intercropped peanut up to 40 DAS (no biological N_2 fixation), but in control (0 N) this mutual association could not be established due to less availability of $KMnO_4$-N (Subba Rao *et al.*, 2001). At later stages, intercropped peanut in control did not face solar radiation and N competitions due to less shading effect from poor cotton crop and high biological N_2 fixation by peanut due to less $KMnO_4$-N availability in soil (Lupwayi and Kennedy, 2007).

Wheat after cotton intercropped with peanut recorded 5% more grain yield than sole cotton; similarly, wheat after sole peanut recorded more grain yield than sole cotton (9–18%) and cotton + peanut (5–12%). This might be because peanut (legume) is widely recognized as a builder of soil fertility and contributes substantial amounts of N for the sustainability of cereal-based cropping systems (Rochester *et al.*, 2001). The inclusion of peanut increases soil fertility and consequently the productivity of the succeeding wheat crop (Ghosh *et al.*, 2007). Peanuts shed their leaves towards maturity and the litter together with residues and roots contains varying amount of biologically fixed atmospheric N_2 which is added to soil, hence affecting the N economy and productivity of the following wheat crop. Among residual effects of fertility levels to cotton, a 50% RDN substitution through FYM had significantly higher grain yield of the succeeding wheat crop. This could be attributed to higher residual nutrient availability and subsequent better uptake that might have resulted in higher dry matter production and improved yield attributes. Wheat recorded significantly higher grain yield with each successive increase in N dose up to 100 kg N ha^{-1} in both the years in both the experiments. This could be ascribed to higher N availability and uptake with corresponding higher N levels and subsequent greater production of photosynthates which ultimately led to higher biomass production. An increase in grain yield with higher N levels was mostly due to improved yield attributes. The increased number of spikes per square metre (data not shown) with higher N dose might be due to the stimulatory effect of N on tillering through cytokinin synthesis resulting in more number of effective tillers of wheat and finally more grain yield (Sharma *et al.*, 2000).

Economics

The cotton + peanut–wheat system on an average fetched US$288 more net returns and thus has 0.37 more B:C ratio than the sole cotton–wheat system. Sole peanut–wheat proved uneconomical of the three cropping systems because of less net return per US dollar invested (0.02). The higher wheat equivalent yield coupled with the corresponding stover yield coupled with minimal increases in the cost of cultivation has resulted in higher net returns and B:C ratio in the cotton + peanut–wheat system. The increase in yield with the substitution of 25% RDN through FYM has more than offset the increased cost, thus having a net gain of income (Das *et al.*, 2006). The reduced cotton yield coupled with a greater cost of FYM (US$8 t^{-1}) in 50% RDN substitution through FYM has resulted in reduced net returns over 100% RDN through urea. The low B:C ratio with FYM application was owing to the greater cost of FYM addition (Singh and Ahlawat, 2011). In experiment 2, growing sole peanut gave much lower returns than cotton either sole or intercropped. Poor returns from peanut due to its lower productivity on account of non-suitability of varieties and non-remunerative prices have been the major factors, discouraging cultivation of peanut in South Asian countries by farmers. This has resulted in no increase in area and productivity of peanut in India during the last four decades (ICAR, 2010). Cotton and wheat were more remunerative crops because of reasonably good yields and remunerative prices. Accordingly, total net returns from the system were maximum in case of the cotton + peanut–wheat system followed by the sole cotton–wheat system.

Nitrogen use indices

Due to the escalating cost of chemical fertilizers, the nutrient uptake and utilization in the cropping system should be most efficient in reducing the cost of production and in achieving a higher profit for the resource-poor cotton farmers. To achieve these objectives, it is important to understand and enhance the nutrient use efficiency. The highest ANUE and ANR by application of a 25% RDN substitution through FYM could be attributed to increase in seed cotton yield with the combined application of inorganic and organic sources of N (Bandyopadhyay *et al.*, 2009). Another reason might be that it improved the N uptake of crop due to the increased humus content of soil that would have slowed down the release of ammonical N and its conversion to nitrates, thereby reducing the leaching loss of N (Fritschi *et al.*, 2004). High N availability in 25% RDN substitution through FYM stimulated the development of larger plants and a more extensive root system capable of supplying the increased water and nutrient demand of the larger plants. The cotton and succeeding wheat crops therefore drew from a larger pool of both added and indigenous N, which influenced the efficiency of fertilizer N (recovery vs. applied) as well overall N efficiency (Boquet and Breitenbeck, 2000). The highest NER and NHI were attributed to the better physical, chemical and biological properties of soil that would have fertilized higher nutrient uptake and yield, leading to better fertilizer use efficiencies.

Response function

In general, the inclusion of peanut either in the intercropping system with cotton or in the sole cropping had much impact on the potential yield of following wheat compared with after sole cotton (Rochester and Peoples, 2005). Evidently, the N contribution from the peanut crop was maximum under no N, and the N dose required to obtain wheat yield equal to that without N (Y_0) indicated the saving of N fertilizer under the peanut crop. Sharma and Behra (2009) reported a saving of 20–25 kg N ha^{-1} in wheat when grown after a legume. Rochester and Peoples (2005) also reported that the cotton + vetch–wheat system is more N fertile over sole cotton in Australia. These findings help explain the rotational benefits of legumes observed in other regions of the world. The N economy was affected not only due to direct N addition through FYM residues and its subsequent mineralization but also due to the enrichment of soil with fixed N_2 from legume root exudates (Zhang *et al.*, 2008).

CONCLUSION

The results of this investigation provided more information regarding productivity of the transgenic cotton–wheat system under peanut intercropping and integrated use of organic and inorganic sources of N. Transgenic cotton is an exhaustive crop due to its higher yield potential, so it requires the integrated use of both inorganic and organic sources of N with substitution of the 25% N requirement through organic sources like FYM and intercropping of legumes like peanut for sustainable crop production on fragmented and small holdings of cotton belt areas of tropical countries like India and Pakistan. However, more comprehensive studies are needed with cotton residue recycling, other nutrients like P and K and other intercrops to find out best nutrient management practices to get a sustainable and economical cash–grain production system in tropical countries.

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