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Research Paper

Nitrogen fertilization of Bt cotton (*Gossypium hirsutum*)–wheat (*Triticum aestivum*) cropping system

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ABSTRACT

A field experiment was conducted during the rainy (*kharif*) and winter (*rabi*) seasons of 2006–07 and 2007–08 at New Delhi, to assess the performance of 3 cotton (*Gossypium hirsutum* L.)–wheat [*Triticum aestivum* (L.) emend. Fiori & Paol.] systems as affected by nitrogen (N) fertilization. In cotton, treatments formed by combination of 3 cotton hybrids [2 Bt ('MRC 6304' and 'RCH 317') and 1 non-Bt hybrid ('LHH 144')] in main plot and 4 levels of N fertilization (0, 60, 120 and 180 kg/ha) in sub-plots were tested. In succeeding wheat, cotton treatments were further sub-divided to accommodate 3 levels of N fertilization (0, 60, and 120 kg N/ha). Pooled data revealed that 2 Bt cotton hybrids being at par gave 55.4% (2.99 tonnes/ha) higher seed-cotton yield (SCY) than non Bt cotton hybrid (1.93 tonnes/ha) and the cotton hybrids did not markedly alter the performance of succeeding wheat. However, the system productivity (cotton-equivalent yield, CEY) of Bt cotton–wheat was 24.2% (4.72 tonnes/ha) higher than the non-Bt cotton–wheat system (3.80 tonnes/ha). The per cent contribution of Bt cotton to CEY of system (69.7) far exceeded that of non-Bt cotton (49.6). Both agronomic nitrogen-use efficiency (ANUE) and physiological nitrogen-use efficiency (PNUE) of Bt cotton and ANUE of succeeding wheat were higher than the non-Bt cotton and following wheat. Yield, N uptake of cotton, wheat and system increased with each successive increase of 60 kg N dose from 0 to 180 kg/ha. The N response of cotton was found to be quadratic with optimum dose of 173.0 kg/ha. ANUE and PNUE of cotton were the highest with 60 (5.73) and 120 kg N fertilization (17.05) and decreased thereafter with increasing N dose. Wheat crop responded to direct application of N up to 120 kg/ha. The currently recommended N input (300 kg/ha) of the non-Bt cotton (180 kg/ha)–wheat (120 kg/ha) system can be reduced by 27.8 kg with adoption of 'MRC 6304' Bt cotton.

Key words: Bt cotton, Cotton equivalent yield, Cotton-wheat system, Economics, Nitrogen, N use efficiency, Seed cotton yield, Wheat

Cotton is one of the most important cash crops of the country, on which the livelihood of about 15 million farmers spread out in over 10 states is dependent (Sharma, 1998). It is grown in rotation with wheat in about 1.5 million ha in North-Western states of Punjab, Haryana and Rajasthan under assured irrigation from canals and tubewells (Mayee, 2004). Cotton rotation with durum wheat (*Triticum durum* Desf.) is also prominent in Maharashtra under assured irrigation. Though the sustainability of this cropping system is dependent upon several interacting factors, which include climate, soil quality, plant nutrition, management, pest incidence, and economic factors; of these factors, nutrient management in cropping system mode appears to be the most crucial. Among the nutrients, nitrogen (N) is the most important as evident from the long-term fertilizer experiments (1984–92) at Sriganganagar, Rajasthan (Mathur, 1997). This holds true for other regions also, as it is universally limiting nutrient of crop production in the country. Studies have indicated that application of recommended dose of N, i.e. 120 and 150 kg N/ha, to both cotton and wheat at Bawal, Haryana (Singh *et al.,* 2005) and 60 and 120 kg N at Delhi (Das *et al.,* 2004) is necessary for high system productivity and sustainability. The introduction of Bt (*Bacillus thuringiensis)* cottons in northern zone since 2005 made it necessary to reassess the N requirement keeping in view the reported increases in Bt endotoxin protein with increase in N fertilization (Yang Chang Qin *et al.,* 2005; Pettigrew and Adamczyk, Jr. 2006). The higher leaf N content (Chen-DeHua et *al.,* 2004) and greater boll load of Bt hybrids (Hebbar *et al.,* 2007) lead to altered N uptake

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also calls for re-standardization of N fertilization. The impact of changed N fertilization of Bt cotton if any needs to be assessed on succeeding wheat crop also. It is in this context, a study was made to assess the N nutrient requirement of Bt cotton–wheat system.

MATERIALS AND METHODS

A field experiment was carried out for 2 years (June–April of 2006–07 and 2007–08) at the research farm of the Indian Agricultural Research Institute, New Delhi. Each year a new plot was used for conduct of study. The soil at the site was sandy loam with pH 7.7–7.8 containing 3,700–3,800 kg/ha organic carbon, 166–168 kg/ha of $KMnO_4$ extractable N, 14.5–14.7 kg/ha 0.5 M $NaHCO_3$–extractable P and 173–179 kg/ha NH_4OAC–extractable K at the start of experiment. The experiment was conducted in a split-plot design with 24 treatments formed by combinations of 3 cotton hybrids [‘MRC 6304’, ‘RCH 134’ (Bt cottons), and ‘LHH 144’ (non-Bt hybrid with resistance to leaf-curl virus that is used as check in the North zone)] and 2 insecticide sprays (control and 3 sprays of insecticide) in main plot and 4 nitrogen (N) levels (0, 60, 120, and 180 kg/ha) in sub-plots and the treatments were replicated thrice. In succeeding wheat, the plots were sub-divided into 3 plots to accommodate doses of N (0, 60, and 120 kg/ha) thus a split-split-plot design was used in wheat crop.

Single-cotton seed was dibbled at 120 cm × 60 cm spacing on a well-prepared soil in the first week of June followed by irrigation. Two-and-half packets (each packet of 450 g) of seed was used/ha sowing. Gap-filling was done 15 days after sowing (DAS) by transplanting seedlings grown simultaneously in plastic bags for this purpose. The seed cotton produced was handpicked thrice in mid-October, first week of November and last week of November (2007)/first week of December (2006). After final picking, cotton stalks were harvested at the ground level. Though non-Bt cotton ‘LHH 144’, continued to put up vegetative growth even in November, the bolls on plant after final seed-cotton picking were picked and kept in shade for opening and their yield was also recorded (it accounted for about 7–10% of total seed-cotton yield). This was done to facilitate timely sowing of succeeding wheat crop. ‘PBW 343’ wheat was sown 8 December 2006 and 13 December 2007 by tractor-drawn seed drill in rows 22.5 cm apart using a seed rate of 125 kg/ha and harvested in the third week of April during both the years.

Both the crops received 26.4–36 kg/ha of phosphorus (P) and potassium (K) as single superphosphate and muriate of potash respectively, and nitrogen (N) was given as per the treatments through prilled urea. All P and K fertilizers were broadcast applied uniformly and were mixed into the soil by tractor-drawn cultivator before sowing. Nitrogen was applied in 3 equal splits on 15, 40 and 80 DAS coinciding with gap-filling, square and early boll-formation stages respectively, after irrigation in cotton. In wheat, N was applied as per treatments in 2 equal splits, one each at sowing and at first irrigation at 21 days later coinciding with crown-root-initiation (CRI) stage. Cotton received need-based irrigations to supplement rainfall while wheat crop received irrigations at 6 critical growth stages in addition to a pre-sowing irrigation.

The nitrogen concentration of economic produce and stalks of cotton along with leaves retained on plant at harvesting and wheat (grain and straw) was determined and uptake was obtained as product of concentration and yield. Nitrogen harvest index was worked out as ratio of N uptake in seed cotton/wheat grain to the total uptake. Agronomic N-use Efficiency (ANUE) was calculated (yield in N applied-yield in no N-applied plot in kg/ha)/ amount of N applied (kg/ha) and reported as kg seed-cotton/kg N-applied. Physiological N-use Efficiency (PNUE) was calculated (yield in N-applied plot-yield in no N-applied plot)/(uptake in N-applied–uptake in no N plot) and reported as kg seed-cotton/kg N uptake. In calculation of economics, minimum support price of produce was taken (₹19,600; 20,300/tonne of seed-cotton and 8,000; 10,000/tonne of wheat grain in 2006 and 2007). The cotton stalks on dry-weight basis and wheat straw were assigned an assumed price of ₹ 500 and 1,500/tonne. The N fertilizer price (₹/kg) of 11 was used. Seed-cotton picking cost was taken as ₹500/tonne, while stalk harvesting was taken @ ₹100/tonne. Seed cost is taken as ₹1,125/ha (non-bt, ‘LHH 144’) and ₹1,875/ha (Bt hybrids). Other management practices were followed as per the crop recommendation for irrigated conditions. The wheat-equivalent yield was worked out by using the minimum support price of produce. The data in respect of insecticide sprays were not presented though significant in cotton but were insignificant in wheat. As the trend of results was same during both the years, pooled analysis was done and the data are presented on pooled basis.

RESULTS AND DISCUSSION

Growth, yield attributes and yield of cotton

The pooled results (Table 1) indicate a significant influence of cotton hybrids and levels of N fertilization on the growth [plant height at maturity and leaf-area index (LAI) and dry-matter production (DMP) both recorded at 120 days after sowing (DAS)], yield attributes (boll number and boll weight) and yield (seed-cotton and stalk) of cotton.

The growth, yield attributes and seed-cotton yield (SCY) of 2 Bt hybrids were statistically similar but were significantly different from non-Bt hybrid. Bt cotton hybrid produced 12.4 cm shorter plants with 0.51 units of lesser LAI than the non-Bt hybrid. The taller plants and higher values of LAI of non-Bt hybrid had resulted in 102.8 g/m^2 more dry-matter than the 2 Bt hybrids. Singh *et al.* (2007) also reported similar differences in growth attributes among Bt and non-Bt cotton hybrids. The Bt hybrids on an average produced 7.13 more bolls/plant and these bolls were 0.48 g heavier than those of non-Bt hybrid. The increased boll number/plant (17.1%) and boll weight (12.4%) of the 2 Bt hybrids together brought in 1.07 tonnes/ha (64.7%) higher SCY than non-Bt hybrid (1.96 tonnes/ha). However, cotton stalk yield (CSY) of non-Bt hybrid were 0.863 tonnes/ha (14.1%) higher than Bt hybrids (5.27 tonnes/ha). The differences in CSY between Bt and non-Bt hybrids were ascribed to taller plants and more branching (data not recorded) of the non-Bt hybrid. The SCY differences between Bt and non-Bt cotton hybrids of the present study are in agreement with the findings of Nehra *et al*. (2004), Singh *et al.* (2007b) and Singh *et al.* (2007a).

Each successive increase of 60 kg N fertilization of cotton significantly enhanced the plant height and LAI up to 180 and 120 kg/ha respectively. The above differences in plant height and LAI of cotton with N fertilization led to the significant differences in dry matter production. Similar impacts of N fertilization on cotton growth were reported by Fernandez *et al.* (1996). Each successive increase of 60 kg N dose from unfertilized control to the highest level of 180 kg/ha increased the boll number and boll weight. Application of 180 kg N/ha resulted in 40% more bolls and 8.3% heavier bolls than the no-nitrogen treatment. The lower boll number and boll weight of cotton in no-N fertilized plots was ascribed to inadequate N supply from the soil that was rated low in available N. A decreased in leaf area (Fernandez *et al.,* 1996) and associated lower assimilates supply leading to low yield attributes formation due to no N fertilization was also reported by Raja Reddy *et al.* (2003). Each successive increase of 60 kg N dose increased the SCY and CSY up to 180 kg N/ha. The SCY (CSY) increased by 0.35 (0.68), 0.32 (0.35) and 0.12 (0.21) tonnes/ha with application of 60, 120, 180 kg N fertilizer over the control, 60 and 120 kg N respectively. The increase in SCY with N fertilization was ascribed to the combined effect of N on improving boll number and boll weight. The increase in CSY with N fertilization was attributed to the impact on more plant height and greater branching.

Interaction effect of cotton hybrids and N fertilization on SCY was found to be significant (Fig. 1, top). Data indicate that the Bt hybrids failed to respond to N fertilization beyond 120 kg/ha, while the non-Bt hybrid responded to 180 kg/ha N fertilization. Further, Bt hybrids without N fertilization showed significantly higher SCY than the non-Bt cotton receiving 180 kg N/ha. The response of non-Bt cotton hybrids to N fertilizer was ascribed to its indeterminate growth habit as compared to determinate growth habit of Bt hybrids. This continuous biomass and yield formation of non-Bt cotton resulted in continuous uptake of nutrients from soil and thus responded to higher N application. Further, the bollworm damage in non-Bt cotton reduced its economic yield.

Table 1. Growth, yield attributes and yields of Bt and non-Bt cotton hybrids as influenced by nitrogen fertilization (pooled data)

Treatment	Plant height (cm)	LAI at 120 DAS	DMP (g/m^2) at 120 DAS	Bolls/ plant	Boll weight (g)	Yield (tonnes/ha)	
						Seed cotton (*kapas*)	Cotton stalk
Cotton hybrid							
'MRC 6304' (Bt)	114	2.60	309	48.4	4.37	3.00	5.28
'RCH 134' (Bt)	115	2.60	309	49.4	4.35	2.99	5.26
'LHH 144' (non-Bt)	127	3.11	412	41.8	3.88	1.93	6.13
SEm±	2.3	0.05	6.8	1.00	0.07	0.036	0.084
CD (P=0.05)	7.3	0.17	21.2	3.10	0.22	0.112	0.260
Nitrogen (kg/ha)							
0	106	2.88	317	38.6	4.02	2.19	4.80
60	117	3.39	345	44.8	4.19	2.54	5.48
120	123	3.77	354	49.0	4.23	2.86	5.88
180	127	3.87	359	54.0	4.35	2.98	6.04
SEm±	1.6	0.037	3.8	0.68	0.048	0.030	0.057
CD (P=0.05)	4.5	0.103	10.8	1.92	0.136	0.087	0.162

DMP, Dry matter production; LAI, Leaf-area index; DAS, Days after sowing

Yield attributes and yields of wheat

The pooled data (Table 2) indicate that cotton hybrids, N fertilization of cotton and wheat had a significant influence on the yield attributes (ear production) and yield of wheat.

Wheat grown after non-Bt cotton recorded significantly higher ears/m^2 (30 additional ears/m^2) than that grown after two Bt cotton hybrids (297) that in turn showed statistically similar ear production. Differences in grains/ear and test weight were not significant. The higher ear production of wheat grown after non-Bt cotton has brought in 0.30 and 0.47 tonne/ha improvement in grain and straw of wheat compared to that after Bt cotton.

Wheat grown after cotton fertilized with 180 kg N/ha produced significantly more number of ears, grains/ear and test weight than the wheat grown after cotton receiving no N. Ears produced by wheat grown after cotton receiving 180 kg N were also significantly higher than that receiving 60 kg N. The above improvements in yield attributes of wheat grown after cotton receiving 180 kg N fertilizer resulted in significantly higher grain and straw yield over no N or 60 kg N receiving cotton which in turn was at par with 120 kg N application.

Each successive increase of 60 kg N fertilization of wheat from 0 to 120 kg/ha significantly increased its yield attributes and yield. Application of 120 kg N to wheat has increased the number of ears/m^2, grains/ear and test

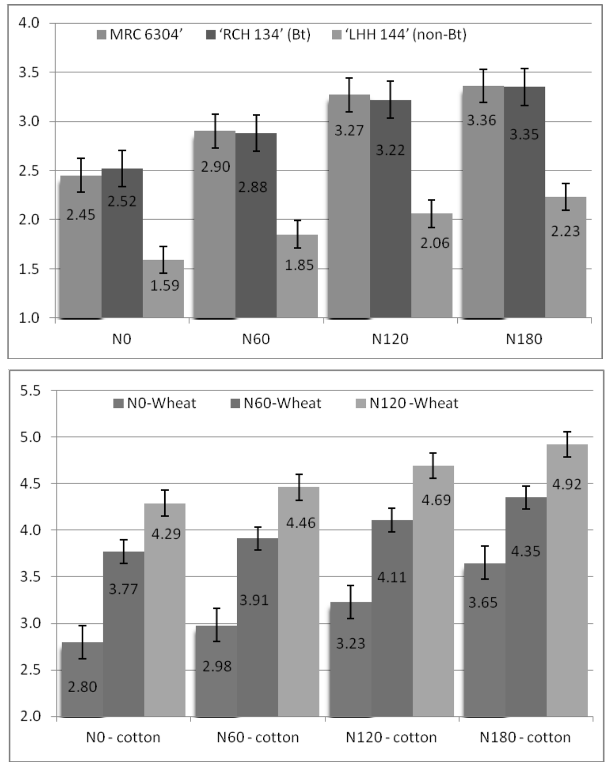

Fig. 1. Interaction effect of cotton hybrids and nitrogen fertilization and nitrogen fertilization of cotton and wheat on pooled seed cotton yield (top) and wheat grain (bottom) yield (tonnes/ha).

Table 2. Yield attributes, yield of wheat and cotton–wheat system productivity as influenced by cotton hybrids, nitrogen fertilization of cotton and wheat

Treatment	Ears/m^2	Grains/ ear	Test weight (g)	Grain yield (tonnes/ha)	Straw yield (tonnes/ha)	*CEY of system (tonnes/ha)
Cotton hybrid						
MRC 6304'	295	45.8	32.8	3.82	4.58	4.72
'RCH 134' (Bt)	300	46.1	33.4	3.83	4.69	4.72
'LHH 144' (non-Bt)	327	47.1	34.5	4.13	5.23	3.80
SEm±	3.3	0.44	0.42	0.043	0.06	0.028
CD (P=0.05)	13.2	NS	NS	0.172	0.22	0.113
Nitrogen (kg/ha) to cotton						
0	288	44.3	31.8	3.62	4.58	3.81
60	298	46.0	33.9	3.78	4.77	4.25
120	312	46.8	34.1	4.01	4.93	4.66
180	331	48.2	35.7	4.30	5.12	4.92
SEm±	7.1	0.96	0.90	0.087	0.114	0.059
CD (P=0.05)	20.9	2.81	2.66	0.262	0.337	0.174
Nitrogen (kg/ha) to wheat						
0	264	38.8	32.5	3.17	4.23	
60	315	48.0	33.9	4.03	4.91	
120	342	52.2	34.9	4.58	5.42	
SEm±	3.8	0.51	0.49	0.048	0.052	
CD (P=0.05)	10.8	1.46	1.38	0.135	0.146	

*CEY: Cotton equivalent yield

weight (g) by 27.9, 4.2 and 1.1 over 60 kg N and by 78.4, 13.4 and 2.1 over no N application. Above increases in yield attributes with N fertilization brought in 1.41 and 0.55 tonne/ha improvement in grain yield of wheat over no N and 60 kg N application. Similar trend in straw yield was also observed owing to direct N fertilization of wheat.

Interaction effect of N fertilization of cotton and wheat (Fig. 1, bottom.) on wheat yield revealed that cotton fertilized with 180 kg N/ha had left residual effects equivalent to 60 kg direct application of N to wheat.

System productivity

System productivity of cotton–wheat expressed as cotton–equivalent yield (CEY) was significantly altered by (Table 3) cotton hybrids, levels of N fertilization of cotton and wheat. The CEY of 2 Bt cotton–wheat systems was identical and significantly higher (24.2%) than the non-Bt cotton–wheat system. CEY of cotton-wheat system increased significantly with each successive increase of 60 kg N application to cotton from 0 to 180 kg/ha.

N uptake and use efficiency parameters

The N uptake and use efficiency parameters of cotton and wheat as influenced by cotton hybrids, levels of N fertilization of cotton and wheat are presented in Fig. 2 top, middle, bottom.

Nitrogen uptake of cotton, wheat and thus the system did not differ statistically among cotton hybrids. The amount of N retained in seed cotton out of the total uptake (NHI) vastly differed and was the highest in Bt cotton (57.9%) and the least in non-Bt cotton (40.5%). The indeterminate growth habit and low SCY of non-Bt cotton resulted in less N accumulation in seed cotton and thus recorded lower NHI values. The total N uptake of cotton, and wheat increased significantly with each successive

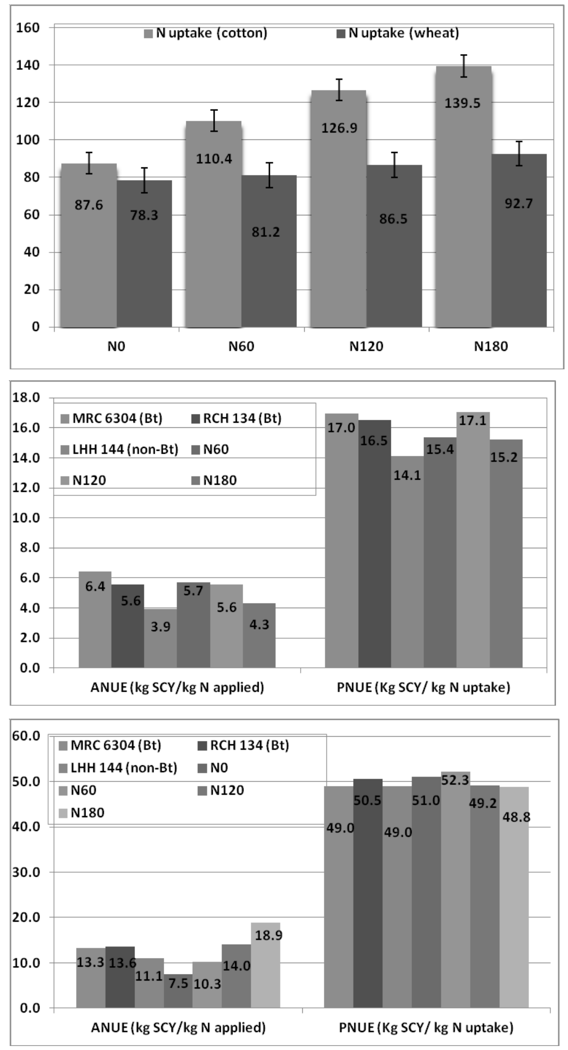

Fig. 2. Nitrogen uptake (top) and its use efficiency in cotton (middle) and wheat (bottom) as influenced by Bt cotton hybrids and N fertilization of cotton

Table 3. Economics (×10³ ₹/ha) of Bt and non-Bt cotton–wheat cultivation as influenced by nitrogen fertilization

Treatment	Cost of cultivation			Net returns		
	Cotton	Wheat	System	Cotton	Wheat	System
Cotton hybrid						
'MRC 6304' (Bt)	24.10	23.50	47.60	41.48	17.94	59.42
'RCH 134' (Bt)	24.10	23.50	47.60	41.26	18.08	59.34
'LHH 144' (non-Bt)	22.91	23.50	46.41	22.01	21.53	43.46
Nitrogen (kg/ha) to cotton						
0	22.20	23.50	45.50	26.82	16.00	42.82
60	23.01	23.50	46.51	33.92	17.77	51.69
120	23.72	23.50	47.22	39.64	20.00	59.64
180	26.08	23.50	49.58	39.86	22.97	62.83
Nitrogen (kg/ha) to wheat						
0		22.00			12.87	
60		23.50			20.24	
120		25.00			24.44	

increase of 60 kg N/ha from 0 to 180 kg/ha. The N uptake of cotton exceeded the application rate in 60 and 120 kg N applied treatments but in 180 kg N/ha treatment, uptake formed only 77.5% of application. The NHI values of cotton decreased with increase in N dose, i.e. 56.3, 52.5, 51.5 and 48.8 with 0, 60, 120 and 180 kg N application. Increase in N uptake with increasing in N dose was due to the increase in N concentration, biological and economic yields. The decrease in NHI with increasing N dose indicates that a greater portion of it is retained in vegetative parts. The ANUE and PNUE of cotton were the highest with 'MRC 6304' Bt and were least in non-Bt cotton. The higher ANUE of Bt hybrids was ascribed to greater increase in SCY with N fertilization. Among N levels, ANUE and PNUE of cotton were the highest with 60 and 120 kg N fertilization and decreased thereafter with increase in N dose. Similarly, the ANUE and PNUE of wheat were the highest with 60 and 120 kg N fertilization. A decrease in ANUE and PNUE with increase in N dose was ascribed to the fact that the increase in SCY (cotton) and grain yield (wheat) were not in proportionate to the N application rate and N uptake.

Response to N fertilization was found to be quadratic. Similarly, Bt hybrids exhibited a quadratic response to N fertilization while non-Bt hybrid showed a linear response. Nitrogen response of cotton (both Bt and non-Bt) was given by $y = 21.772 + 0.0736x – 0.0002x^2$ (R^2=0.9975) with 170.3 kg optimum N dose, with a response of 3.96 kg SCY/kg N at optimum dose and a return of ₹6.23/₹ invested on N. Nitrogen response of 'MRC 6304' Bt is given by the quadratic equation $y = 24.376 + 0.0968x – 0.0003x^2$ (R^2=0.9948); with 152.2 kg optimum dose, with a response of 5.11 kg SCY/kg N at optimum dose and a return of ₹8.34/₹ invested on N. The N response equation for RCH 134 is : $y = 25.021 + 0.0773x – 0.0002x^2$ (R^2=0.9953); with 179.6 kg optimum N dose, with a response of 4.14 kg SCY/kg N at optimum dose and a return of ₹6.57/₹ invested on N. Based on N response, 'MRC 6304' was found more efficient in utilizing N and producing economic yields.

Economics

The economic analysis of the investigation (Table 3) reveals that Bt cotton–wheat had 36.6% higher net income than non-Bt cotton–wheat system (₹43,457/ha). Further, the contribution of wheat to system net income was reduced from 49.6% in non-Bt cotton–wheat system to 30.3% in Bt cotton–wheat system. The higher SCY of Bt hybrids (1.07 tonnes/ha) with marginal increase (₹/ha 1,190) in cost of cultivation (₹750 due to seed and rest due to increased seed cotton picking costs) as compared to non-Bt hybrids resulted in the above trend of net returns. Nitrogen fertilization of Bt cotton enhanced net returns of the cotton, succeeding wheat and thus the system with each successive increase of 60 kg N dose up to 180 kg/ha. However, the increase in net income was at a decreasing rate as N dose increased. Direct N fertilization of the wheat up to 120 kg/ha increased the net returns.

From the 2 year investigation it is concluded that introduction of Bt cotton–wheat system had 24.2% enhanced productivity than non-Bt cotton–wheat. Owing to the determinate growth habit, Bt cottons exhibited quadratic N response. Nitrogen requirement of Bt cotton is within the current recommended dose of 180 kg/ha (152.2 kg N for 'MRC 6304' Bt and 179.6 kg N ('RCH 132' Bt), while non-Bt cotton required higher than the above dose. However, the current recommended N fertilization of 120 kg N/ha wheat holds good irrespective of cotton hybrid grown in NWPZ.

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