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Resource use efficiency of transgenic cotton and peanut intercropping system using modified fertilization technique

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Abstract

Of the several mechanisms that can bring about efficient resource use, the most widely-applicable one is intercropping systems that can make better use of resources. The aim of this study was to evaluate resource capture and resource use efficiency in transgenic cotton-peanut intercropping system and in their respective sole crops with using 25-50% substitution of recommended dose of nitrogen (RDN) of cotton through farmyard manure (FYM) along with 100 % RDN through urea and control (0N). Apparent crop water productivity, nutrient use efficiency, economic returns and modern intercropping indices (system productivity index, actual yield loss, intercropping advantage index, nitrogen stress factor, etc.) were measured for making better understanding of resource use efficiency. Comparisons of intercropped peanut with sole peanut were emphasized because of shrinking area of peanut in the south-east Asian region represents a threat to agricultural system sustainability. Cotton + peanut intercropping system resulted in improved water productivity (19%), nutrient use efficiency (15-20%) and monetary advantage index (16,709) as measured with modern tools of intercropping indices compared with sole crops of cotton and peanut. Peanut cultivated as sole crop attained the least resource productivity in terms of apparent crop water productivity (0.71 kg m^{-3}), nutrient use efficiency (4.47 kg grain kg N^{-1}) and total factor productivity (0.07). Among fertility levels, substitution of 25% RDN of cotton through FYM maintained higher apparent crop water productivity (17%), monetary advantage index (6%), system productivity index (9%) and nutrient use efficiencies (15-17%) over 100% RDN through urea only. This work provides basis for efficient resource use by peanut intercropping with cotton which simultaneously enhances domestic oilseed production and reduce import load of cooking oil without sacrificing the productivity of main crop of cotton in India and other cotton growing countries of the world.

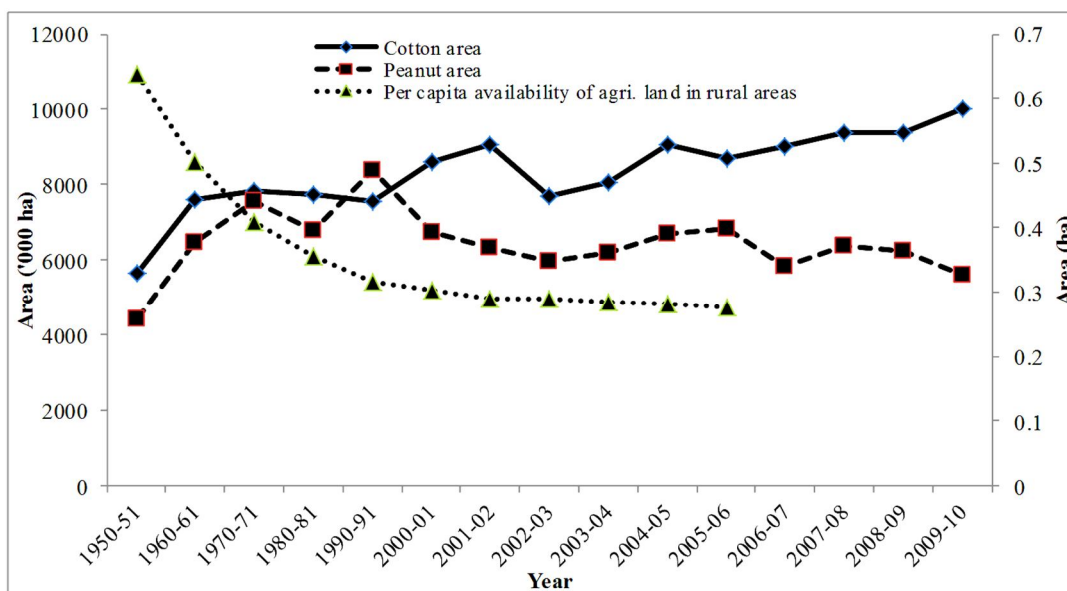*Keywords:* Bt-cotton; Intercropping indices; Nitrogen; Peanut; Resource use efficiencies.

Introduction

Agricultural productivity depends on how factors are efficiently used in the production process. Therefore, intensification of agricultural land and expansion of technology use must be accompanied by resource use efficiency that enhances productivity of factors. Resource use efficiency is a holistic approach to resource use and environmental management that seeks to identify and implement activities that reduce energy, water and other resource use and to minimize waste (NRAM, 2012).
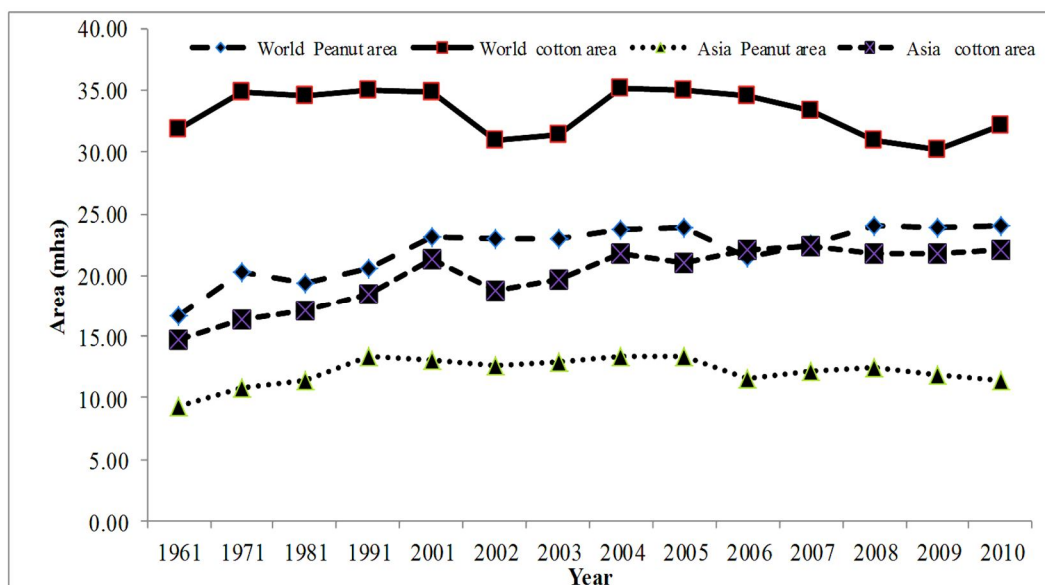
Improvements in resource use efficiency hence increase in productivity will reduce encroachment of population to marginal agricultural lands. In turn, this will protect the resource base of the poor against degradation. More importantly, efficient resource use is the basis for achieving universal food security and poverty reduction strategies particularly in the developing countries.

Cotton (*Gossypium sp.)* is one of the most important textile fibers in the world, accounting for around 35 percent of total world fiber use. It is a major cash crop in the world and is grown commercially in more than 50 countries. World cotton area is almost stagnant from last five decades (only 8% increase from 1961-2012) but production has been markedly increased (179%) because of steep rise in productivity (158%) due to introduction of insect resistant transgenic technology *i.e. Bacillus thuringiensis* (*Bt*) particularly in Asian countries like India, China and Pakistan (Figure 1). At present, almost the entire cotton acreage is planted under *Bt* transgenic hybrids (Venugopalan et al., 2009). Compared to the world average, however, productivity levels are still low mainly because of the abiotic constraints. Due to more income generation from transgenic cotton hybrids, peanut area in major peanut producing states of India (Gujarat, Andhra Pradesh and Tamil Nadu) is replaced by cotton (Singh and Ahlawat, 2014; Singh et al., 2015). Same trend is also observed in Asia but at global level, area of both crops are moreover static (Figure 2). This decreasing peanut area in India resulted into import load of cooking oil having economic value of $ 5600 million (Economic Survey, 2012). The per capita availability of agricultural land in rural areas has declined from 0.64 hectare in 1951 to 0.28 hectare in 2005-06 and is likely to decline further to 0.18 hectare in 2035 (Figure 1). This decline in per capita land availability in the country is mostly on account of rising population (National Land Use and Conservation Board, 2011).

Source: Ministry of Agriculture, Government of India (2012)

Figure 1. Area trend of cotton, peanut and per capita availability of agricultural land in rural areas of India.

Source: Food and Agricultural Organization (2012)

Figure 2. Area trend of cotton and peanut in world and Asia.

The implication is that there is scope for additional increases of output from existing hectares of cotton, if resources are properly harnessed and efficiently allocated. Of the several mechanisms that can bring about efficient resource use (Willey, 1979), the most widely-applicable one is that intercropping systems that can make better use of resources. Willey (1990) described intercropping as the growing of two or more crops simultaneously on the same piece of land with distinct row arrangement. According to Willey (1985), intercropping has been associated with advantages like better utilization of environmental factors, greater yield stability, soil protection and socio-economic advantages like higher yields, greater gross returns per unit area and insurance against mono-crop failures. One way of increasing production by the small farmers is to efficiently use all the resources available in the production process. Transgenic cotton hybrids are sown at wider row spacing (90-120 cm) hence provides sufficient space for cultivation of short duration intercrop like peanut (Waterworth, 1994; Singh et al., 2009). Intercropped peanut benefit the associated cotton crop by either transferring a part of fixed N_2 or sparing effect because of their less N requirement (Lupwayi and Kennedy, 2007; Singh et al., 2013). This also provides 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 equivalent yield is generally higher in intercropping than in sole stand (Singh and Ahlawat, 2011). This practice stabilizes the productivity besides enhancing the total returns (Singh et al., 2013). Among the agronomic packages of any crop, nitrogen (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 costly input, efficient utilization of this resource through optimum synergistic combination is essential for higher productivity and input use efficiency of *Bt*-cotton.

Information on the resource use efficiency of transgenic cotton and peanut intercropping system is very limited in India as well as on global level. Hence, in this paper, we have attempted (i) to examine the benefits of peanut and transgenic cotton hybrids association on resources use by modern intercropping indices and (ii) to assess the benefits of nitrogen management through peanut and farmyard manure (FYM) addition for realizing maximum resource use efficiencies of the system.

Material and Methods

Experimental site

This field experiment was conducted in the *kharif* season (warmer rainy season, June-September) of the years 2006 and 2007 at the Indian Agricultural Research Institute (IARI), 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. It has a semi-arid and sub-tropical climate with hot dry summers and severe cold winters. The total precipitation during the study period was 505.8 mm during 2006 and 457.0 mm during 2007 (Figure 3). A composite representative soil sample was collected from the experimental field prior to experimentation and analysed (Table 1). It belongs to the hyperthermic family of Typic Haplustept. Water table remained below 3.5 m deep from ground surface during crop growth period.
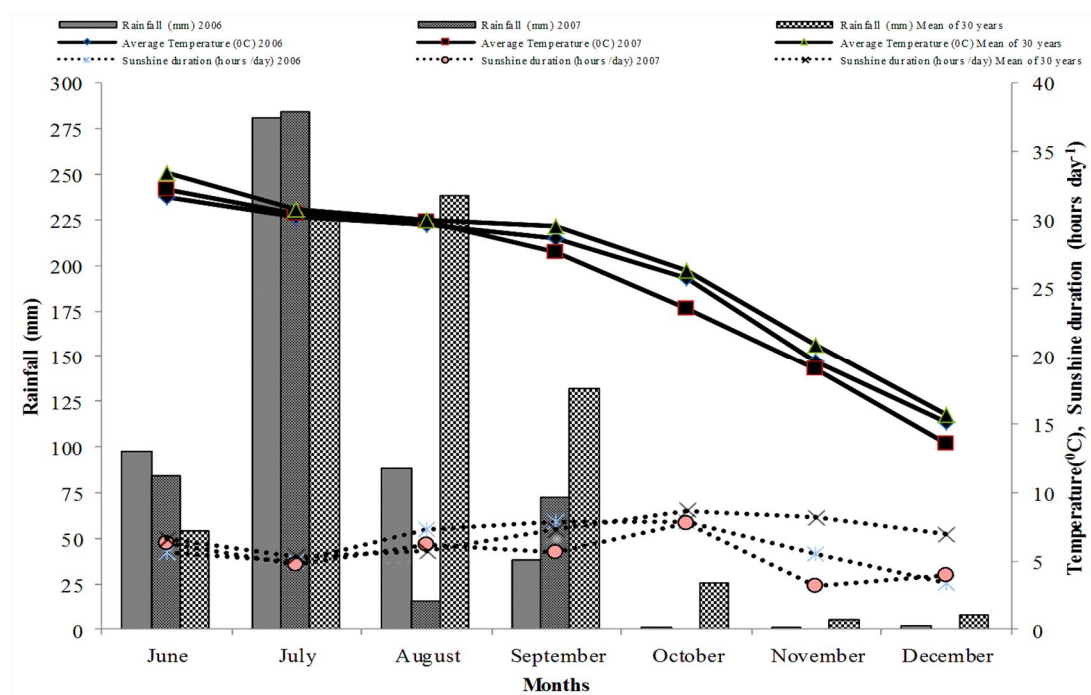

Figure 3. Mean monthly meteorological data of the experimental site.

Table 1. Initial characteristics of the experimental soil from 0-30 cm depth (air dry weight basis).

Parameters	Value
Sand (%)	66.8
Silt (%)	14.3
Clay (%)	18.9
Textural class	Sandy loam
Bulk density (Mg m^{-3})	1.52
Field capacity (%)	17.48
Permanent wilting point (%)	4.32
Organic carbon (mg kg^{-1} soil)	490
KMnO$_4$-N (mg kg^{-1} soil)	96.4
Olsen's P (mg kg^{-1} soil)	5.9
NH$_4$OAc-K (mg kg^{-1} soil)	122.7
pH (1:2.5::soil: water)	7.8
ECe (dSm^{-1} at 25 ^{o}C)	0.32
CEC (Cmol kg^{-1})	10.3

Treatments and crop culture

The nine treatments comprising combination of two cropping systems (C_1- sole cotton and C_2- cotton + peanut) and four fertility levels [F_0- control (0N), F_1- 100% recommended dose of nitrogen (RDN) through urea, F_2- 75% RDN through urea + 25% N through farmyard manure (FYM) and F_3- 50% RDN through urea + 50% N through FYM] to cotton along with sole peanut (with recommended doses of N and P) were laid out in a factorial randomized block design with three replications. In cotton, 150 kg N ha^{-1} was used as RDN. In sole peanut, a uniform basal dose of 20 kg N + 26.2 kg P ha^{-1} was applied. No K fertilizer was applied to both the crops. Field was initially ploughed twice in May after the harvest of 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 left-over 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 dry weight basis contained 178-5.0-2.0-5.0 g kg^{-1} organic C-N-P-K, respectively. Half N and full dose of P were applied at the time of sowing. Remaining N was top-dressed in the form of urea at square initiation stage of cotton at 60 DAS along with second irrigation. In FYM treatments, the quantity of P and K was variable owing to different quantity of FYM addition. 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 using a seed rate of 45 kg ha^{-1}. 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), the experiment was repeated in the different location with same layout. Peanut was harvested in last week of September in both of years while cotton was harvested manually in two pickings in second and first fortnight of November, respectively in both the years. The entire above ground biomass of cotton

and peanut was removed at harvest. There was no incidence of bollworms during study period in *Bt*-cotton.

Sampling and analysis of soil and plants

Destructive soil samples (0-30 cm) were collected during crops period and at harvesting of cotton and peanut. At day 0 (just before FYM mixing), the soil sample was taken immediately. The $KMnO_4$-N was estimated by alkaline $KMnO_4$ method suggested by Subbiah and Asija (1956) and expressed in mg kg^{-1} soil. At all crop growth stages, five randomly selected cotton plants from each plot were segmented into leaf, stem and reproductive parts and then the plant parts were kept separately in paper bags for sun drying. Sun dried samples were transferred into a thermostatic drying oven and were dried at 65 °C (36 to 48 hours) to obtain a constant dry weight. After the final picking, the plants were cut close to the soil surface. Sun dried weight of the stalks from each plot was recorded. The total DM $plot^{-1}$ was worked out by adding the seed cotton yield $plot^{-1}$ to this dry weight. Five plants of peanut from each plot were selected at random and observations on DM accumulation and partitioning were recorded. The weight of total produce harvested from each plot was recorded after sun-drying and expressed as total DM $plot^{-1}$. At harvest, plant samples of cotton and peanut were analysed for total N using a micro-Kjeldahl method, while total P and K were determined using sulphuric-nitric-perchloric acid digest as per procedures described by Prasad et al. (2006). Nutrient uptake was estimated by multiplying nutrient concentration of plant samples with their representative DM yield and summed up the two values for total uptake.

Apparent crop water productivity

Apparent crop water productivity (kg m^{-3}) was estimated by dividing the seed cotton equivalent yield by the amount of water applied as irrigation (Jalota et al., 2008). In sole cotton and cotton intercropped with peanut in both the years five irrigations were applied including land preparation and digging of peanut. In sole peanut only three irrigations were applied in both the years. In each irrigation, five cm depth of irrigation water was applied through check-basin method.

Economic efficiency

For economic analysis, after considering the cost of fertilizers, FYM and intercrop management, the incomes from seed cotton yield were used for economic analysis (CIMMYT, 1988) using the formulas:

$$Net\ return\ = (value\ of\ increased\ yield\ obtained\ -\ cost\ of\ mineral\ and\ /$$
$$or\ organic\ nutrient\ sources) \tag{1}$$

$$Value\ cost\ ratio\ (VCR) = \frac{Value\ of\ increased\ yield\ obtained}{cost\ of\ mineral\ and/or\ organic\ nutrient\ sources} \tag{2}$$

$$Relative\ increase\ in\ income\ (RII) = \frac{Net\ income\ in\ particular\ treatment}{Income\ in\ control} \times 100 \tag{3}$$

The monetary advantage index (MAI) was calculated according to Banik et al. (2006) as follows:

$$MAI = Value\ of\ combined\ intercrops \times \frac{(LER-1)}{LER} \tag{4}$$

The problem with land equivalent ratio (LER) is that such calculation does not account for the value of the crops that are being sown. The solution to this problem is provided in calculating relative value total (RVT) of the crop mixtures. Such calculation is relevant for the farmer that has monetary value as his farming goal. RVT is given as by Alabi and Esobhawan, (2006).

$$RVT = \frac{(aP_1)+(bP_2)}{aM_i} \tag{5}$$

Where a and b are market prices of cotton and peanut, respectively; P_1 and P_2 are yields of cotton and peanut in intercropping and m_i is yields of sole cotton and peanut in monoculture.

A slightly more complex but a better measure of economic advantage of intercropping or mixed cropping was given by Moseley, (1994), termed replacement value of intercropping (RVI). RVI is superior to RVT because it accounts for variable cost in production process. RVI is computed as:

$$RVI = \frac{(aP_1)+(bP_2)}{aM_i-C} \tag{6}$$

Where a, b, P_1, P_2 and m_i are as defined previously. C is the variable costs associated with monocropping. The variables costs (C) in this experiment are labour cost, cost of seed material and sowing of peanut.

Intercropping indices

It is difficult to ascertain whether less uptake of a particular nutrient is the cause for fewer yields in intercropping situations. The nutritional relationships between intercrop components were evaluated using relative yield totals (RYT) (Hall, 1974). The RYT for total dry matter (DM) was calculated as:

$$RYT_{DM} = \frac{IDM_a}{SDM_a} + \frac{IDM_b}{SDM_b} \tag{7}$$

Where IDM_a and IDM_b are intercrop DM for crop 'a' and crop 'b' and SDM_a and SDM_b are sole crop DM for crop 'a' and crop 'b'. This is identical to land equivalent ratio. Relative yield is identical to the partial land equivalent ratio. The RYT for the nutrients was computed similar to that of RYT for total dry matter, in which uptake of corresponding nutrients instead of dry matter were used in the formula. The RYT, relative yield totals for N (RYTN), relative yield totals for P (RYTP) and relative yield totals for K (RYTK) were used to estimate the N, P and K status of the component crops of the cotton/peanut intercropping system. Theoretical consideration was that (i) if RYT $\geq$ RYTN, N is exploited less by the intercrops compared with other resources indicating

that N is a limiting factor in intercropping performance, (ii) If RYT ≤ RNYT, N is exploited more by the intercrops compared with other resources indicating that N is not a limiting factor in intercropping performance (Hall, 1974). Similar was the case with RYTP and RYTK.

Another index for assessing intercrops is the system productivity index (SPI), which standardizes the yield of the secondary crop (peanut) in terms of the primary crop (cotton) (Agegnehu et al., 2006) and is calculated as:

$$SPI = \left(\frac{S_a}{S_b}\right) \times Y_b + Y_a \tag{8}$$

Where S_a and S_b are the mean yield of cotton and peanut in monocrop and Y_a and Y_b are the mean yield of cotton and peanut in mixed culture. Moreover, Banik et al. (2006) reported that the actual yield loss (AYL) index, based on yield per plant, gave more precise information than other indices about the competition between and within component crops and the behaviour of each species in intercropping. The AYL is the proportionate yield loss or gain of intercrops compared with the respective monocrop, *i.e.* it takes into account the actual sown proportion of the component crops with their pure stand. In addition, partial actual yield loss (AYL_a or AYL_b) represent the proportionate yield loss or gain of each species when grown as intercrops relative to their yield in pure stand. The AYL is calculated according to the following formula (Banik et al., 2000):

$$AYL = AYL_a + AYL_b \tag{9}$$

$$AYL_a = \left[\frac{Y_{ai}/Z_{ai}}{Y_a/Z_a}\right] - 1 \tag{10}$$

$$AYL_b = \left[\frac{Y_{bi}/Z_{bi}}{Y_b/Z_b}\right] - 1 \tag{11}$$

Where Z= sown proportion and i= intercrop,

The AYL can have positive or negative values indicating an advantage or disadvantage accrued in intercrops when the main objective is to compare yield on a per plant basis. These competition indices do not provide any information about the economic advantage of an intercropping system. For this reason, the intercropping advantage (IA) index was calculated according to Ghosh (2004) as follows:

$$IA = IA_a + IA_b \tag{12}$$

$$IA_a = AYL_a \times P_a \tag{13}$$

$$IA_b = AYL_b \times P_b \tag{14}$$

Where P_a and P_b are the commercial value of cotton and peanut, respectively.

Competitive ratio (CR), introduced by Willey and Rao (1980), measures competitive ability of different species. Morris and Garrity (1993) used it as an indicator of the advantage in nutrient uptake by one species in intercropping over the other as follows:

$$CR_{ab} = \frac{(\frac{NU_{ia}}{NU_{sa}}) \times Z_a}{(\frac{NU_{ib}}{NU_{sb}}) \times Z_b} \tag{15}$$

Where NU_{ia} and NU_{ib} are nutrient uptake by species a and b in intercropping, Nu_{sa} and NU_{sb} are nutrient uptake by species 'a' and 'b' in sole cropping, Z_a and Z_b are the proportions of the area occupied by crops 'a' and 'b' in the intercropping. When CR_{ab} is greater than 1, competitive ability in taking up given nutrient by crop 'a' is greater than 'b' in intercropping and vice-versa.

Nutrient use efficiency

Two different harvest indexes (HI; dimensionless) were calculated according to Hernandez-Ramirez et al., (2011) to estimate aboveground partitioning for both DM and N as follows:

$$Dry\ matter\ harvest\ index\ (DMHI)\ = \frac{GDM}{ABDM} \tag{16}$$

$$Nitrogen\ harvest\ index\ (NHI)\ = \frac{GN}{ABN} \tag{17}$$

Where G is grain or economic yield and AB is total aboveground biomass.

We define nitrogen use efficiency (NUE) according to Ló´pez-Bellido and Ló´pez-Bellido, (2001), where NUE is the ratio of yield (in tone dry matter ha^{-1} annum^{-1}) to N supply and N supply is the sum of soil NO_3-N and N fertilized.

Factor productivity is the ratio of output value to the cost of the input (Dawe and Dobermann, 1999). It may be a total factor productivity (TFP), that is the ratio of total output value to the total cost of all inputs or partial factor productivity (PFP), the ratio of output value to a specific input. PFP is considered to be more useful than TFP because it provides information on the efficiency with which individual inputs are used. As fertilizer nitrogen is the most commonly used input for increasing crop yields in India, we have determined PFP for nitrogen for all the treatments as:

$$PFP_N = \frac{Y}{FN} \tag{18}$$

Where Y is the economic yield of cotton and peanut and FN the amounts of N applied in kg ha^{-1}.

Nitrogen stress factor (NSF) was calculated as:

$$NSF = \frac{SDW_{adequate} - SDW_{deficient}}{SDW_{adequate}} \times 100 \tag{19}$$

Where SDW= shoot dry weight in g plant[-1].

Apparent recovery of fertilizer N was calculated as percentage recovery of fertilizer N according to Mei et al. (2012),

$$N \; recovery \; efficiency \; (NRE)(\%) = \frac{U_f - U_0}{N_f} \times 100 \tag{20}$$

Where U_f is the uptake of N with fertilizer N, U_0 the uptake of N without fertilizer N and N_f is the amount of applied fertilizer N. Considering the whole crop system, we calculated the NRE for sole crops as:

$$NRE_{Sole}(\%) = \frac{U_{Sole \, f} - U_{Sole \, 0}}{N_f} \times 100 \tag{21}$$

and for intercropping as:

$$NRE_{Intercropping}(\%) = \frac{U_{Intercropping \, f} - U_{Sole \, 0}}{N_f} \times 100 \tag{22}$$

U_{Solef} and U_{Sole0} are the weighted means of N uptake with fertilizer N and without fertilizer N application in sole crops, respectively and $U_{Intercropping \, f}$ is the uptake of N with fertilizer N in the intercropping system.

Nitrogen uptake efficiency (kg N in biomass kg N available in soil[-1]) and nitrogen utilization efficiency (kg grain kg N in biomass[-1]) were calculated according to Cossani et al. (2012) as:

$$\tag{23}$$

$$N \; uptake \; efficiency \; = $$
$$\frac{N \; uptake \; (kg \; N \; in \; biomass \; at \; maturity \; ha^{-1})}{N \; available \; in \; soil \; (kg \; N \; in \; soil \; at \; maturity \; ha^{-1})} + kg \; N \; in \; biomass \; at \; maturity \; ha^{-1}$$

$$N \; utilization \; efficiency \; = \frac{Economic \; yield \; (kg \; ha^{-1})}{N \; uptake \; (kg \; N \; in \; biomass \; at \; maturity \; ha^{-1})} \tag{24}$$

Statistical analysis

The data collected on different parameters were subjected to appropriate statistical analysis following the procedure described by Cochran and Cox (1957). Significance of difference between means was tested through 'F' test and the critical difference (CD) was worked out where variance ratio was found significant for treatment effect. The treatment effects were tested at 5% probability level for their significance. We used average mean data of two years because it would be very difficult to present separate two years data for intercropping indices calculations. Although, we obtained moreover similar trend in both the years, so we used average data of two years.

Results

Apparent crop water productivity and economic efficiencies

Cotton and peanut intercropping system maintained significantly 19 per cent higher apparent crop water productivity than sole cotton. This system also maintained monetary advantage index (MAI) of 16,709, relative value total (RVT) of 1.23 and replacement value of intercropping (RVI) of 1.49 than sole cotton (Table 2). Among fertility levels, substitution of 25% RDN through FYM maintained significantly higher apparent crop water productivity (17%) and MAI of 980 over no substitution. No N fertilization (0N) maintained the highest RVT and RVI over N fertilized treatments. 100% RDN through urea produced the highest net returns, value cost ratio and relative increase in income. 50% RDN substitution through FYM produced negative net return and value cost ratio.

Table 2. Apparent crop water productivity and economic efficiencies of *Bt* cotton and peanut intercropping system with using different fertility levels (mean data of two years).

Treatment	Apparent crop water productivity (kg m^{-3})	Net return (Rs. ha^{-1})	Value cost ratio	Relative increase in income (%)	Monetary advantage index	Relative value total	Replacement value of intercropping
			Cropping systems				
Sole cotton	1.04	-	-	-	-	-	-
Sole peanut	0.71	-	-	-	-	-	-
Cotton +peanut	1.24	11,917	1.08	38.4	16,709	1.23	1.49
L.S.D. (*P*=0.05)	0.08						
		N dose (kg ha^{-1}) and source (% urea- N- % FYM-N)					
Control (0-0)	0.80	-	-	-	11,290	1.37	1.86
150 (100-0)	1.20	19,450	9.60	79.6	15,489	1.21	1.44
150 (75-25)	1.40	18,387	3.39	88.3	16,469	1.18	1.38
150 (50-50)	1.12	-611	-0.07	29.3	12,946	1.24	1.51
L.S.D. (*P*=0.05)	0.06				1025		

Intercropping indices

In cotton + peanut intercropping system, RYTDM (1.62) was comparatively less than the RYTN (1.67) and more than the RYTP (1.54) and RYTK (1.58). Among fertility levels, significantly the highest RYTDM (1.72) was maintained when full RDN of cotton was applied through urea only and it was 4% higher than the control (0N) but FYM containing treatments maintained 4-7% less RYTDM than the control. However, control maintained significantly the highest RYTN, RYTP and RYTK over other fertility levels. RYTN was comparatively higher than RYTDM in all N fertilized treatments except 50% RDN substitution through FYM. Although RYTP and RYTK were comparatively lower than the RYTDM for all fertility levels except RYTK for control (Table 3).

Table 3. Intercropping indices of *Bt* cotton and peanut intercropping system with using different fertility levels (mean data of two years).

Treatment	RYTDM	RYTN	RYTP	RYTK	SPI	AYL			IAI		
						Cotton	Peanut	Total	Cotton	Peanut	Total
Cropping systems											
Sole cotton	-	-	-	-	-	-	-	-	-	-	-
Sole peanut	-	-	-	-	-	-	-	-	-	-	-
Cotton +peanut	1.62	1.67	1.54	1.58	3.99	+3.39	-0.41	+2.98	+68139	-6293	+61846
N dose (kg ha^{-1}) and source (% urea- N- % FYM-N)											
Control (0-0)	1.66	1.76	1.62	1.73	3.47	+3.51	-0.29	+3.22	+70551	-4452	+66099
150 (100-0)	1.72	1.74	1.56	1.62	4.31	+3.39	-0.46	+2.93	+68139	-7061	+61078
150 (75-25)	1.60	1.69	1.54	1.54	4.70	+3.35	-0.48	+2.87	+67335	-7368	+59967
150 (50-50)	1.57	1.53	1.50	1.51	3.93	+3.38	-0.40	+2.98	+67938	-6140	+61798
L.S.D. (*P*=0.05)	0.25	0.19	0.22	0.18	1.25						

RYTDM=Relative yield total for total dry matter; RYTN=Relative yield total for nitrogen uptake; RYTP=Relative yield total for phosphorus uptake; RYTK= Relative yield total for potassium uptake; SPI=System productivity index; AYL= Actual yield loss; IAI= Intercropping advantage index.

Cotton + peanut intercropping system maintained system productivity index (SPI) of near 4.0 and 25% substitution of RDN through FYM maintained the highest SPI over other fertility levels and it was 9.0% higher than the 100% RDN through urea. The results of actual yield loss (AYL) conformed that cotton was dominant species over peanut for all the treatments because of negative values for peanut in the system; however, the total AYL values were positive and greater than 0 in all the treatments. Among all the fertility levels, control maintained the highest positive values for total AYL followed by 50% substitution of RDN through FYM. The highest loss in peanut yield was observed when 25% RDN of cotton was substituted through FYM. Intercropping advantage index values followed a similar trend with the AYL values (Table 3).

In cotton+ peanut intercropping, the N, P and K nutrient competitive ratios of cotton relative to peanut irrespective of treatment always exceeded to 1 during co-growth of two species (Table 4), suggesting that N, P and K acquisition ability of cotton was greater than peanut during the co-growth stage. However nutrient competitive ratios of peanut in intercropping system were also exceeded to 1 except for K (0.93). Without N application (control), N competitive ratio of cotton relative to peanut was the highest over other fertility levels, while P and K competitive ratios of cotton were the highest with 100% RDN application through urea only. Nutrient competitive ratios of peanut with FYM treatments were ≤ 1.

Table 4. Nutrient competitive ratio and nutrient use efficiency of *Bt* cotton and peanut intercropping system with using different fertility levels (mean data of two years).

Treatment	N Competition ratio		P Competition ratio		K Competition ratio		Dry matter harvest index		N harvest index	
	CR_{ab}	CR_{ba}	CR_{ab}	CR_{ba}	CR_{ab}	CR_{ba}	Cotton	Peanut	Cotton	Peanut
Cropping systems										
Sole cotton	-	-	-	-	-		0.36	-	0.38	-
Sole peanut	-	-	-	-	-		-	0.24	-	0.21
Cotton +peanut	9.36	1.04	9.75	1.07	8.43	0.93	0.36	0.21	0.33	0.21
L.S.D. (*P*=0.05)							NS	NS	NS	NS
N dose (kg ha^{-1}) and source (% urea- N- % FYM-N)										
Control (0-0)	10.50	1.17	10.79	1.19	8.76	0.96	0.30	0.21	0.35	0.22
150 (100-0)	9.90	1.09	11.06	1.22	9.34	1.03	0.39	0.20	0.33	0.21
150 (75-25)	9.13	1.00	8.85	0.97	8.23	0.90	0.36	0.21	0.38	0.20
150 (50-50)	8.34	0.92	9.01	0.99	7.97	0.87	0.36	0.20	0.43	0.21
L.S.D. (*P*=0.05)							0.51	NS	0.48	NS

CR_{ab}=cotton intercropped with peanut; CR_{ba} = peanut intercropped with cotton.

Nutrient use efficiency

Cotton in sole as well as in intercropping system maintained similar dry matter harvest index (DMHI) but N harvest index (NHI) was higher for sole cotton (Table 4). Similarly, peanut in sole as well as in intercropping system maintained similar NHI but DMHI was higher for sole peanut. Among fertility levels, 100% RDN through urea maintained significantly the highest DMHI of cotton and FYM containing treatments maintained similar DMHI. 50% RDN substitution through FYM maintained significantly the highest NHI of cotton over other fertility levels. DMHI of peanut was almost similar in all the fertility levels although the highest NHI was recorded with control (0N).

Sole cotton maintained the highest N use efficiency (NUE), N uptake efficiency (NUtE) and N utilization efficiency (NUlE) over intercropped cotton. The highest partial factor productivity of N (PFP$_N$) was observed with sole peanut. Cotton + peanut intercropping system maintained the highest total factor productivity (TFP) over other cropping systems. Peanut in intercropping system maintained higher NUtE and NUlE over sole peanut. Among fertility levels, 25% RDN substitution through FYM maintained significantly the highest NUE, PFP$_N$, N stress factor for cotton, N recovery efficiencies and NUlE of peanut. Application of 100% RDN through urea and 25% RDN substitution through FYM maintained moreover similar TFP and NUtE values. The highest NUtE of peanut and NUlE of cotton were observed with no application of N (Table 5).

Table 5. Nutrient use efficiency of Bt cotton and peanut intercropping system with using different fertility levels (mean data of two years).

Treatment	NUE* (kg grain kg N⁻¹)	TFP**	PFP$_N$*** (kg grain kg N⁻¹)	N stress factor (cotton)	N recovery efficiency (%)			N uptake efficiency (kg N ha⁻¹ in plant per kg N ha⁻¹ in soil)		N utilization efficiency (kg grain kg N⁻¹)	
					Sole cotton	Intercropped cotton	Intercropped/ sole cotton	Cotton	Peanut	Cotton	Peanut
					Cropping systems						
Sole cotton	7.89	0.13	17.3	-	-	-	-	0.37	-	17.3	-
Sole peanut	4.47	0.07	53.0	-	-	-	-	-	0.28	-	9.2
Cotton +peanut	7.84	0.15	20.7	-	-	-	-	0.35	0.40	15.6	10.1
L.S.D. (P=0.05)	NS	NS	-	-	-	-	-	NS	NS	NS	NS
					N dose (kg ha⁻¹) and source (% urea- N- % FYM-N)						
Control (0-0)	8.00	0.12	-	-	-	-	-	0.32	0.23	21.2	10.2
150 (100-0)	7.50	0.16	20.0	28.2	46.2	60.2	75.8	0.43	0.14	15.2	9.8
150 (75-25)	8.75	0.16	23.3	32.4	88.1	108.2	124.0	0.42	0.11	14.7	10.5
150 (50-50)	7.00	0.11	18.7	27.7	46.5	41.7	57.5	0.30	0.13	17.5	9.7
L.S.D. (P=0.05)	0.50	0.08	-	-	-	-	-	0.62	0.82	1.21	NS

*Nitrogen use efficiency (NUE) = $\frac{Economic\ yield}{N\ supply}$, here yield=seed cotton equivalent yield and N supply = initial value of available soil N + N added through FYM + N supply through fertilizer + estimated N added through biological N_2 fixation in soil by peanut.

** Total factor productivity (TFP) = $\frac{Total\ output\ value}{Total\ cost\ of\ all\ inputs}$ *** Partial factor productivity of N = $\frac{Seed\ cotton\ equivalent\ yield}{Amount\ of\ N\ applied}$

Discussion

Cropping systems

Cotton with peanut intercropping system maintained higher apparent crop water productivity and total factor productivity over sole cotton and sole peanut cropping systems (Table 2). This is because of higher cotton equivalent yield by applying same amount of irrigation water and other fertilizer inputs in intercropping system (Jalota et al., 2008; Singh and Ahlawat, 2011). In cotton + peanut intercropping system (Table 3), RYTDM (1.62) was comparatively less than the RYTN (1.67) and more than the RYTP (1.54) and RYTK (1.58) which indicates that N is exploited more in system and it is not limiting factor but P and K are exploited less by the system compared with other resources indicating P and K are limiting factors in intercropping system (Alabi and Esobhawan, 2006). Sole cotton maintained higher NHI, NUE, N uptake and N utilization efficiencies over intercropped cotton (Tables 4 and 5). The relative differences in seed cotton equivalent yields for each treatment (analyzed as the ratio between economic yield of the species) were directly related to the relative differences in apparent crop water productivity (Table 2) or N uptake and utilization efficiencies between them (Cossani et al., 2012). Sole peanut maintained higher DMHI and PFP_N (Table 5) over intercropped peanut and cotton+ peanut system, respectively because of higher pod yield (data not shown) due to non-competitive environment and low dose of N (20 kg ha^{-1}) application in comparison to intercropped peanut (150 kg ha^{-1}) (Hernandez-Ramirez et al., 2011). Intercropped peanut maintained higher N uptake and utilization efficiencies over sole peanut due to less total N uptake because of low pod yield and similar quantity of N available in soil at harvest (Singh et al., 2009; Singh et al., 2013).

Fertility levels

The highest values of RVT (1.37) and RVI (1.86) were recorded in control which means that the farmers that practiced intercropping of cotton and peanut will be making 137% of the income of the farmers who are involved in cotton and peanut monocropping (Table 2). This may be as a result of high yields resulting from the no competitions between the crops. The RVI is 1.86, which means that the farmers who planted cotton and peanut will be making a profit of 86% more than the farmers who are involved in monocropping of these crops. This can be accounted for by inclusion of variable costs in computing RVI (Alabi and Esobhawan, 2006). Positive AYL values for cotton clearly indicated cotton as dominant species in the intercropping system for all the fertility levels with peanut. However, in all the fertility levels, the control values of AYL were greater than for N fertilized treatments, indicating that cotton was more competitive than peanut when there is severe competition for N (Table 3). Similarly, greater competitive ability of non-legumes to exploit resources in association with chickpea or peanut (legumes) has been reported by other researchers (Ghosh, 2004; Banik et al., 2006). The IAI values of all fertility levels were positive, clearly indicating the yield advantages of intercropping over monocropping systems (Table 3). Thus, among the different fertility levels, the maximum economic profit was noted when cotton did not fertilize by N and it was totally dependent on inherent soil $KMnO_4$-N and biologically fixed N_2 by associating peanut intercrop. In our study, the approximate

amount of biological N_2 fixation by sole peanut (132 kg ha^{-1}) as reported by Subba Rao (1988) was considered and this value was halved for the intercropping system. In addition, the advantages of the intercropping systems found in this study can be attributed to better utilization of growth resources. These findings are also in agreement with the results of Lithourgidis et al. (2011). N utilization efficiency in cotton (Table 5) was also the highest for control followed by 50% substitution of RDN of cotton through FYM over other treatments due to less total N uptake for producing moreover similar economic yields of cotton (Singh et al., 2009; Singh et al., 2013).

100% RDN application through urea maintained the highest net return and relative increase in income (Table 3) due to less cost of cultivation and energy input in comparison to FYM treatments (Singh and Ahlawat, 2015). Benefit to cotton in association with peanut was also assessed in terms of RYTDM, RYTN, RYTP and RYTK (Table 3). All of these values at all fertility levels were more than 1.0. This suggested that cotton was not disadvantaged by the intercropping with peanut in terms of growth and N, P and K uptake. Control (0N) maintained the highest values of RYTN, RYTP and RYTK over other fertility levels because of relatively less NPK uptake by sole cotton over intercropped cotton. Further, the RYTDM of system was lesser than its RYTN at all the fertility levels indicating that N is exploited more and it is not limiting factor (Ghosh et al., 2006). Reverse trend was found with RYTP and RYTK except for RYTK at control which indicates that P and K are exploited less by the intercropping system compared with other resources indicating P and K are limiting factor in intercropping. The highest DMHI of cotton was also observed with 100% RDN application through urea only (Table 4) because of less above ground biomass in comparison to seed cotton yield (Hernandez-Ramirez et al., 2011). This fertility level also maintained the highest N uptake efficiency in cotton over other fertility levels (Table 5) because of less soil N available at harvest and moreover similar N uptake in comparison to FYM containing treatments (Cossani et al., 2012).

Conclusions

This study has evaluated the performance of transgenic cotton and peanut intercropping system over its sole crop counterparts with substitution of 25-50% RDN with FYM in the north-western India. These findings are applicable to all the cotton growing countries of the world because of higher nitrogen demand and wide rows cultivation practices of new era transgenic cotton cultivars. Without applying any extra dose of inputs, cotton and peanut intercropping system maintained higher monetary advantages (16,709) and resources productivity in terms of improved water productivity (19%) and nutrient use efficiency (15-20%). This is relevant considering the need for crop diversification to minimize the risks associated with sole transgenic cotton in the transgenic cotton growing area of 24 million hectares in eleven countries of the world and to reduce the import load of cooking oil in India and other Asian countries due to decreasing peanut area. By substitution of 25% RDN of cotton through FYM resource productivity in terms of apparent crop water productivity (17%), monetary advantage index (6%), system productivity index (9%) and nutrient use efficiencies (15-17%) was markedly increased over 100% RDN through urea only. This finding is relevant in the context of increasing transgenic cotton area in the developing countries where cotton growing soil is inherently poor in soil organic carbon. Peanut yield was limited by the

cotton component, so futures investigations like paired row planting, strip cropping etc. should be studied that increased the ability of peanut to recover from the competition of the former crop.

Acknowledgements

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