RESEARCH ARTICLE

Nitrogen Loss from Cotton (*Gossyium* spp.) Plants Grown on Rainfed Vertisols

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Abstract

Low recovery efficiency of nitrogen (N) is mainly attributed to the various losses from the soil after application. N loss from the plants could be substantial probably contributing to the low and inefficient use of N by the cotton cultivars belonging to the different species. However, there is limited information on the recovery efficiency, especially for the transgenic *Bt* cotton hybrids grown in India with surplus fertilization. In an on-going field experiment, we estimated N uptake and determined the recovery efficiency of cotton grown on a rainfed Vertisol. A difference in N uptake at peak boll formation and at final harvest was considered as the N volatilized from the cotton plant. The transgenic hybrid, 'Ajeet-155 BGII', had the highest N uptake followed by Upland cotton cultivar 'Suraj' and an Asiatic cotton cultivar 'Phule Dhanwantary'. However, the recovery efficiency was the least with 'Ajeet-155 BGII' hybrid (27.2%) that also had the highest N loss from the plant (32.3-63.9 kg N/ha). Proportion of fertilizer-N lost in the transgenic cotton was >18.0% as compared to 3.6% for 'Phule Dhanwantary' and 10.5% for the cultivar Suraj. Among the species, Asiatic cotton (*G. arboreum*) had higher recovery efficiency of N and lower N loss from cotton plants than the Upland cotton (*G. hirsutum*) cultivar (Suraj) and transgenic *Bt* hybrid (Ajeet-155 BGII). Growing Asiatic cotton would have the potential to reduce environmental damage and contribute to a cleaner cotton-based production system. Taking into account the plant N loss from plants could be used as one of the important criteria for improving use efficiency and also to calculate an accurate N balance sheet.

Keywords: Asiatic cotton, Nitrogen, Recovery efficiency, Transgenic cotton, Volatilization.

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Introduction

Clothing is only next to food as a human need and cotton has played a major role in meeting this need. Cotton has been an important cash crop in India and Indian cotton, mostly the Asiatic cotton (*Gossypium arboreum*) cultivars, was the backbone of British textile industry in late nineteenth and early twentieth century. Even now India is numero uno in terms of cotton acreage and production in the world followed by China, USA, Brazil and Pakistan. Cotton is now grown on an area of approx. 12.5 million hectares, both under irrigation as well as on rainfed conditions. Traditionally, the Asiatic cotton cultivars were grown with limited fertilizer inputs (Blaise *et al.*, 2014). Fertilizer-N usage increased 1.5 to 2-folds with the N-responsive Upland cotton cultivars and hybrids (60-90 kg N/ha). Further increases in N application rates were witnessed since the inception of the Upland transgenic *Bt* cotton (*G. hirsutum*) hybrids in 2002. Application rates ranged from 90-120 kg N/ha to the rainfed crop and 120-150kg N/ ha applied to cotton grown under irrigation (Blaise *et al.*, 2014). Fertilizer-N being a costly input to the poor Indian farmers, hence its efficient utilization is a must. However, few reports are available on the recovery efficiency of N (RE_N) in cotton in India (Venugopalan *et al.*, 2009) as compared to the cereals such as rice and wheat (Katyal *et al.*, 1987; Pathak *et al.*, 2006).

Nitrogen is absorbed in upland crops, such as cotton mostly as nitrates, which are reduced to ammonia (NH_3) and are later transformed to amino acid glutamine in roots and shoots of the plants; the proportions reduced in roots and shoots vary in different plants. Amino acids then combine to form proteins. Most absorption by roots is over by the plant vegetative phase. After anthesis, N from the leaves gets transported to the fruit/ seed after protein catabolism. It is in this catabolism that the proteins and amino-acids break down in the senescing leaves and NH_3 is produced in leaves. Some of it escapes to the atmosphere through stomata which open for the absorption of CO_2 in photosynthesis (Stutte and Weiland, 1978). N is lost from the crop canopy either as gaseous NH_3 (Keys *et al.*, 1978) or other forms of N_2 (Stutte and Silva, 1981). Ammonia is produced during decarboxylation of glycine in the mitochondria (Keys *et al.*, 1978), amino acid deamination in cytosol (Olea *et al.*, 2004) and also in lignin biosynthesis (Nakashima *et al.*, 1997). Nitrogen loss from tops of plants has not received much attention, although Wetselaar and Farquhar (1980) had long back suggested that net losses from the above-ground parts of plants can be as high as 75 kg N/ha. In India, most studies on the RE_N have been in cereals, namely, rice and wheat and that, too, centred on the soil N loss mechanisms (Katyal *et al.*, 1987; Prasad and Power, 1995; Pathak *et al.*, 2006).

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The hypothesis of the study was that the transgenic *Bt* cotton hybrids with high N application rates may result in lower RE_N and higher N loss from the cotton plants as compared to the Asiatic and Upland cotton cultivars. The objective of the current investigation was to address RE_N and N loss from cotton plants of different species. Field experiments were, therefore, conducted to study the RE_N and the N loss from cotton plants.

Materials and Methods

Study location

Cotton was sown with the onset of rains on the Vertisols under rainfed conditions during 2018-19 and 2019-20 rainy season at the ICAR-Central Institute for Cotton Research Farm (21° 03° N and 79° 05′ E). The farm is situated at approx. 310 m above the mean sea level. The soil at the site is a deep black soil classified as a Typic Chromustert. The soils are low in organic C (4.8 g/kg), N (0.47 g/kg) and P (6 mg/kg) and high in exchangeable K (350 mg/kg). The region has a sub-humid tropical climate with an annual rainfall of 1050 mm rainfall received during the months of June to September.

Treatments

Cultivars included in the trial were 'Phule Dhanwantary' an Asiatic cotton cultivar, 'Suraj' an Upland cotton cultivar and 'Ajeet-155 BGII' an Upland cotton hybrid. 'Suraj' and 'Phule Dhanwantary' were sown at a spacing of 60 × 15 cm with an animal drawn seed drill. The cotton crop was grown following the recommended agronomic practices. Fertilizer application rates differed among the cultivars. The recommended dose of fertilizer (RDF) application was 60 kg N, 13 kg P and 25 kg K/ha for 'Phule Dhanwantary' and 80 kg N, 13 kg P and 25 kg K/ha for 'Suraj' and 90 kg N, 25 kg P and 37 kg K/ha for 'Ajeet-155 BGII' hybrid. Each cultivar had six rows, 10 m long. Apart from the recommended fertilizer dose, a check plot (N0) was also maintained for each cultivar wherein no fertilizer was applied and served as a control. In an adjacent field, Ajeet-155 BGII hybrid was grown. Seeds were sown by manual dibbling at intersections of 90 × 60 cm. Treatments included in the study were (i) N omission as check plot that received no N, (ii) the recommended dose of fertilizers (RDF), the farmers' practice (FP) that is followed in the region of central India, fertilizer application rates recommended by the Nutrient Expert (NE) and an additional treatment with surplus fertilizer application to represent the farmers adopting excess fertilizer application. Each individual plot was 100 m^2. All the treatments were arranged in a randomized block design replicated thrice. In all the treatments, N was applied in three split doses, half at the time of sowing and the remaining in two equal splits at the square and boll formation stages.

N analysis

Fifteen plants were collected, five plants from a sample row from each replicate, at peak boll formation (120 days after sowing) and at harvest (ca. 180 days after sowing) for each cultivar from the fertilized area and separately from the N0 plots. At the harvest stage, most of the leaves and aborted fruiting forms were collected from 1-m^2 area in each plot. The plant samples were air-dried followed by oven drying (65 ± 2 °C) and dry matter was determined. The plant samples were ground using a Wiley mill to pass through a 2-mm sieve. A portion of the sample (0.5 g) was acid digested to determine the N content using the Auto Kjeltec Analyzer. N uptake was calculated by multiplying the N content with the plant dry matter. N uptake at the harvest stage included the above ground vegetation and the fallen litter.

Recovery efficiency of N (RE_N) was determined by taking into account the differences in total N uptake (N_{upt}) at harvest (kg/ha) between the fertilized and the check plot (Eq 1). The difference in N_{upt} at the boll formation and cotton harvest was considered as the amount of N lost from the cotton plants (NLCP). NLCP was estimated using equation 2. This loss expressed as percent of the applied fertilizer-N was determined using equation 3.

$$REN\,(\%) = \frac{100 * (Nupt\ at\ harvest\ in\ fertilized\ plot\ Nupt\ in\ check\ plot)}{N\ applied} \tag{1}$$

$$NLCP\,(kg\,/\,ha) = \frac{(N_{upt}\ at\ boll\ formation\ - N_{upt}\ at\ harvest)}{N\ applied} \tag{2}$$

$$N\ loss\,(\%\ of\ applied\ N) = \frac{100 * (NLCP\ in\ fertilized\ plot - NLCP\ in\ check\ plot)}{N\ applied} \tag{3}$$

Results

The N_{upt} in the varieties as well as the BGII transgenic hybrid was greater at the boll formation stage than at harvest (Table 1). Among the treatments, averaged over cultivars/hybrid, N_{upt} was the least in the control (zero N fertilizer treatment). At recommended N application rate, the N_{upt} was nearly two times that of the control treatment. The N_{upt} was the highest with the transgenic BGII cotton hybrid, 'Ajeet-155 BGII', followed by the Upland cotton cultivar, 'Suraj', and the Asiatic cotton cultivar, 'Phule Dhanwantary'. However, the RE_N was the highest with the Asiatic cotton cultivar 'Phule Dhanwantary' followed by 'Suraj' and the least with 'Ajeet-155 BGII' hybrid. In the BGII hybrid, among the fertilizer treatments, N_{upt} was the highest in the plots wherein N was applied in abundance and the NE treatment followed by the RDF, FP and the N omission plots. However, RE_N was the highest in the RDF followed by the NE, N abundance and the least in the FP.

N loss from the cotton plants (NLCP) ranged from 6.4 to 63.9 kg N/ha with lower values from the check plot. The Ajeet-155 BGII hybrids had NLCP 2.4 to 3.8-fold greater than the 'Phule Dhanwantary' and 'Suraj' plots receiving RDF. The amount of NLCP was the highest in the plots receiving abundance of N followed by the NE and the FP treatments. The proportion of fertilizer-N lost from the cotton canopy was 18.0 to 27.6% while it was hardly 3.6 and 10.5% for the cultivars 'Phule Dhanwantary' and 'Suraj', respectively.

Discussion

As the plants senesce, the proteins and amino-acids break down in the senescing leaves and N is lost from the crop canopy either as gaseous NH_3 (Keys *et al*., 1978) or the other forms of N_2 (Stutte and Silva, 1981). Based on this assumption, we estimated the differences in N_{upt} between the peak boll formation (ca. 120-135 days after sowing) and the final harvest (ca. 180 days) for the different cotton species (Asiatic cotton cultivars vs. Upland high yielding cotton cultivars and the transgenic BGII hybrids). Our studies indicated the Asiatic cotton cultivars had the highest RE_N

Table 1: Effect of cultivars and nutrient management on N uptake (kg/ha), recovery efficiency of N (RE_N) and N loss from cotton plants (NLCP)

Variety	*N applied (kg/ha)*	*N uptake (kg/ha)*		*RE_N (%)*	*NLCP (kg/ha)*	*Fertilizer-N loss (%)*
		Boll formation	*Harvest*			
Phule Dhanwantary	0	35.3	28.9	-	6.4	-
	60	77.7	69.1	67.0	8.6	3.6
Suraj	0	39.8	34.6	-	9.4	-
	80	81.9	67.9	41.6	13.6	10.5
Ajeet-155 BGII						
N omission	0	78.9	64.6	-	14.3	-
FP	120	126.4	86.1	17.9	40.4	21.7
RDF	100	135.4	103.0	38.4	32.3	18.0
Nutrient Expert	150	158.5	116.4	34.5	42.1	18.5
Abundance	180	166.6	102.7	21.2	63.9	27.6

and these values are comparably higher than those we observe for the cereals under the Indian conditions (Prasad, 2013), but those of the transgenic cotton hybrid was low. The highest RE_N with the Asiatic cotton cultivar indicates better utilization of the applied N that could be due to better root foraging. The Asiatic cotton cultivars have a slow above-ground growth but greater root growth when compared to the Upland cotton cultivars and hybrids. Furthermore, RE_N, in general, is higher with low N application rates (Niu *et al.,* 2021). The Asiatic cotton cultivars were fertilized with the lowest N rates (60 kg N/ha) while the BGII hybrids received the highest N (100-180 kg N/ha). Decline in the RE_N with higher N rates have been reported in cereals (Prasad, 2013).

Low values of NLCP from 'Phule Dhanwantary' and 'Suraj' (3.6 and 10.5% of the applied fertilizer-N) could be due to a combination of factors; (i) high RE_N and (ii) better translocation of the N to the fruiting parts. While in the case of the 'Ajeet-155 BGII' hybrids, higher N application results in more vegetative growth. However, due to a cessation in the monsoon, abrupt senescence set in the plants. Thus, NLCP is higher with the BGII hybrids. On an average, N loss from the above-ground vegetative portion was 4.5 and >18.5%, respectively, for the low (60-80 kg N/ha) and high N application rates (>100 kg N/ha). Farquhar *et al*. (1983) pointed out that the losses are the highest for plants grown under high N conditions that lead to higher leaf-N content than those grown under low N conditions. Furthermore, greater supplies of N result in higher leaf area index. Wetselaar and Farquhar (1980) reported sizeable N loss from a variety of crops across geographies and higher N loss from crops with high leaf area index >5 having high leaf-N content. Consequently, we observed greater NLCP of the 'Ajeet-155 BGII' hybrid than those of the 'Phule Dhanwantary' and 'Suraj'. Although our studies indicate a substantial loss of fertilizer-N from the cotton plants of the transgenic cotton hybrids, N loss may vary across locations due to variability in environmental conditions, soil types and agronomic management practices. This could be used as a yardstick for improving use efficiency of fertilizer-N. Furthermore, N balance sheets that were constructed, in general, did not consider N loss from plants (Katyal *et al*., 1987). Considering the substantial N loss from cotton plants, an accurate balance sheet will be possible if N loss from the plants is included.

Conclusion

Our studies indicate a high recovery efficiency of applied fertilizer-N in the cultivars of Asiatic and Upland cotton compared to the transgenic BGII cotton hybrids. N volatilization from the cotton plants was the highest with the transgenic cotton hybrids and the least with the cultivars. Plant N loss was the greatest when fertilizer N was applied in amounts greater than the recommended rate. Thus, adopting right amount and methods of fertilization, can not only improve the use efficiency but also reduce an unwanted N loss to the environment.

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