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Productivity and nitrogen-use efficiency yardsticks in conventional and *Bt* cotton hybrids on rainfed Vertisols*

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The overwhelming adoption of *Bt* transgenic cotton by farmers world over is a testimony to the power of this technology. *Bt* cotton was introduced into India in 2002–03 and by 2010, it occupied 86% of the total area of 11 million ha under cotton (Mayee 2011). The synchronous boll development make *Bt* hybrids early maturing and in general *Bt* hybrids matured 20–30 days earlier than their non-*Bt* counterparts (Venugopalan *et al.* 2009). It is unclear whether this early-maturing habit could be utilized for delayed planting of rainfed cotton in years experiencing delayed onset of monsoon. Currently, in Central India farmers prefer sorghum or soybean over cotton under such situations. Several studies indicate higher yields and improved nutrient use efficiency in *Bt* hybrids (Venugopalan *et al.* 2009). However, whether this is accomplished by an increased nutrient uptake or improved nutrient utilization is not understood and this information is essential in formulating fertilizer management practices. The present investigation was carried out to verify whether *Bt* hybrids perform better than conventional ones under delayed sowing and to understand which nutrient-use efficiency parameter is responsible for yield improvement in *Bt* hybrids.

Field experiments were conducted during the monsoon season of 2005–06 and 2006–07 at the Central Institute for Cotton Research Farm, Nagpur (21°N and 79°E), Maharashtra, characterized by a hot dry sub-humid climate. The site had a deep black, clayey soil dominated by smectitic clay (Typic Haplustert). The weighted mean (0–60 cm) soil moisture content at 33 and 1500 KPa were 36.0 and 19.9 percent respectively. During the crop season of 2005–06 a rainfall of 1 040 mm was received in 51 days, while in 2006–07 it was 926 mm in 41 rainy days as against the average annual rainfall of 958 mm. The experiment was laid out in a split plot design with two dates of sowing, viz. Normal (D1) and Delayed (D2) sowing as main plots and 3 cultivars, viz. MECH 184, RCH 2 and NCS 145 as sub-plots. There were four replications. MECH 184 was a short duration (140–160 days) *Bt* (BG) hybrid, RCH 2 was a medium duration (160–180 days) *Bt* (BG) hybrid and NCS 145 was a medium duration (160-180 days) non *Bt* hybrid. Normal sowing (D1) was done on 25 June 2005 and 30 June 2006 and delayed sowing (D2) was done 15 days later. Crop was raised with the recommended package of practices and was fertilized with 90 kg N, 45 kg P_2O_5 and 45 kg K_2O/ha.

At maturity, five plants/plot were harvested, separated into leaves, stem, carpels, seed, lint and other floral parts and dried to calculate dry matter yield. N content in various plant parts was estimated and total N uptake was calculated. Seed cotton yield was recorded for the entire net plot (4.8 m × 4.7 m). Nitrogen-use efficiency (NUE) and its components, N-uptake efficiency (N Upt E) and N utilization-efficiency (N Uti E), were calculated on a kg/kg basis according to Moll *et al.* (1982), where: NUE = N Upt E x N Uti E and in turn N Upt E = Nt/ Na and N Uti E= SCY/ Nt, where Nt, Na and SCY denote N uptake, N applied and seed cotton yield, respectively. As proposed by Ortiz- Monasterio *et al.* (1997), N Uti E was further subdivided into harvest index (HI) and nitrogen biomass production efficiency (NBPE) and in turn NBPE = DMP/Nt, where DMP is dry matter production(at maturity). Since the trend in data was similar in both years, pooled data was subjected to ANOVA (Gomez and Gomez 1984). Soil moisture was periodically analysed from 0–20, 20–40 and 40–60 cm depth by gravimetric method.

The yields of both the *Bt* hybrids (MECH 184 and RCH-2) were higher than the non-*Bt* hybrid NCS 145 (Bunny) and among the *Bt* hybrids RCH 2 being a longer duration one out yielded MECH 184 (Table 1). Across cultivars, delayed

*Short note

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Table 1 Yield, yield attributes and N under normal and delayed sowing

Treatments	MECH 184	RCH 2	NCS 145	Mean
Seed cotton yield (SCY) kg/ha				
Normal (D_1)	1 136	1 435	1 052	1 208
Delayed (D_2)	964	825	771	853
Mean	1 050	1 130	912	
CD	Dates 56.1	Cultivar 65.0	D × C = 93.3	
Boll number/plant				
Normal (D_1)	16.4	22.1	16.5	18.3
Delayed (D_2)	12.8	14.5	10.3	12.5
Mean	14.6	18.3	13.4	
CD	Dates 0.41	Cultivar 1.39	D × C = 1.96	
Boll weight (g)				
Normal (D_1)	3.11	2.88	2.65	2.88
Delayed (D_2)	2.93	2.59	2.57	2.70
Mean	3.02	2.74	2.61	
CD	Dates NS	Cultivar = 0.113	D × C =NS	
Dry matter yield (kg/ha)				
Normal (D_1)	3 136	3 908	3 392	3 479
Delayed (D_2)	3 040	2 857	3 127	3 008
Mean	3 088	3 383	3 260	
CD	Dates = 195.9	Cultivar = 147.2	D × C = 208.1	
Nutrient uptake (kg/ha)				
Normal (D_1)	65.9	80.4	69.0	71.8
Delayed (D_2)	62.9	58.2	64.4	61.8
Mean	64.4	69.3	66.7	
CD	Dates = 3.77	Cultivar = 3.20	D × C = 4.52	

sowing significantly reduced yields by 29.4%. Cultivars × sowing date interaction was significant. Under delayed sowing, the reduction in yield was only 15.1% in the early maturing MECH 184 *Bt* as against 42.5% in RCH 2 *Bt* confirming that an early maturing cultivar was better suited for late planting (Ali *et al.* 2009).

In 2005–06 (Fig 1a), the soil moisture in the surface (0–20 cm) as well as subsurface layers (20–40 and 40–60 cm) remained above 29% i e 80% of the field capacity till 96 days after sowing after which there was a gradual decline but remained above permanent wilting point (19%) till harvest. During 2006–07 (Fig 1b), which was slightly drier year the decline started early (73 DAS), and the moisture content in the surface layer reached the permanent wilting point at 103 DAS but sub-surface layers had sufficient moisture. Similar pattern of soil moisture depletion was reported on Vertisols by Singh *et al*. 2011. There was sufficient moisture in the sub-surface layers in both the years to meet the crop demand and soil moisture was not a limitation. The *Bt* hybrids under late-sown conditions could not profitably exploit the available residual soil moisture and it appears that the sub-optimal temperatures during the boll development phase would have induced early cut out. The optimum temperature during boll development phase is 22–27°C (Venugopalan *et al.* 2009) and the mean temperature declines rapidly during this phase inducing early cut out (Hebbar *et al.* 2010). Further, the decline in yield with delayed sowing was primarily due to a decrease in boll number and not due to a lower boll weight (Table 1).

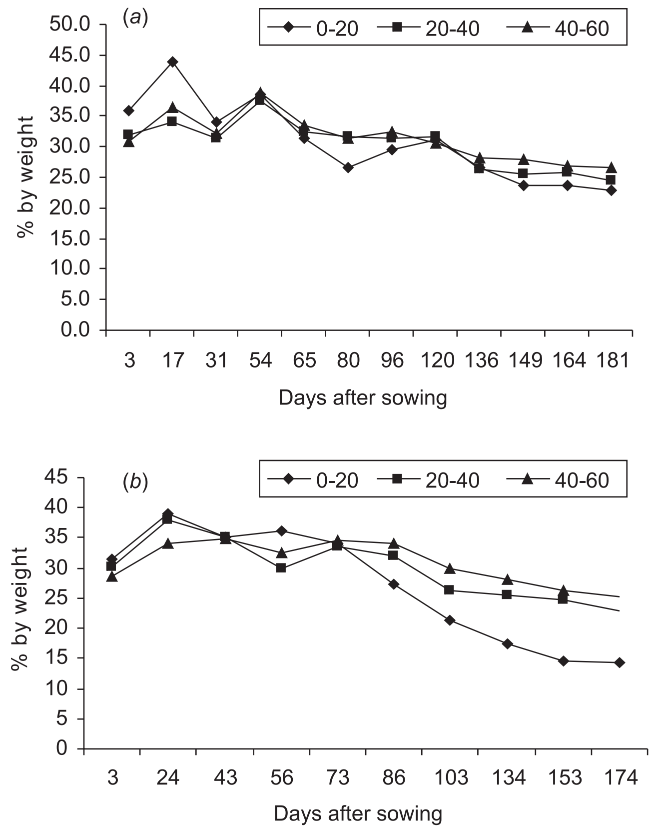

Fig 1 Soil moisture content in surface (0–20 cm) and sub-surface (20–40 and 40–60 cm) layers in (*a*) 2005–06 and (*b*) 2006–07

Late sowing reduced the photo-assimilate accumulation, there by significantly reducing dry matter yield and N uptake (Table 1). Medium duration hybrids RCH 2 *Bt* and NCS 145 had similar dry matter yield and N uptake. Dry matter yield was significantly lower in early maturing *Bt* hybrid (MECH 184). Sowing date × cultivar interaction was significant for N uptake. Delayed sowing significantly reduced N uptake for medium duration hybrids (RCH 2 *Bt* and NCS 145) whereas the difference was not significant in short-duration *Bt* hybrid (MECH 184 *Bt*). Earlier Hellikeri *et al.* (2009) indicated that early sown crop had a higher N uptake.

Nutrient-use efficiency is dependent on two inter-related groups of plant factors, viz. uptake efficiency (Upt. E) and utilization efficiency (Uti. E). NUE, N Upt E and N Uti E values reported (Table 2) are in agreement with the values reported for cotton under similar agro-ecological conditions by Venugopalan *et al.* 2011. The mean NUE was significantly lower at later sowing date (Table 2) and both

Table 2 Nutrient-use efficiency parameters under normal and delayed sowing

Treatments	MECH 184	RCH 2	NCS 145	Mean
Nutrient-use efficiency (partial factor productivity)				
Normal (D_1)	12.63	15.94	11.68	13.42
Delayed (D_2)	10.70	9.17	8.56	9.48
Mean	11.65	12.56	10.12	
CD	Dates 0.62	Cultivar 0. 72	D × C = 1.021	
Nutrient-uptake efficiency				
Normal (D_1)	0.732	0.898	0.767	0.797
Delayed (D_2)	0.700	0.646	0.716	0.687
Mean	0.716	0.770	0.741	
CD	Dates = 0.042	Cultivar = 0.036	D × C = 0.050	
Nutrient-utilization efficiency				
Normal (D_1)	17.3	17.7	14.7	16.5
Delayed (D_2)	15.3	13.8	11.2	13.4
Mean	16.3	15.7	12.9	
CD	Dates 0.37	Cultivar 0.55	D × C = 0.78	
Nitrogen biomass production efficiency				
Normal (D_1)	47.6	49.0	49.5	48.7
Delayed (D_2)	48.3	49.1	49.1	48.8
Mean	48.0	49.1	49.3	
CD	Dates NS	Cultivar NS	D × C =NS	
Harvest index				
Normal (D_1)	0.36	0.36	0.30	0.34
Delayed (D_2)	0.33	0.28	0.23	0.28
Mean	0.35	0.32	0.27	
CD	Dates 0.007	Cultivar 0.012	D × C = 0.017	

the *Bt* hybrids showed higher NUE than the non-*Bt* hybrid (NCS 145). Cultivar × date interaction was significant and the cultivar differences in NUE were more significant under normal (D_1) than late planting (D_2). Braunack and Bange (2010) also reported decline in NUE with delayed planting. Low NUE under late planting was a consequence of both a lower N Upt E and a lower N Uti E. The N Upt E of non-*Bt* NCS-145 was not significantly different than the *Bt* hybrids. Bt hybrids had a shallower root systems than non-*Bt* hybrids (Bhalerao *et al.* 2009) and it is unlikely that they will have a high N Upt E. On the other hand, N Uti E was significantly higher in *Bt* hybrids (MECH 184 and RCH-2) than the non-*Bt* hybrid (NCS 145) in both normal (D_1) and delayed planting (D_2). A further evaluation of the components of N Uti E indicated that NBPE (which was not significantly different) remain unchanged with date of sowing or cultivars but HI declined with delayed sowing. The difference in HI among *Bt* hybrids was significant in delayed sowing (D_2). Both the *Bt* hybrids MECH 184 and RCH 2 had a significantly higher HI than the non-*Bt* NCS 145. N Uti E in cotton was more closely related to HI. *Bt* hybrids are more efficient in translocating assimilates to the reproductive sink (Prakash *et al*. 2009) and therefore maintained a higher HI and had higher N-utilization efficiency.

SUMMARY

The yield of *Bt* hybrids (MCEH 184 and RCH 2) was higher than non-*Bt* NCS 145 and among *Bt* hybrids, the medium duration RCH 32 *Bt* was superior to short-duration MECH 184 under normal sowing date. Under late sown conditions, the performance of both RCH 2 *Bt* and NCS-145 were similar and *Bt* hybrids are not likely to be more advantageous late sown conditions where a decline in temperature induces cut out. N UtiE and not N Upt E was primarily responsible for a higher NUE in Bt hybrids RCH 2 and MECH 184 than the non-*Bt* hybrid NCS-145. A higher HI enabled *Bt* hybrids to utilize N more efficiently.

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