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Within-plant yield distribution in *Bt* cotton following fruiting form removal

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ABSTRACT

Cotton (Gossypium hirsutum L.) yields varied considerably among years and locations, even under adequate nutrient and water supply. Since photosynthesis is one of the principal components in determining yield. So, the objective of this study was to determine how manipulations of ratio of photosynthetic source to reproductive sink affect cotton lint yield and yield components. Field studies were conducted in 2011 and 2012 on a loamy sand soil of Ludhiana, India with four source to sink manipulations; [P1 (All fruiting forms were removed except first position), P2 (All fruiting forms were removed except second position), P1P2 (All fruiting forms were removed except first and second position) and untreated control] imposed on three genotypes (MRC 7017, MRC 7031 and RCH 314) in split plot design with four replications. The results revealed that the P1P2 yielded 23.2 and 22.02 per cent higher seed cotton yield over P1 and 55.5 and 52.9 per cent over P2 during 2011 and 2012, respectively. However, the seed cotton yield recorded in P1 was 26.3 and 25.4 per cent higher than P2. The increase in yield was attributed to higher yield attributes in P1P2 followed by P1 as compared to P2. These results suggest that cotton may not be able to achieve its full yield potential if limited to one boll per fruiting branch.

Keywords : Fruiting forms, position, seed cotton yield, yield attributes

Abscission of fruiting forms due to stress or insect damage during reproductive development often exhibit altered fruiting patterns in mature cotton plants. Guinn (1985) showed several stress induced reductions in boll retention which have been often attributed to reduced carbohydrate supply. Shortage in photosynthate supply has often been considered to be a major cause of abscission (Wullschleger and Oosterhuis, 1990). The loss of reproductive structures alters the physiological growth and development of the plant by redirecting assimilates which normally are incorporated into these abscised organs to other plant parts.

Floral buds appear sequentially on sympodia and thus, fruiting forms of different age and at different positions on the sympodia compete for assimilates in cotton. According to Heitholt (1997) cotton normally produces only one floral bud per fruiting site. Fruiting forms at different positions on the sympodial branches have a marked influence on yielding behaviour of the cotton plant (Kerby and Buxton, 1981). Under normal field conditions, more lint is harvested from cotton bolls on proximal fruiting sites than from the distal fruiting sites on sympodial branches. It is due to the presence of more bolls with higher retention on first fruiting position than on the second, third or lateral positions (Jenkins *et al*, 1990). Heitholt and Schmidt (1994) also reported that first position produce largest fruit, more fruit and higher retention at this particular position and the fruiting position affects not only yield components but also fibre properties. Matthews (1979) emphasized that natural shedding of cotton bolls had a significant effect on adjacent bolls. The shedding of boll from the first fruiting position increases the tendency for the boll to be retained at the second fruiting position. As fruiting structures (squares and bolls) are shed from the sympodia, a redistribution of assimilates destined for these structures occur. Heitholt (1997) also showed that second position fruit was also important as first position fruit because with the removal of fruits from second position yield was significantly reduced. This suggests it is essential to retain both first and second position fruits whether the removal of first position fruit reallocated assimilates to the second position boll which were destined for the first position bolls and resulting in a larger fruiting structure.

The key is to investigate how yield components are altered by position of fruit removal and how these interact with genotype and growing conditions. Cotton can shed up to 70 per cent of all initial fruiting structures during reproductive stage of development (Peoples and Matthews, 1981) but its extent in Punjab, India is unknown and warrants immediate attention. So, whole plant boll retention *i.e.* total bolls per total flowers are an imperative process which affects lint yield. Thus, the removal of fruiting forms from specific fruiting positions may also help in understanding the relative contribution of fruiting sites to boll weight as well as the retention behaviour of fruiting bodies at different positions.

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MATERIALS AND METHODS

A field experiment was conducted at Research Farm, Department of Agronomy, Punjab Agricultural University, Ludhiana, India during *kharif* seasons of 2011 and 2012. The experimental site is situated at 30°54' N and 75°48' E at 247 metres above mean sea level. This region is characterized with subtropical, semiarid climate having three distinct seasons *i.e.* hot and dry summers (April-June), hot and humid monsoon (July-September) and cold winters (November-January). Soil of experimental site was loamy sand, normal in reaction, low in organic carbon, and available nitrogen, medium in available phosphorus and available potassium. The experiment was laid out in split plot design keeping three *Bt* cotton hybrids (MRC 7017, MRC 7031 and RCH 314) in main plots and four types of manual removal of fruiting forms (i) P1 All fruiting forms were removed except first position (ii) P2 All fruiting forms were removed except second position (iii) P1P2 All fruiting forms were removed except first and second position (iv) Check (untreated control) in subplots plot design with four replications. Hand removal of squares started in the second week of square initiation (40-45 days after sowing) till the boll open initiation and during removal fruiting forms that met the size criteria (*i.e.* at pin head stage) were grasped with index finger and thumb, and twisted until the peduncle snapped and disjoined (Bednarz and Roberts, 2001).

Bt cotton hybrid seeds were sown on a well prepared seed bed by dibbling two seeds per hill keeping row to row and plant to plant spacing of 67.5 and 75 cm, respectively, on 13-May-2011 and 11-May-2012. Gap filling was done 25 days after sowing to maintain 100 plant stand. Three week old nursery was raised in polythene bags filled with soil and farm yard manure in 1:1 for gap filling. Whereas, thinning was done after first irrigation keeping one plant per hill. The recommended dose of nitrogen (187.5 kg ha^{-1}) was applied as urea in two equal splits, first at sowing and remaining half at the appearance of the first flower. The recommended dose of phosphorus (30 kg ha^{-1} P_2O_5) as single super phosphate (SSP) was applied at the time of sowing. Disease, pest and weed control measures were adopted as per the package developed by the Punjab Agricultural University, Ludhiana for cultivation of cotton crop.

Plant height was measured from the base of main stem to the base of top leaf. At maturity, the number of main stem internodes of five tagged plants from each plot were counted and expressed on per plant basis. The number of flowers of five tagged plants were counted daily from the time of square initiation upto end of flowering period and expressed as plant^{-1} basis. Total bolls were calculated as total opened bolls at each picking plus total unopened bolls at the time of last picking from each plot from five tagged plants and their mean was taken to express on plant^{-1} basis. Picked bolls plant^{-1} were expressed as the total number of the bolls picked at each picking from five tagged plants and their mean was taken to express on plant^{-1} basis. The seed cotton of each picking was collected from each plot and was weighed. The total yield of all the pickings was expressed as kg ha^{-1}. The data of all the paramerters were statistically analyzed by general linear model (GLM) procedure (SAS Software 9.3, SAS Institute Ltd., U.S.A.) as per the standard procedure for the analysis of variance (ANOVA) for split plot design for both years. All possible pairs of treatment means were compared with Duncan's multiple range test (DMRT) at 5 per cent probability level.

RESULTS AND DISCUSSION

Growth analysis

Plant height and number of sympodial branches plant^{-1} of cotton hybrids differ significantly during 2011 and 2012 (Table 1). Hybrids MRC 7017 and MRC 7031 though statistically *at par* among themselves but attained significantly higher plant height than RCH 314 during both the years. Similarly, the number of sympodial branches which arise from monopodial branches and bear reproductive structures were significantly higher in hybrid MRC 7017 (24.2 and 29.5 plant^{-1}) during 2011 and 2012 respectively. Hybrid MRC 7017 produced higher number of sympodial branches plant^{-1} and was significantly superior to the hybrid RCH 314 which produced 22.1 and 26.3 number of sympodial branches plant^{-1} in 2011 and 2012, respectively. Hybrid MRC 7031 produced 23.4 and 28.8 number of sympodial branches plant^{-1} during 2011 and it was statistically *at par* with both MRC 7017 and RCH 314. The variation in plant height and number of sympodial branches plant^{-1} recorded by different cotton hybrids could be attributed to their respective genetic constitution. Results obtained by Brar (1997) also emphasize the same point. Leaf area index, main stem internodes and monopodial branches plant^{-1} did not differ significantly in any of the hybrid during both the years of study (Table 1).

During 2011 and 2012, plant height was significantly greater in the P2 treatment (137.6 and 151.9 cm, respectively) than in the check (128.8 and 135.7 cm respectively) but it was statistically *at par* with P1 and P1P2 during both the years (Table 1). Similar results were recorded for leaf area index (LAI), main stem internodes (MSI), monopodial and sympodial branches per plant during both the years. The diversion of assimilates from fruiting bodies towards the apical

Table 1: Impact of selective fruiting form removal on growth and growth attributes of different cotton hybrids.

Treatment	Plant height (cm)		Leaf area index		No. of main stem internodes plant^{-1}		Monopodial branches plant^{-1}		Sympodial branches plant^{-1}	
	2011	2012	2011	2012	2011	2012	2011	2012	2011	2012
Hybrids										
MRC 7017	136.8 a	149.9 a	3.7 a	4.3 a	19.7 a	28.5 a	3.9 a	4.5 a	24.2 a	29.5 a
MRC 7031	136.8 a	147.2 a	3.7 a	4.3 a	19.6 a	28.5 a	3.7 a	4.3 a	23.4 ab	28.8 ab
RCH 314	126.9 b	136.6 b	3.6 a	4.2 a	18.8 a	25.6 a	3.7 a	4.2 a	22.1 b	26.6 b
F(p)	< 0.001	0.001	0.502	0.547	0.360	0.009	0.323	0.150	0.024	0.017
Fruiting form removal										
Check	128.8 b	135.7 b	3.5 b	4.1 b	17.8 b	25.3 b	3.5 b	4.2 b	21.7 b	26.9 b
P1	134.9 a	146.5 a	3.7 a	4.3 a	20.3 a	28.5 a	3.9 a	4.5 a	23.9 a	28.7 ab
P2	137.6 a	151.9 a	3.7 a	4.3 a	20.1 a	28.4 a	3.9 a	4.3 ab	23.7 a	29.4 a
P1P2	132.7 ab	144.2 a	3.7 a	4.3 a	19.4 ab	27.9 a	3.8 ab	4.4 ab	23.6 a	28.3 ab
F(p)	0.009	0.003	0.041	0.049	0.017	0.033	0.042	0.013	0.051	0.016

Note: (i) Check (untreated control) (ii) P1 (All fruiting forms were removed except first position), (iii) P2 (All fruiting forms were removed except second position) (iv) P1P2 (All fruiting forms were removed except first and second position).

Table 2: Impact of selective fruiting form removal on yield and yield attributes of different cotton hybrids.

Treatment	Total Bolls		Picked bolls		Unopened bolls		Boll weight		Seed cotton yield (kg ha^{-1})	
	2011	2012	2011	2012	2011	2012	2011	2012	2011	2012
Hybrids										
MRC 7017	38.8 a	56.9 a	33.9 a	49.9 a	4.8 a	6.9 a	3.3 a	3.8 a	1550 a	2120 a
MRC 7031	36.6 ab	53.8 ab	32.0 ab	47.5 ab	4.6 a	6.3 a	3.3 a	3.8 a	1480 a	1980 a
RCH 314	33.8 b	50.2 b	29.2 b	44.2 b	4.6 a	3.1 a	3.1 a	3.7 a	1290 b	1740 b
F(p)	0.001	0.001	0.001	0.001	0.85	0.331	0.410	0.804	< 0.001	< 0.001
Fruiting form removal										
Check	49.7 a	67.9 a	43.1 a	58.7 a	6.7 a	9.2 a	3.08 b	3.6 b	1980 a	2710 a
P1	29.9 c	48.1 c	26.6 c	43.9 c	3.2 c	4.8 c	3.4 a	4.05 a	1250 c	1680 c
P2	24.9 d	43.3 d	21.4 d	38.0 d	3.5 c	5.3 c	3.3 ab	3.8 ab	990 d	1340 d
P1P2	41.1 b	55.3 b	35.8 b	48.9 b	5.2 b	6.5 b	3.2 ab	3.8 ab	1540 b	2050 b
F(p)	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	0.004	0.051	< 0.001	< 0.001

Note: (i) Check (untreated control) (ii) P1 (All fruiting forms were removed except first position), (iii) P2 (All fruiting forms were removed except second position) (iv) P1P2 (All fruiting forms were removed except first and second positions).

growing points with the removal of floral parts might be the possible reason for significantly higher plant height, main stem internodes, LAI, monopodial and sympodial branches plant^{-1} in P2 treatment. Bednarz and Roberts, (2000) also reported that the loss of reproductive structures can alter the physiological growth and development of the plant. A severe fruit loss diverted excess carbohydrates to vegetative growth which resulted in increased plant height. The increase in plant height with intense flower removal was also reported by Mustafa *et al.,* (2004).

Yield distribution

The growing seasons 2011 and 2012 provided very distinct environments which caused fewer yields during 2011 as compared to 2012. The lesser yield during 2011 was due to the higher rainfall received during the month of August which resulted in shedding of flowers and also made congenial conditions for pest build up. Regressions of weekly mean maximum and minimum temperatures against time are also shown in fig. 1. The mean maximum and minimum temperature were lower from 24 to 35 meteorological standard weeks during 2011 as compared to the year 2012. This decrease in temperature was attributed to the heavy rainfall during these standard weeks. However, the magnitude of difference between the temperatures was not as great in further standard weeks. Wells (2001) also reported that unfavourable weather conditions during maximum growth stage resulted in lesser yields in cotton.

Data represented in table 2 depict that the hybrids differed significantly for the total seed cotton yield during both the years of experimentation. Maximum total seed cotton yield (1550 and 2120 kg ha^{-1}) was recorded in hybrid MRC 7017 which was statistically *at par* with the hybrid MRC 7031 (1480 and 1980 kg ha^{-1}) during 2011 and 2012, respectively. The total seed cotton yield of RCH 314 was significantly lower than MRC 7017 and MRC 7031 by 16.8 and 12.8 per cent, respectively during 2011. During 2012 the percentage yield reduction in RCH 314 was 17.9 and 12.1 per cent as compared to MRC 7017 and MRC 7031, respectively. Higher seed cotton yield in MRC 7017 and MRC 7031 might be because of better growth and development due to its higher genetic potential as evident from higher plant height and dry matter accumulation in fruiting bodies which eventually resulted in increased number of sympodial branches plant^{-1} (Table 1), total flowers, total bolls and picked bolls plant^{-1} (Table 2) as recorded by the hybrids. These results are in conformity with findings of Singh *et al.,* (2011).

Among the site specific fruit retention treatments, when compared with P1 the greater percentage of total bolls (37.5 and 15.0 %) were recorded in P1P2 treatment during 2011 and 2012 respectively (Table 2). Similarly, P1P2 attained (65.1 and 27.7 %) greater bolls than P2 during 2011 and 2012 respectively. The percent seed cotton yield (23.2 and 55.5 %) was also significantly higher in P1P2 than P1 and P2, respectively during 2011. Similarly, during 2012 the higher percentage of 55.5 and 52.9 per cent of seed cotton yield was recorded in P1P2 as compared to P1 and P2, respectively. The maximum increase in seed cotton yield was attributed to higher total number of bolls along with significantly higher number of picked bolls and flowers plant^{-1}. This increase in yield attributes and yield in P1P2 treatment was clearly depicted that both first position (FP1) and second position (FP2) fruits are important for yield contribution. However, the number of total flowers, bolls and picked bolls plant^{-1} were less in P1 treatment than P1P2, but the number was significantly higher than P2 treatment (Table 2). It was due to that the P1 treatment provided a physiological situation that favoured increased assimilation to FP1 bolls as indicated by greater seed cotton yield with higher boll weight. This might be due to that the assimilates which were earlier translocated to vegetative parts instead of fruiting bodies due to the removal of fruiting bodies were remobilized towards the existing fruits on first (P1) position. Bednarz *et al.,* (2006) also observed that superior fruiting positions in terms of overall quality occur at first positions which are also known as inner fruiting positions. Increased boll size in response to fruiting form was also reported by Pettigrew (1994).

The percentage of bolls harvested or picked from P1 (24.3 and 15.5 %) were greater than P2 treatment during 2011 and 2012, respectively. The increase in number of picked bolls in P1 was clearly attributed to the higher setting percentage (Fig 2) as compared to the P2 during 2011. However, during 2012 the setting percentage for P1, P2 and P1P2 was statistically at par with each other. The significant improvement in the setting percentage with retaining of fruits at different positions *viz*. P1, P2 and P1P2 might be due to better partitioning of assimilates towards the existing fruiting bodies at specific positions thereby exerting a favorable effect on retention of fruiting bodies by preventing their abscission. The number of unopened bolls at different positions differed among the treatments (Table 2). The FP1 and FP2 bolls in P1 and P2 treatments, respectively had least number of fruit abortion as the percentage of abortion increases in P1P2 followed by check. Decrease in number of unopened bolls plant^{-1} with higher removal of fruiting forms was due to remobilization of assimilates which normally are incorporated into these missing reproductive structures towards the vegetative

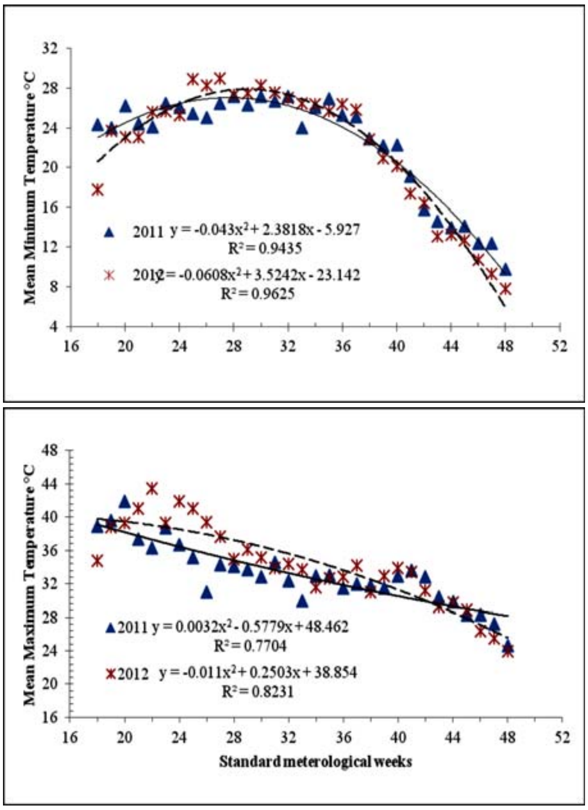

Fig. 1: Regressions of mean minimum and maximum temperature as a function of standard meteorological weeks for check and fruiting form removal treatments during 2011 and 2012.

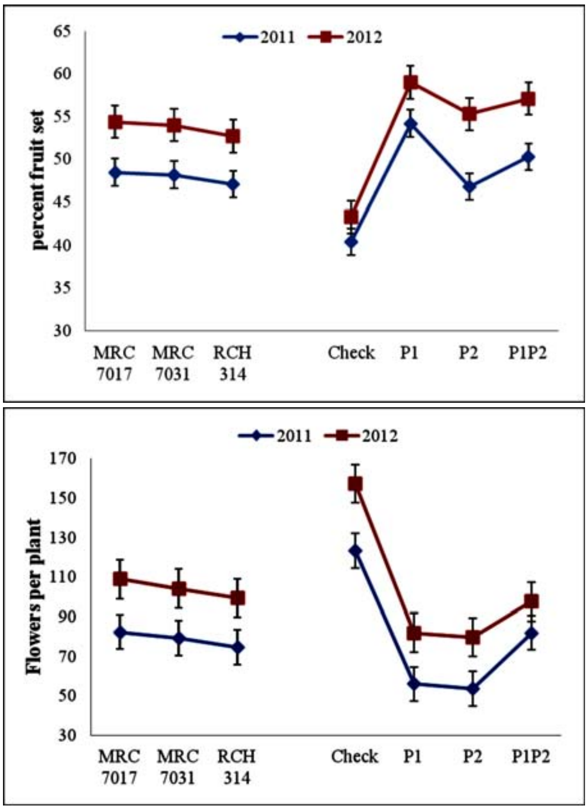

Fig. 2: Fruit set percentage (A) and flowers plant^{-1} (B) of different cotton hybrids as affected by fruiting form removal from specific fruiting positions. Each data point represents a mean values for each fruiting form removal treatment and hybrids.

parts of the plant and increased chlorophyll content. The higher chlorophyll content resulted in higher photosynthetic rate leading to more allocation of assimilates towards the existing fruiting bodies at later stages of crop growth thereby reducing the number of unopened bolls plant^{-1} by improving the source-sink relationship.

This significant increase of seed cotton yield in P1P2 as compared to P1 and P2 was due to the less removal of fruiting parts from P1P2 because fruiting forms were removed from the positions lateral than first and second positions which commemorated more number of flowers, total bolls and picked bolls plant^{-1} and ultimately resulted in higher seed cotton yield as compared to P1 and P2. The data further manifested that the productivity of *Bt* cotton increased significantly when fruiting bodies were retained at first position (P1) as compared to second position (P2) of the sympodial branch. It indicates that first position (P1) has a higher retaining capacity as it is the dominant carbohydrate sink on sympodia as compared to the second position (P2). The treatment where fruiting bodies were retained at first position (P1) produced 26.3 and 25.4 per cent higher seed cotton than the treatment where fruiting bodies were retained at second position (P2) during 2011 and 2012, respectively. Jenkins *et al.*, (1990) also observed that bolls at position one (FP1) on sympodial branches produced more total yield than those at position two (FP2) and all other positions on sympodial branches. The significantly more number of picked bolls at P1 rather than P2 emphasize that the boll retention at the first position (P1) was higher than boll retention at second position (P2). Heitholt (1997) also reported that the removal of fruiting forms from proximal or distal fruiting form positions produced greater percentage of bolls at first position (P1) as compared to second position (P2).

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