Development of agro-technology to increase yields of a shy-bearer desi cotton species, *Gossypium arboreum* race *cernuum* in a non-traditional area of cultivation

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The rapid adoption of *Bt* cotton hybrids has wiped out the desi cotton varieties, causing a huge shortage of coarse raw cotton needed by the surgical cotton industry. The cultivation of desi cotton, *Gossypium arboreum* race *cernuum* with big boll size, good locule retentivity and quality parameters ideal for surgical end-use, is a promising option to revive the surgical cotton industry in Central India. This communication provides the results of a study in India and elsewhere to standardize the agro-techniques – plant density and growth regulator requirements for cultivation of *cernuum* plants. Our results indicate that on rainfed black soils of Central India, for maximizing productivity *cernuum* plants must be planted at 45 × 10 cm spacing accommodating 148,148 plants/ha. Further, application of a growth retardant, mepiquat chloride @ 50 g ai/ha in two equal splits at peak squaring (55–65 days stage) and peak flowering (75–85 days stage), ensures a more efficient translation of photosynthates to bolls, increased boll weight and further enhances yield at high planting densities.

Keywords: Agro-technology, growth regulators, mepiquat chloride, plant density, surgical cotton.

NATIVE *Gossypium arboreum* species is an extremely valuable bio-resource for India. Varieties of desi cotton, *G. arboreum*, with high micronaire, high fluid absorbency and low ash content are ideal for surgical/ absorbent use[1]. With a rise in population, economic growth and increasing awareness about personal hygiene, the demand for surgical cotton is increasing. With a current market value of Rs 57,000 crores, a 11% growth in forecast has been made for surgical cotton industry[2], with huge export potential to the EU countries, USA and Japan. Kranthi[3] estimated the current annual demand of raw cotton for this sector as 3.4 lakh metric tonnes. In the last decade, the spread of *Bt* cotton hybrids has virtually wiped out *G. arboreum* plants, causing huge losses to the surgical cotton manufacturers of Central India. Currently, *G. arboreum* varieties are sparsely grown in Rajasthan and North East India. Industries located in Central and South India are now procuring desi cotton having short staple lint (<20 mm) from North and NE India at high procurement price and huge transportation cost.

A preliminary analysis of the existing varieties and advanced cultures available in the Central Institute for Cotton Research (CICR) gene bank was done to identify suitable varieties for manufacturing absorbent surgical cotton[4]. Fibres from the popular *G. arboreum* varieties Y_1, AKA7, AKA8401, JLA794 and PA255 do not meet all the quality requirements of surgical absorbent cotton. Despite their tolerance to biotic and abiotic stresses, these varieties are not currently preferred by farmers due to their small boll size and poor locule retentivity. The short-stapled, coarse-fibred *G. arboreum* race *cernuum* plant with big bolls, good locule retentivity and high ginning out turn (50%) and other quality parameters is ideal for making surgical cotton[5].

The race *cernuum* of *G. arboreum*, evolved in the Garo hills of Assam, is traditionally cultivated in the hilly tracts of NE India. A few attempts were made in the past to develop varieties of the *cernuum* race adaptable to Central and South India for commercial cultivation. One such variety 'MD-LABB1' was developed[6], but it could not become popular because of low yields and indeterminate growth habit. Though Raju[7] concluded that it would be economical for surgical cotton manufacturers to cultivate *cernuum* plant in Central India under contract farming to meet their needs of raw cotton, agro-technologies for either profitable cultivation or maximizing yields of *cernuum* plant have hitherto not been attempted anywhere in India or other parts of the world. This cotton is essentially a sympodial, shy-bearer[6], with indeterminate habit and hence its growth must be carefully regulated to maximizing yields. Manipulation in plant density or spacing[8,9] and growth regulators[10,11] have been employed in upland *G. hirsutum* plant to modify the morpho-frame of the plants and enhance yield. The present study standardizes the planting density/geometry and growth regulator requirements of *cernuum* plant to modify its growth and maximize productivity on rainfed black soils of Central India, a non-traditional area.

Field studies were conducted using a split-plot design on a medium-deep black soil (Vertic Haplustepts) at the CICR, during the rainy season of 2012–13 and 2013–14, under rainfed conditions. The soil had 4.8 g/kg organic carbon, 5 mg/kg available P and 310 mg/kg available K. The location is characterized by hot, dry sub-humid bio-climate. The cotton plant was evaluated at six crop geometries (planting densities), viz. 45 × 15 cm (148,148 plants/ha), 60 × 15 cm (111,111 plants/ha), 45 × 30 cm (74,074 plants/ha), 60 × 30 cm (55,555 plants/ha), 45 × 45 cm (49,382 plants/ha) and 60 × 45 cm (37,037 plants/ha) in the main plots. The sub-plots comprised of mepiquat chloride (MC; *N–N*-dimethyl piperidinium chloride), spray (two sprays each @ 25 g ai/ha at peak squaring and peak flowering stage) and water spray (no MC). The seeds of *cernuum* (IC 412229) available in the

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Germplasm Unit of CICR, were multiplied and planted on 18 June 2012 and 13 June 2013. All the plots received 60 kg N, 13 kg P and 25 kg K/ha. Nitrogen content in the topmost opened leaf was analysed using standard procedure[12]. At boll opening stage, four random plants/plot were cut just above ground level separated into plant parts (stem, leaves, rind, seed cotton, flowers/squares), dried and weighed to calculate dry matter production and harvest index on per plant basis. The plant parts were powdered to analyse N content and calculate N uptake. To estimate leaf/stem ratio, leaf dry matter was divided by above-ground vegetative parts[13]. Both the number of open bolls and boll weight were calculated as average of six random plants. Bartlett's earliness index was calculated using the formula

$$\frac{P_1 + (P_1 + P_2) + (P_1 + P_2 + P_3) + ... + (P_n)}{n(P_1 + P_2 + P_3 + ... + P_n)},$$

where (P_1, P_2, P_n) are the weight of seed cotton picked during first, second and *n*th picking respectively, and *n* is the total number of pickings.

As the effects of treatment were similar in both the years, the data were pooled over years and analysed using ANOVA[14]. Critical difference (CD) that indicates the least significant difference was used to separate treatment means at 5% level.

Results of ANOVA indicated that spacing had a significant influence on seed cotton yield, boll number, boll weight, plant height, harvest index and N uptake. Likewise, MC had a significant effect on seed cotton yield, boll weight, plant height, leaf nitrogen, earliness, harvest index and leaf/stem ratio of *cernuum* plant. The interaction effect of spacing and MC was significant only for seed cotton yield and leaf/stem ratio.

The height of *cernuum* plants was reduced at closer spacing (Table 1) either with or without the application of MC; presumably due to greater competition between plants for space, light, water and nutrients. Additionally, MC application reduced the height of *cernuum* plants by approximately 12 cm (at 45 × 15 cm) to 21 cm (at 60 × 45 cm). MC, a gibberrelic acid inhibitor[15] reduces height by decreasing the number of nodes[10,16]. MC application also induced leafiness and improved the leaf/stem ratio by 18%. Ren *et al.*[13] also made a similar observation in *G. hirsutum*. The leaves of MC-treated plants were greener and had significantly higher N content (2.29%) than untreated plants (2.12%). Zhang *et al.*[17] also observed a higher N in MC-treated leaves of *G. hirsutum.* Reddy *et al.*[11] attributed the greenness to an increase in chlorophyll content following application of MC.

A crop geometry that provides optimum plant density and spatial distribution of plants is a pre-requisite for better light interception and dry matter production leading to high yield. In the plant density range evaluated (37,037–148,148 plants/ha), the seed cotton yield was highest with 148,148 plants/ha (45 × 15 cm) and a linear increase in yield with plant density (R^2 of 0.94) was observed. The yields at other spacings were significantly lower than those at 60 × 15 cm or 45 × 15 cm spacing (Table 2). Venugopalan *et al.*[18] reported that some *G. arboreum* varieties yielded best at higher densities. Across spacing, application of MC increased yield by 165 kg/ha. A significant MC × spacing interaction testifies that the effect of MC is more pronounced at closer spacing, i.e. 45 × 15 cm (148,148 plants/ha) and 60 × 15 cm (111,111 plants/ha) than other wider spacings. Thus MC application may be more rewarding to *cernuum* planted at higher density. Mao *et al.*[19] concluded that in *G. hirsutum* planted at high density, MC improved plant architecture, light use efficiency and yield.

Although an individual *cernuum* plant bore fewer open bolls, the boll number/m^2 was significantly higher at closer spacing primarily due to a higher number of plants/unit area. Bolls/unit area is the most important contributor to cotton yield[20]. In the present study the number of bolls/m^2 almost doubled when the spacing was reduced from 60 × 45 cm to 45 × 15 cm (Table 1). Wilson *et al.*[21]

Table 1. Effect of plant density and mepiquat chloride (MC) morphological and physiological parameters and yield attributes

Treatment Spacing (cm)	Population/ha	Plant height at maturity (cm)	Leaf/stem ratio	Leaf nitrogen (%)	Open bolls/m^2	Earliness index	Harvest index (%)
45 × 115	148,148	109	0.27	2.20	30.4	0.63	27.2
60 × 15	111,111	117	0.31	2.17	22.1	0.62	25.8
45 × 30	74,074	115	0.30	2.24	15.5	0.60	20.7
60 × 30	55,555	122	0.26	2.18	16.9	0.60	21.2
45 × 45	49,382	119	0.27	2.24	14.3	0.61	20.8
60 × 45	37,037	130	0.24	2.18	15.5	0.60	20.0
SE		3.9	0.022	0.057	1.90	0.019	1.74
CD 5%		8.7	NS	NS	4.22	NS	3.87
MC		111	0.29	2.29	19.7	0.64	24.1
No MC		126	0.25	2.12	18.5	0.57	21.2
SE		2.3	0.005	0.023	0.86	0.011	0.49
CD 5%		5.1	0.012	0.050	NS	0.023	1.08

NS, Non-significant.

Table 2. Effect of plant density and MC on yield, boll weight and nitrogen (N) uptake

Spacing (cm)	45 × 15	60 × 15	45 × 30	60 × 30	45 × 45	60 × 45	Mean
Population/ha	148,148	111,111	74,074	55,555	49,382	37,037	
Seed cotton yield (kg/ha)							
MC	1,684	1,500	1,071	1,098	1,016	854	1,202
No MC	1,450	1,143	885	998	853	885	1,037
Mean	1,567	1,321	978	1,048	935	870	1,120
SE	Spacing – 106.4, MC – 40.2, spacing × MC – 98.4						
CD 5%	Spacing – 237.1, MC – 87.5, spacing × MC – 127.2						
Boll weight (g)							
MC	6.21	6.21	6.33	6.16	6.52	6.43	6.31
No. MC	5.38	5.9	5.86	5.84	5.78	6.24	5.83
Mean	5.8	6.05	6.09	6	6.15	6.34	6.07
SE	Spacing – 0.146, MC – 0.091, spacing × MC – 0.222						
CD 5%	Spacing – NS, MC – 0.20, spacing × MC – NS						
N uptake (kg/ha)							
MC	105.8	97.3	68.9	72.4	67.9	56.2	78.1
No MC	101.4	80.9	65.5	75	64.1	64.7	75.3
Mean	103.6	89.1	67.2	73.7	66	60.5	76.7
SE	Spacing – 5.01, MC – 2.16, spacing × MC – 5.30						
CD 5%	Spacing – 11.17, MC – NS, spacing × MC – NS						

also made a similar observation in *G. hirsutum* and attributed it to greater retention of sympodial bolls at the first position. There was an inverse relationship between plant density and individual boll weight of *cernuum* (Table 2), a phenomenon also common in other species of cotton[22]. Darawsheh *et al.*[23] attributed the decline in boll weight to a decrease in both its components – seeds/boll and lint/boll. MC application in *cernuum* increased boll weight at all spacings, in a manner similar to that observed in *G. hirsutum* cotton[13]. Thus the boll weight of MC-treated *cernuum* plants at closer spacing (6.33 g at 60 × 15 and 6.21 g at 45 × 15 cm) was comparable to that at 60 × 45 cm (6.24 g) without MC. Seed cotton yield is a function of both boll density and weight of individual boll. Although the former increased and the latter was slightly reduced at higher plant density (closer spacing), the net increase in yield was significant. MC application can adequately compensate reduction in boll weight at higher densities and further enhance yield of *cernuum* at high densities.

Higher values of Bartlett's index indicate earliness. Earliness in *cernuum* plant was not influenced by spacing, but MC application imparted earliness by increasing the proportion of bolls harvested during the first picking (Table 1). Closer spacing improved the harvest index per plant, presumably because of a higher competition among closely spaced neighbouring plants for water and nutrients, resulting in a reduction in the growth of individual plants. Application of MC also increased the mean harvest index from 21% to 24%. This could be attributed to an enhancement in the diversion of assimilates towards bolls[24].

A four-fold increase in plant density of *cernuum* (from 37,037 at 65 × 45 cm to 148,148 plants/m^2 at 45 × 15 cm) increased N uptake by 88% with MC application and 57% without MC (Table 2). Closer spacing also increased the uptake efficiency (N uptake/N applied, including soil N), but did not increase the N utilization efficiency (seed cotton yield/N uptake) because the latter remained in the range 14.2–15.1 across the different spacings evaluated.

The sympodial nature of *G. arboreum* race *cernuum* makes it amenable to high-density planting. On black soils of Central India, *cernuum* can be planted at 148,148 plants/ha (45 × 15 cm) for maximizing its productivity. Additionally, application of MC @ 50 g ai/ha, in two equal splits at peak squaring (55–65 days after germination) and peak flowering (75–85 days after germination) would ensure a more efficient translocation of photosynthates to bolls, increase boll weight and further enhance yield at high planting densities.

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Modelling fluid flow through fractured reservoirs: is it different from conventional classical porous medium?

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Two-thirds of peninsular India being composed of hard rocks, a thorough understanding of fluid flow through fractured aquifers becomes inevitable in order to address groundwater recharge and contaminant transport problems, and subsequently to deduce better groundwater management decisions. In this context, an attempt has been made to clearly delineate fundamental differences associated with conceptual modelling of fluid flow through a fractured reservoir from that of conventional classical porous medium. The differences deduced from this study convey that fluid flow through a fractured reservoir deserves special attention and its associated fluid flow analysis cannot be simplified using conventional Darcy-based approach. Further, a brief discussion on the upscaling issues associated with the fractured reservoir is given and the study demonstrates that the upscaling issues associated with a classical porous medium cannot be directly applied to analyse fluid flow through a fractured reservoir.

Keywords: Darcy, fluid flow, fractured reservoir, porous medium, upscaling.

IT is well-known that two-thirds of peninsular India is composed of hard rocks with the inclusion of Deccan Traps as well. This hard rock terrain is essentially drought-prone and heavily depends on the use of groundwater. Groundwater aquifers in such hard rock terrain are predominantly unconfined in nature, and subsequently the respective watershed and its associated groundwater system are directly connected. However, the groundwater flow associated with such unconfined aquifers generally do not follow the surface gradient as observed in a typical homogeneous porous medium. As a result, the discharge from such aquifers does not necessarily get into streams and/or rivers, and subsequently, the estimation of base flow component remains extremely challenging. In other words, the knowledge of fluid desaturation and its associated water level fluctuation within a hard rock aquifer system remains a mystery as it fundamentally requires a knowledge of fluid migration within a hard rock aquifer system. Since the hard rock geological unit is generally associated with a particular degree of fracturing resulting

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