RESEARCH ARTICLE

High density planting system in cotton -The Brazil Experience and Indian Initiatives

MV VENUGOPALAN[1*], KR KRANTHI[1], D. BLAISE[1], SHUBHANGI LAKDE[1] AND K SANKARANARAYANA[2]

[1]*Central Institute for Cotton Research, Nagpur*

[2]*Central Institute for Cotton Research, Regional Station, Coimbatore – 641 003, Tamil Nadu, India*

Received 2 Nov 2013, Accepted 27 December 2013, Published on the web: 8 March 2014

Abstract

The manipulation of plant density and crop geometry is a time tested agronomic technique for achieving high crop yield. Several leading cotton producing countries like USA, Australia, Brazil, Uzbekistan and China have developed suitable plant types to accumulate plant densities varying from 1 lakh to 2.5 lakh plants/ha with using narrow and ultra narrow row spacing. This paper traces the transformation in the cotton production in Brazil through a strategic geographical shift in the cotton production region to Mato Grosso, development of early dwarf and compact genotypes, adoption of Safrina system and a producer demand driven research initiatives. The paper also discusses the research initiatives on high density planting system using straight varieties in the Indian context, which provided 25 – 30% higher yield over recommended spacing on shallow to medium deep soils under rainfed conditions. Appropriate genotypes like PKV 081, NH-615, Suraj, KC3, Anjali, F2383 and ADB-39 could be planted at high densities viz 1.5 to 2.0 lakh plants/ha at 45 or 60 cm row spacing depending upon the soil type . Appropriate agronomic practices like nutrient management, weed control and canopy management to sustain high yields under HDPS are also discussed. The successful outcome of the demonstration of this technology in 8 districts of the rainfed cotton belt in Vidarbha (Maharashtra) on marginal soils is also summarized.

Keywords: Cotton, High density planting system

[**Citation**: MV. Venugopalan, KR.Kranthi, D. Blaise, Shubhangi Lakde and K. Shankaranarayanan. 2013. High density planting system in cotton-The Brazil Experience and Indian Initiatives. *Cotton Res. J*. 5(2) 172-185]

*For correspondence: E-mail: mvvenugopalan@gmail.com

Introduction

The manipulation of row spacing, plant density and the spatial arrangements of cotton plants, for obtaining higher yield have been attempted by agronomists for several decades in many countries. The most commonly tested plant densities range from 5 to 15 plants/m^2 (Kerby *et. Al.* 1990) resulting in a population of 50000 to 150000 plants/ha. The concept on high density cotton planting, more popularly called Ultra Narrow Row (UNR) cotton was initiated by Briggs *et. Al.* (1967). UNR cotton has row spacings as low as 20 cm and plant population on the range of 2 to 2.5 lakh plants/ha, while conventional cotton is planted in rows 90 to 100 cm apart and has a plant population of about 100,000 plants/ha. However in India, the recommended plant density for cotton seldom exceeded 55000 plants/ha.

The UNR system is popular in several countries like Brazil, China, Australia, Spain, Uzbekistan, Argentina, USA and Greece (Rossi *et. Al.* 2004). The availability of compact genotypes, acceptance of weed and pest management technologies including transgenics, development of stripper harvesting machines and widespread application of growth regulators have made these high density cotton production systems successful in these countries. The obvious advantage of this system is earliness (Rossi *et. Al.* 2004) since UNR needs less bolls / plant to achieve the same yield as conventional cotton and the crop does not have to maintain the late formed bolls to mature. The UNR cotton plants produce fewer bolls than conventionally planted cotton but retain a higher percentage of the total bolls in the first sympodial position and a lower percentage in the second position (Vories and Glover, 2006).The other advantages include better light interception, efficient leaf area development and early canopy closure which will shade out the weeds and reduce their competitiveness (Wright *et. Al.* 2011). The early maturity in soils that do not support excessive vegetative growth (Jost and Cothern, 2001) can make this system ideal for shallow to medium soils under rainfed conditions, where conventional late maturity hybrids experience terminal drought. Therefore the high density planting system (HDPS) is now being conceived as an alternate production system having a potential for improving the productivity and profitability, increasing input use efficiency, reducing input costs and minimizing the risks associated with the current cotton production system in India.

Cotton scenario in Brazil

Cotton production pattern in Brazil has witnessed radical changes during the last few decades. During the 1980's the production was adversely affected by the boll weevil *Anthomonas grandis*. The demand for domestic cotton also declined due to strong subsidies provided for foreign cotton. These factors caused a drastic decline in cotton area after 1985 (Table 1).

Table 1 Average area, production and productivity of cotton in Brazil

Years	Area (000 ha)	Production (metric tons)	Productivity (kg/ha)
1971-1975	2290.6	557	242.4
1976-1980	2981.4	561.2	189.6
1981-1985	3189.6	758.2	236.6
1986-1990	2174	717.8	331
1991-1995	1333.6	503.6	385
1996-2000	784.2	575.6	723.2
2001-2005	923.6	1052.0	1136.2
2006-2010	1048.8	1517.2	1443.8
2010-2011	1400	1960	1400
2011-2012	1393	1877	1347
2012-2013	894	1275	1426

(Source: Cotton: World statistics Bulletin of ICAC, Sept 2013)

Prior to 1990, the mid west and south east regions, together called the Meridian area accounted for 80% of the area under cotton (Gillhan *et. Al.*1995). During the second half of 1990's there was a radical shift in cotton areas to the savanna region, the Cerrado. Currently, nearly 80% of the cotton area and 81% of the production is from the Cerradoes comparing of Mato Grosso and Bahia Provinces. Today Brazil cultivates cotton in about one third of the area it did in 1980s but the yield increased fivefold (Table 1). Only around 6800 farms are involved in cotton production in 0.8 to 1.0 million hectares (IBGE, 2010). This turn around made Brazil the 5th largest cotton producer after China, India, USA and Pakistan. Brazil emerged as a strong competitor to USA for cotton markets in Asia and Europe. The reasons for this transformation after the spatial shift in cotton areas to the Cerrados could be:

(i) Intensification of research and implementation of new technologies (Buainain and Batalha, 2007). In 1989 the Grupo Itamarti and Embarpa Algodao established a public private partnership to intensify research and make cotton production viable. This first success of this partnership was the development of CNPA ITA 90 an early a dwarf and compact genotype. CNPA ITA 90 was twice as productive as traditional varieties and was amenable to high density planting and mechanical picking. Suinaga (2003) attributed the development of cotton cultivation in Cerrodos and rise in cotton productivity to this variety.

(ii) Cotton producers in Mato Grosso and Gaias established a second crop cycle "Safrina" and made soybean- cotton rotation possible (Fig. 1).

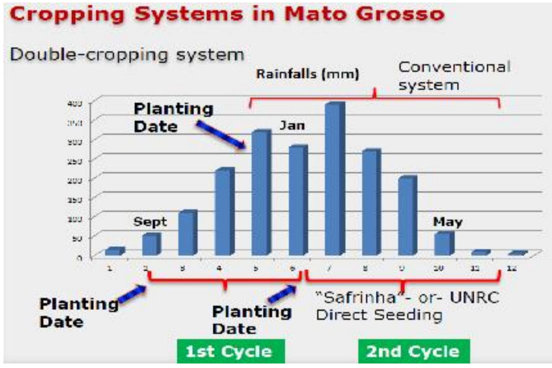

Figure 1 Conventional and safrina system of cotton planting in Mato Grosso (Brazil)

(iii) Under this system, cotton is planted late (in mid February) after soybean. Cotton producers in the mid-west switched over to narrow row cotton (75cm spacing) which was sown in January after the harvest of soybean. At this spacing, 10 plants / m row was found to be optimum (Silva *et.al.* 2012).

(iv) Growing conditions in Mato Grosso were found favorable for ultra-narrow row (45 cm) spaced Safrina cotton and cotton growers invested in this technology (ABRAPA, 2009). Cotton Producers Association of Mato Grosso (AMPA) promoted this venture in 2008-09, helped growers to import stripper type pickers and sponsored research programmes at the Instituto Mato Grosso do Algodao-IMAmt for developing management practices for high density cotton.

(v) The Cerrado region is characterized by soils, temperature and rainfall pattern favourable for second season cotton under high density cotton and farmers adopted the appropriate technology for high density planting. The soils are red – yellow Oxisols which are well drained and field operations are seldom impaired by rainfall but they are poor in fertility and required heavy fertilization. The temperature and rainfall regimes are monomodal. The rainy season begins in September and lasts till April and the maximum rainfall occurs between the months of December and February. The annual precipitation ranges from 1800-2000mm. There is a rain free period during boll maturity which in turn minimizes crop damage and also improves fibre quality (Francisco and Hoogerheide 2012). High yields are obtained under the high density system. In Mato Grosso, at densities greater than 220000 plants / ha, with 0.45 cm row spacing, the crop matured in 135- 150 days compared to 180-220 days in the conventional 0.9 m row spacing and the lint yield obtained was up to 3500 kg lint / ha.. Earliness is achieved since a plant produces only 5-7 bolls and the plant height at harvest is only 0.8m (Belot *et. Al.* 2010). Recent studies also indicated that further reduction in row spacing to 36 cm offered no additional advantage (Silva *et. Al.* 2012). During the 2009-10 season, around 12% of the 42800 ha under cotton in Mato Grosso was under high density planting at 0.45 cm spacing.

(vi) A Brazilian seed company MDM reported yield increase of 10-20% with UNR cotton. The cost of production was significantly lowered. They also observed that a 30 day early closure of canopy resulted in reduced weed competition, better light interception and an increase in water use efficiency. With new short statured varieties, the row spacing could be reduced to 45 cm.

Kranthi, (2012) made the following observations based on a visit to Brazil in April 2012.

(i) Cotton in Brazil is cultivated in 1.0 to 1.4 M hectares and the yields are high at 1500-1800 kg lint per ha. Almost all of Brazil's cotton is cultivated under rain-fed conditions. Though average rainfall is 1800 mm, cotton is sown mainly during the rainy season utilizing around 900-1000 mm and rest of rainy season is used for soybean, maize or other crops.

(ii) Higher productivity in Brazil was achieved through development of compact sympodial varieties suited for high density planting geometry. High density planting with specification of 90X10 cm and 76X10 cm is done with zero monopodial (sympodial) varieties. In some farms ultra-narrow-row planting with 45X10 cm spacing is used. Mepiquat chloride is sprayed 3-4 times to arrest vegetative growth, which, otherwise hinders higher productivity. High Density Planting method is practiced which enables higher number of plants at 150,000 to 250,000 per hectare. Thus, with more number of plants per hectare and with 8-14 bolls per plant at 4.0 gm per boll, the productivity is high at 45 to 55 q seed-cotton per ha and therefore production, is much higher. Cotton is sown during December-January and harvested during June-July i.e. a crop for almost 180 days. Sowing of crop is carried out by using tractor drawn planters.

(iii) Cotton hybrids are not cultivated in Brazil. Thus farmers use farm saved seeds. About 14% of the area in Brazil is under Bt cotton varieties. Adoption of GM cotton is slow because of the non-availability of any GM trait to protect cotton against the main insect pest boll weevil *Anthonomus grandis*. The nine GM traits approved in cotton deal with resistance to bollworms and herbicide.

(iv) Since soils are poor in fertility, high dose of fertilizers is applied to the extent of 150 kgs each of nitrogen, phosphorus and potassium, apart from additional applications of gypsum, boron and sulphur. Extensive use of chemicals is made to check insect pest attack, application of insect pests such as aphids, whiteflies, boll weevils and the fungal disease is common on cotton and requires about 10-14 insecticide applications and 4-5 fungicide applications. Per hectare cost of cultivation is to the tune of US$ 2500-3000, a significant component of which is consumed in use of high level of fertilizers and insecticides. Harvesting of crop is done by using cotton pickers from John Deere, Chase companies.

(v) The Brazilian practices of cotton cultivation, i.e. high investment; high mechanization and large scale farming are not possible to be emulated in India due to small size of Indian agricultural holding and low capacity of the farmers to invest. However, the narrow spacing between plants at 10 cm within a row, irrespective of the row to row spacing of 45, 76 or 90 cm coupled with the use of plant growth regulators are important lessons for Indian rain-fed cotton.

HDPS Initiatives in India:

In central India, traditionally cotton was sown in lines using locally fabricated seed drills (*mogha* or *tiffan* or *sarta* or *nai*). The distance between rows ranged from 30 to 60 cm. The common spacing was 30 to 55 cm in Marathwada, 45 cm in Khandesh and Vidarbha (all Maharashtra), 35 cm in Malwa and Nimar (Madhya Pradesh) and 45 to 60 cm in Mathio (Saurastra, Gujarat). The seed rate was 17-23 kg/ha for *G. racticin* and 8-11 kg/ha for *G. hirsutum*. The distance between plants within row was 22 to 30 cm (Sikka *et. Al.* 1961). For traditional *G. hirsutum* varieties (Buri) a spacing of 60 x 30 cm was found to be optimum (Bhatt and Kumbhare 1956). Choufuli (square planting) at 35x35 cm also became popular in Vidarbha region since this method facilitated intercultural operations in both directions (Sikka *et. Al.* 1961). This system gained further acceptance after the introduction of cotton hybrids. Several research experiments conducted later indicated that with increase in plant density yield per unit area increased to an upper limit (optima), plateaued later and ultimately declined. The optimum plant density in this parabolic (density – yield) relationship was a function of the genotype, soil type, climate and management. Before the advent of hybrid cotton, the highest plant density recommended for varieties of *G. hirsutum* and *G. racticin* were 55000 and 89000 plants/ha (Bonde and Raju, 1996). World over, during the last 50 years, breeding efforts concentrated on developing sympodial varieties with fewer bolls per branch and more bolls closer to the main stem. The objectives were two fold, to fit in more plants per unit row length and to improve fibre quality. Bolls that were closer to the main stem received better nutrition, were more uniform and were expected to produce lint of good quality. As a result most of the varieties developed during the last three decades in many cotton growing countries except India could be fitted to narrow row spacing (38 to 76 cm) with 8-10 plants/m row length and these systems become widely accepted in several countries. These high density planting systems did not take off in India owing to the following reasons.

(i) No conscious effort was made to develop short, compact, early maturing varieties with fruiting bodies close to the main stem and the breeders' continued to select for robust plants bearing more number of bolls / plant (CICR, 2010).

(ii) HDPS with specific aim to maximize productivity per unit area by manipulating plant density was not a priority for agronomists. The agronomic research concentrated on finding the optimum geometry / density for a given cultivar or in optimizing crop geometry or row spacing to facilitate different crop management options like intercropping, inter-culture, soil moisture conservation etc.

(iii) Plant monitoring based use of plant growth regulators was never standardized to alter growth habit and provide a morpho-frame to fit the existing varieties into high density planting.

(iv) It was feared that the altered micro-climate under high density planting would aggravate weeds, insect-pests and diseases. With the new, more potent insecticides and post-emergence weedicides, HDPS systems were not evaluated.

During 2007-2012, under the Technology Mission on Cotton (TMC) project (Identification of *G. hirsutum* genotypes suitable for machine picking and development of agronomic package), some promising genotypes were evaluated at 100X10 cm spacing accommodating100,000 plants/ha. Concerted efforts on high density planting system using straight varieties were initiated under the leadership of the Central Institute for Cotton Research (CICR), Nagpur only in 2010 under the following projects:

- Development of HDPS for maximizing the productivity of rainfed cotton
- Development of nutrient management schedule for *G. hirsutum* and *G. racticin* under HDPS –(TMC).

- Evaluation of compact genotypes for HDPS under rainfed and irrigated situations in different agro-eco regions (AICCIP, 2012).

i. Evaluation of Genotypes under HDPS:

An ideal variety having better adaptation to high-density planting is the first step for successful HDPS. On vertic Inceptisols, 5 genotypes viz (Anjali, CCH 724, NISC 50, AKH 081 and CNH 120MB) were evaluated at 5 spacings viz 60X30 cm (55,000 plants / ha), 45X20 cm, 30X30 cm (both 1, 11,000 plants/ha), 45X13.5 cm and 30X20 cm (both 1,66,000 plants/ha) during 2010-11. Genotype AKH 081 popularly called PKV 081 was found most suitable for HDPS based on yield (Table 2), morphological features, earliness, tolerance to sucking pests and boll weight. Data further indicated that all genotypes do not respond favorably to high density planting and there is a need for screening genotypes under HDPS. Silva *et. Al.* (2012) and Rossi et al (2007) also observed significant interaction between plant density and genotype and recommended a density dependent selection of genotypes. Further, for a particular density, the difference between a narrow row and a wide row was not significant on yield but a wider row may facilitate interculture. Earlier, Heitholt *et.al. (*1996) observed that at equal densities, narrow row may allow each plant to intercept more light and increase seasonal light interception but this advantage is seldom translated into improvements in yield.

Table 2 Effect of planting density/spacing (cm) on seed cotton yield (kg/ha) in some *G. hirsutum* genotypes

Spacing (cm)	60x30	45x20	30x 30	45x 13.5	30x20	Mean
Population/ha	55000	111000	111000	166000	166000	
Anjali	502	847	853	965	795	792
CNH120MB	1030	975	1138	1249	1288	1136
AKH 081	1199	1713	1418	1921	1966	1643
NISC 50	1055	890	1103	1016	1051	1023
G5 CCH 724	679	843	680	864	834	78
Mean	893	1054	1038	1203	1187	
	Spacing	Genotypes	Interaction			
CD at 5%	97.6	70.2	170.7			

(Venugopalan et al, 2011)

During 2011-12, ten genotypes were evaluated at 60X15 (111,000 plants/ha) and 45X15 (148,000 plants/ha) for their suitability for HDPS on vertic Inceptisols of Nagpur rainfed conditions (Figure 2).

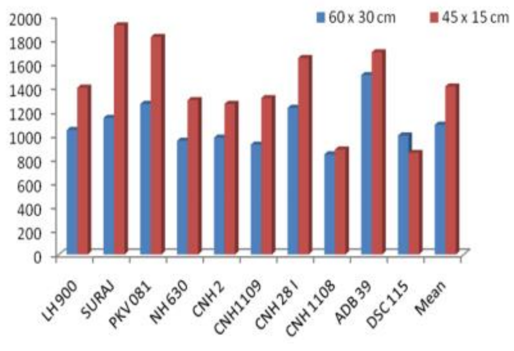

Figure 2: Seed cotton yield (kg/ha) of different genotypes under normal (60x 30 cm) and high density planting (45x15 cm)

Results indicated that genotypes Suraj, PKV 081, ADB 39 and 28I were more promising in terms of yield (Figure 2), morphological features, earliness and nutrient use efficiency under HDPS (45x15cm resulting in 148,000 plants/ha). Averaged over the 10 genotypes the yield increase with HDPS over recommended spacing was 29.5 %, but it was as high as 67% in Suraj, 44% in PKV 081 and 34% in CNH 28I. HDPS (with 148,000 plants/ha) may not be suitable for taller genotypes CNH 1108 and DSC 115. Earlier, Kerby *et. Al.* (1990) also concluded that increase in yield under high plant densities was low in tall varieties with more indeterminate growth. Coffey and Davis, (1985) suggested that varieties that produce fewer and shorter and fewer fruiting branches are ideal for high density planting.

During 2012-13 thirteen genotypes developed under diverse agro-climate conditions viz., NH 615 and NH 545 (Nanded), ADB 39 and MDLH 1 (Ailabad), Suraj, LRK 516 (Coimbatore), KC 3 (Kovilpatti), RS 875 (Ganganagar), CSH 3178 (Sirsa), F 2383 (Faridkot), H 6 Bt (BG II) and H 8 Bt (BG II) (Surat) and PKV 081 (Akola) were evaluated at 3 spacings 45x15cm (148,000 plants/ha), 60x15cm (111,000 plants/ha) and 90x15cm (74,000 plants/ha) on a shallow black soil (Vertic Inceptisol).

Table 3 Effect of planting density on seed cotton yield (kg/ha) of different genotypes 2012-13

Genotype	45x15cm (148,000/ha)	60x15 cm (111,000/ha)	90x15 cm (74,000/ha)	Mean
NH 615	2512	2633	2201	2449
NH 545	2550	2830	2839	2740
ADB 39	3009	2539	2535	2694
SURAJ	2748	2976	2632	2785
PKV 081	3011	2798	2355	2721
KC 3	3071	3113	2709	2964
RS 875	2555	1911	1776	2080
CSH 3178	2795	2468	2501	2588
MDLH 1	1690	1813	1519	1674
LRK 516	2814	2643	2345	2601
F 2383	2379	2142	2081	2201
H 6 Bt	3756	4074	3581	3804
H 8 Bt	2868	3596	2945	3136
Mean	2751	2733	2463	
CD 5%	Spacing: 238.3, Genotype: 335.9, Interaction: 581.9			

The effect of spacing, genotypes and spacing x genotype interaction were significant (Table 3). Averaged over the 13 genotypes the yield improvement with 45x15cm over 60x15cm spacing was not significant but the yield in both superior to 90X15 cm spacing. However, the genotypes ADB 39 (3000 kg/ha), PKV 081 (3011 kg/ha) and LRK 516 (2814 kg/ha) performed best at 45x15cm spacing whereas for genotypes NH 545 (2830 kg/ha), KC 3 (3113 kg/ha) and Suraj (2976 kg/ha) 60x15cm spacing was found to be optimum.

During the year 2011-12, promising genotypes were also evaluated under HDPS under the AICCIP and the top five entries are enlisted in Table 4.

Nutrient Requirement under HDPS:

A pertinent question to be resolved is whether the demand for nutrients is greater under HDPS since the plant population is higher. Multi –location trails were conducted (under Technology Mission on Cotton) to determine whether the recommended fertilizer dose (RDF) for conventional cotton (at normal density) is also applicable for cotton planted under HDPS. Preliminary results (Table 5) indicated that 25% additional fertilizers would be needed to meet the increased requirement of the crop under HDPS with a population of 148000 plants/ha (Singh et al , 2012).

Table 4 Top ranking entries under HDPS at various AICCIP Centres

Rainfed (45x15 cm, 148000 plants/ha)					Irrigated (60x15 cm, 111000 plants/ha)		
Akola	Nagpur	Nanded	Aruppukotai	Nandyal	Dharwar	Coimbatore	Guntur
GSHV01/1338	NH-615	NH-615	AKH-081	NH-545	BS-41	GSHV01/1338	GSHV01/1338
NH-615	BS-41	NH-545	ADB-39	NH-615	CNHO-12	TCH-1705	TCH-1608
NH-545	NH-545	BS-41	TCH-1605	CNHO-12	TCH-1705	BS-41	CNH-1109
GJHV-460	GJHV-460	DCS-115	CNHO-12	AKH-2006-2	CNH-1109	CNH-1109	ADB-39
ADB-39	AKH-081	NH-615	NH-545	BS-41	Sahana	Suraj	AKH-081

(Compiled from: AICCIP, 2012)

Table 5 Seed cotton yield (kg/ha) of *G. hirsutum* under HDPS at different fertility levels at different locations (Mean of 2010-11 and 2011-12)

	Parbhani	Akola	Khandwa	Nagpur	Nandyal
75 % RDF	1179	1698	1580	972	2026
100 % RDF	1210	1796	1680	1182	2060
125 % RDF	1341	1921	1780	1353	2133
150 % RDF	1263	1873	1770	1311	2083
CD 5%	71.0	136		136	NS

RDF(N:P:K): Parbhani-84:18:36, Akola-50:20:0, Khandwa: ,Nagpur-60:13:26, Nadyal:40:9:18

Studies elsewhere (Rinehardt *et al*. 2003) also indicated that about 30% more N is required under Ultra Narrow row cotton compared to the conventional row cotton. However, in 10 genotypes evaluated under HDPS (148000 plants/ha, there was no consistent increase in yield with 125% RDF (Recommended Dose of Fertilizers)+2 t/ha Vermicompost over RDF alone (CICR, 2012). The plants grew taller and there was delay in maturity with additional fertilizer dose. Wiatrak *et al*, (2000) opined that application of higher dose of N to high density cotton increased hard-locks (immature bolls) and delayed maturity. More studies are therefore needed to conclude on N requirements on HDPS.

Crop canopy management under HDPS:

Mepiquat chloride (1,1-dimethyl-piperidinium chloride), a plant growth regulator is widely used to manage cotton morphoframe, regulate plant development and hasten maturity under high plating densities (Stuart *et. Al.* 1984). Although plant growth regulators have been thoroughly widely tested in cotton in India, there are no specific recommendations regarding their dose and timing for modifying crop morphoframe to accommodate our varieties at high planting densities.

Mepiquat chloride @ 50 or 75 g ai/ha at different application schedules were tested on Suraj, AKH 081 and NH 615 varieties planted at 148,000 plants/ha under rainfed condition on a vertic Inceptisol at Nagpur (CICR, 2013). There was a dose dependent reduction in plant height, decrease in height / node ratio, an increase in boll weight and a delay in maturity with the application of growth regulators but the effect on yield was not significant. Application of mepiquat chloride makes the plant more compact, with fewer nodes (Reddy et al., 1990), shorter internodes and fewer reproductive branches (Bogiani and Rosolem, 2009) and these changes were also noted in all the 3 varieties. The results were slightly different under irrigated conditions at Coimabtore (Tamilnadu) as well as Sirsa (Haryana) where there was a positive response to mepiquat chloride application. Application of mepiquat chloride reduced leaf area and increased the number of bolls per unit area at high plant density. It also helped in retention of bolls on lower sympodia and increased the synchrony of boll maturation (Gwathmey and Clement, 2010)

However, the effect of mepiquat chloride on cotton is affected by environmental conditions, particularly temperature (Rosolem et al 2013) and this might have resulted in differential response across centres. At Coimbatore there was a variety dependednt response to mepiquat chloride application @ 75gai/ha in three splits at 45, 60 and 75 DAS in winter irrigated cotton planted at 45x15 cm spacing (Figure 3).

There was a reduction in plant height, sympodial length and LAI and an enhanced the number of burst boll/m^2 leading to an increase in yield at Coimbatore. Across cultivars, application of mepiquat chloride increased seed cotton yields from 1330 kg/ha to 1530 kg/ha. Interaction effect of cultivars and application of mepiquat chloride was significant. Taller cultivars – TCH 1608 and 1705 benefitted more with application of mepiquat chloride compared to the other cultivars having a compact growth habit. Cultivars with a more indeterminate growth habit responded more positively Mepiquat chloride application (Craig and Gwathmey, 2005). There is a need for detailed investigations on this aspect before any recommendations are given.

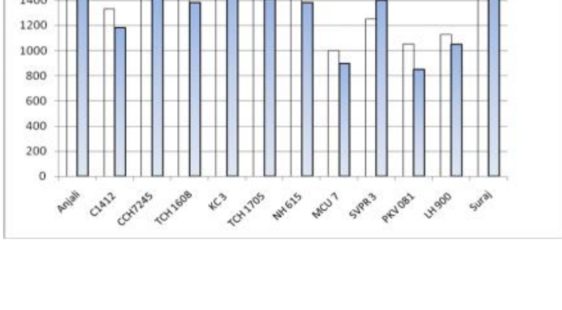

Figure 3:Effect of application of mepiquat chloride (75g ai/ha) on seed cotton yield under HDPS

Weed Management:

The opportunities for interculture are limited in HDPS and hence weed management becomes more critical. Nevertheless, early closure of canopy results in reduced weed competition. However improper plant stand due to uneven germination and seedling establishment may increase weed density within crop rows and these weeds are difficult to manage and under these circumstances, application of post emergence herbicides become necessary. Although the results on weed management exclusively under HDPS have yet not been concluded, preliminary results indicate that effective control of weeds could be accomplished with pendimethalin @ 1kg/ha+1 interculture + 1 hand weeding (to remove remaining weeds) + 1 post emergence spray of tank mixed Pyrthibac Na@75gai/ha and Quizalofop ethyl @ 50 g/ha. The option of a combination of the weedicides or single application of either of them depends upon the nature of weed flora.

Demonstration of HDPS on farmers' field.

Encouraged with the three year experimental farm results, the CICR demonstrated this technology through a farmer mode on marginal soils under rain-fed conditions of one-acre (0.4 ha) fields of 155 farmers in the eight cotton growing districts of Vidarbha during the *kharif* season of 2012. The varieties Suraj, NH615 and PKV081 were planted at 45x10 cm or 60x10 cm spacing with early onset of monsoon at a seed rate of 15 kg/ha.

Despite delayed onset leading to delayed sowing and erratic rainfall during the vegetative phase, high yields of 25 to 30 quintals per hectare of seed-cotton were obtained by several farmers. Across the trials, the yields averaged at 15 to 18 quintals, which is double the average of Vidarbha and more than the national average. Highest yields were obtained in Chandrapur, Amaravati, Nagpur, Yavatmal and Akola districts (table). Severe drought in Buldhana, Washim and some parts of Wardha resulted in relatively lower yields of 800-1000 kg per hectare. The increase in yields was estimated to be at least 35-40% above the yields that were normally obtained by the farmers in the previous years. The cost of cultivation was Rs 20,000 to 25,000 per hectare. Net profit ranged from Rs 12,000 to 90,000 per hectare.

Table 6 Seed cotton yield (q/ha) in HDPS demonstrations in Vidarbha

District	No. of Trials	Minimum	Maximum	Average
Akola	20	10.2	18.8	15
Amravati	37	6.3	20.7	11.2
Buldhana	28	5	11.3	9.7
Chandrapur	20	4.5	31.2	12.8
Nagpur	13	8.8	20.9	12.2
Washim	8	7.9	13.4	10.3
Wardha	13	5	21	9.5
Yavatmal	16	12.5	30	18.1

Further analysis of the data indicated that yields were higher on coarse but shallow soils which offered better internal drainage compared to deep soils although the latter favoured vegetative growth. A distinct advantage was observed wherever the sowings were completed before 25th June. The advantage of early sowing advantage was more pronounced on shallow soils. An outbreak of *Helicoverpa armigera* was noticed in the initial fruiting phase and 2 insecticide applications had to be given to control the pest. Damage due to bollworms early in the season caused loss of first position bolls and consequently the plants grew taller, yet farmers were reluctant to use growth retardants. Under these circumstances, the maturity was also delayed, particularly on deep soils.

High density planting systems is a highly technical system and racticing this system needs careful planning, timely planting, rigorous monitoring and timely interventions. Several, management related issues are yet to be resolved. Since large scale adoption of this system would involve substantial alternations in the way cotton is produced today there is a need for end to end package of practices along with do's and don'ts. Agronomic and plant protection recommendations–implements, weed control, use of growth regulators, pest and disease management needs to be fine tuned for HDPS. Breeders need to identify suitable early, compact plant type for each agro-ecological region. If the HDPS system clicks, it would be boon for rainfed cotton farmers of particularly those cultivating cotton on marginal soils.

Acknowledgment: The financial support provided by ICAR under the Technology Mission on Cotton for carrying out the research is gratefully acknowledged.

References

ABRAPA, (2009) – Algodao adensado atria interesse de produtore – *Journal da ABRAPA, ed. Outubro*. 8p.

AICCIP (2012) – AICCIP Annual report 2011-2012, All India Coordinated Cotton Improvement Project, Coimbatore, Tamilnadu – 641 003.

Belot, Jean-Louis and Salles, Alvaro O. (2010) – Second – cycle cotton growth with high plant density in Mato Grosso, Brazil – *ICAC Recorder*. June 2010.

Bhatt, R. S. and Kumbhare, B. M. (1956) – A study into cultural and manorial requirements of Madhya Pradesh cottons. 7th Conf. Cott. Gr. Probl. India, I.C.C.C., Bombay, 161.

Bogiani, J.C. and Rosolem, C.A. (2009) – Sensibility of cotton cultivars to mepiquat chloride – *Pesquisa Agropecuária Brasileira* **44**: 1246–1253 (in Portuguese, with abstract in English).

Bonde, W.C. and Raju, A.R. (1996) – Effect of varying plant densities and fertilizer levels on rainfed cotton yields in vertisols. – *J. Indian Soc. Cotton Improvement*. **21**:50-55.

Briggs, R.E., L.L. Patterson, and G.D. Massey. (1967) – Within and between-row spacing of cotton. – Arizona Annual Report. P. 6–7. Univ. of Arizona Agric. Ext. Service, Arizona

Buainain, A. M.and Batalha, M.O. Cadeia , (2007) – produtiva do Algodao. Agronegocios 4. Ministerio da Agricultura, Pecuaria e Abastecimento/IICA. Brasilia, 108 p.

CICR (2010) – CICR-Vision 2030. Compiled by K. R. Kranthi, M.V. Venugopalan, M. Sabesh and M. S. Yadav. (2010). Central Institute for Cotton Research (CICR), Nagpur. 55p.

CICR (2012) – CICR Annual report 2012-2013, Central Institute for cotton Research, Nagpur , India – PP 79.

CICR (2013) – CICR Annual report 2012-2013, Central Institute for cotton Research, Nagpur , India – PP 87.

Coffey, B.N., and D. D. Davis Short.(1981) – Branch and cluster-fruiting habit inheritance in crosses of eight cotton lines – *Crop Science*.,**25**: 729 – 731

Craig, C. C., and C. O. Gwathmey. (2005) – Variety response to mepiquat chloride applications. In Proc. Beltwide Cotton Conf., New Orleans, LA. 4-7 Jan. 2005. Natl. Cotton Counc. Am., Memphis, TN.p 1946

Francisco, E. and Hoogerheide, H. (2013) – Nutrient Management for High Yield Cotton in Brazil – *Better Crops With Plant Food*, 97, **2**: 15-17.

Gillhan Fred E. M., Thomas M. Bell, Arin T., Matthews G. A., Rumeur C. Le. And Hearn A. B. (1995). Cotton production prospects for the next decade – World Bank technical paper no. 287. Washington, D. C. pp. 1-275.

Gwathmey C.O. and J.D. Clement (2010) – Alteration of cotton source–sink relations with plant population density and mepiquat chloride- *Field Crops Research* **116** : 101–107

Heitholt, J. J., Meredith, W. R., Jr. and Williford, J.R. (1996) – Comparison of cotton genotypes varying in canopy characteristics in 76-cm and 102-cm rows – *Crop Science*. **36**: 955-960.

IBGE. (2010) – Instituto Brasilerio de Geografia e Estatistica (IBGE), (The Brazilian Institute of Geography and Statistics). http://www.ibge.gov.br/english/.

Jost, P.H., and J.T. Cothren (2001) - Phenotypic alterations and crop maturity diff erences in ultra-narrow row and conventionally spaced cotton - *Crop Science* **41**:1150–1159.

Kerby, T.A., K.G. Cassman; and M. Keekey , (1990) - Genotypes and plant densities for narrow-row cotton system. I. Height, nodes, earliness, and location of yield - *Crop Science*, **30**:645-649.

Kranthi, K. R. (2012) - Deputation report of visit to Brazil in April 2012. Submitted to ICAR, New Delhi.

Reddy, V.R.; Baker, D.N.; Hodges, H.F. (1990) - Temperature and mepiquat chloride on cotton canopy architecture - *Agronomy Journal* **82**: 190–195.

Rinehardt, J.M., K.L. Edmisten, R. Wells, and J.C. Faircloth (2003) – Response of ultra narrow and conventional spaced cotton to variable nitrogen rates – *J. Plant Nutr*. **27** : 741- 753.

Rosolem, CA, D. M. Oosterhuis, , Fabio S. de Souza (2013) - Cotton response to mepiquat chloride and temperature - *Scientia Agricola* 70, 2 :.82-87

Rossi, J., Novick, G., Murray, J., Landivar, J., Zhang, S., Baxevanos, D., Mateos, A., Kerby, T., Hake, K. and Krieg D (2004) - Ultra Narrow Row Cotton: Global Perspective and Reduce Pesticide use Proceedings of the Technical Seminar of the 3rd Plenary Meeting of the ICAC: How to improve yields. Mumbai, India. Nov 2004, pp. 7-11.

Rossi,J, Eva Braojos, and Baxevanos, D. (2007) - Varietal Response to Ultra Narrow Row Cotton in Spain. World Cotton Research Conference 4. Sept 10-14, 2007, Lubbock, Texas. http://wcrc.confex.com /wcrc/2007/techprogram/P1772.

Sikka S. M., Singh A., Singh A., Gadkari P. D., Balasubrahmanyan R., Iyengar N. K., Sawhney K., Bederker V. K., Patel G. B., Pandya P. S., Paranjpe V. N. and Panigrahi N. S. (1961) - Cotton in India A Monograph. Indian Central Cotton Committee (ICAC), Bombay. Pp. 1-375

Silva P. T., Macedo, F. G., Camacho, M. A., Santos, C., Santi, A., Krause, W. and Rambo. J. R. (2012) - Spacing and plant density effect on reproductive development of herbaceous cotton - *Scientia Plena* 8, **5** : 1-9

Singh JV, Shilpa Babar, Shalu Abraham, M.V. Venugopalan, and G. Majumdar. (2012) - Fertilization of High Density, Rainfed Cotton Grown on Vertisols of India. *Better Crops with Plant Food* 96,**2** :26-28

Stuart, B.L., Isbell, V.R., Wendt, C.W., Abernathy, J.R., (1984) - Modification of cotton water relations and growth with mepiquat chloride - *Agron. J*. **76** : 651–655.

Suinaga, F. A. (2003) - Impacto das novas cultivares de algodão sobre a área plantada no Centro Oeste brasileiro. Campina Grande: Embrapa-CNPA, 2003. 15 p. (Documentos, 104).

Venugopalan, M. V., Prakash, A. H., Kranthi, K. R., Deshmukh, Rachana, Yadav, M. S. and Tandulkar, N. R. (2011) - Evaluation of cotton genotypes for high density planting systems on rainfed Vertisols of central India. *In* Book of papers, World Cotton Research Conference (WCRC-5), November 7th to 11th, Mumbai, ICAC, ISCI, ICAR. pp. 341-346

Vories, E. D. and Glover, R. E. (2006) - Comparison of Growth and Yield Components of Conventional and Ultra-narrow Row Cotton -*The Journal of Cotton Science* **10** :235–243.

Wiatrak P.J., D.L. Wright, J.A.Pudelko and B. Ki Bollich, P.K. (2000) - Tillage and Nitrogen Influence on Ultra Narrow Row and Conventional Row Cotton (ed). Proc. 23rd Annual Southern Conservation Tillage Conference for Sustainable Agriculture. Monroe, LA 19-21 June 2000. Louisiana Agri. Exp. Sta., LSU Agri. Center Manuscript No. 00-86-0205, Louisiana State Univ. Crowley, LA 70527-1429. http://www.ag.auburn.edu/auxiliary/nsdl/ scasc/ Proceedings/2000/proc2000.html

Wright, D. L., Marois, J. J., Sprenkel, R. K. and Rich J. R. (2011) - Production of Ultra Narrow Row Cotton. University of Florida (UF), IFAS Extension. SS-AGR-83.