IDENTIFICATION OF COTTON GROWTH STAGES AND GROWTH PATTERN STUDIES IN COTTON GENOTYPES

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B. Sc. (Ag.)

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(CROP PHYSIOLOGY)

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By

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B.Sc. (Ag.)

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CERTIFICATE

Mr. **Y. JANAKI RAMULU** has satisfactorily prosecuted the course of research and that thesis entitled **"IDENTIFICATION OF COTTON GROWTH STAGES AND GROWTH PATTERN STUDIES IN COTTON GENOTYPES"** submitted is the result of original research work and is of sufficiently high standard to warrant its presentation to the examination. I also certify that neither the thesis nor its part thereof has been previously submitted by him/her for a degree of any University.

Date: 08-06-2016
Place: Hyderabad

(Dr. T. RAMESH)
Chairperson

CERTIFICATE

This is to certify that the thesis entitled **"IDENTIFICATION OF COTTON GROWTH STAGES AND GROWTH PATTERN STUDIES IN COTTON GENOTYPES"** submitted in partial fulfilment of the requirements for the degree of **'Master of Science in Agriculture'** of the Professor Jayashankar Telangana State Agricultural University, Hyderabad is a record of the bonafide original research work carried out by **Mr Y. JANAKI RAMULU** under our guidance and supervision.

No part of the thesis has been submitted by the student for any other degree or diploma. The published part and all assistance received during the course of the investigations have been duly acknowledged by the author of the thesis.

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DECLARATION

I**, Y. JANAKI RAMULU,** hereby declare that the thesis entitled **"IDENTIFICATION OF COTTON GROWTH STAGES AND GROWTH PATTERN STUDIES IN COTTON GENOTYPES"** submitted to the **Professor Jayashankar Telangana State Agricultural University** for the degree of **Master of Science in Agriculture** is the result of original research work done by me. I also declare that no material contained in the thesis has been published earlier in any manner.

Place: Hyderabad **(Y. JANAKI RAMULU)**

Date: 08-06-2016 **I. D. No: RAM/14-71**

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(Y. JANAKI RAMULU)

LIST OF CONTENTS

LIST OF TABLES

LIST OF PLATES

LIST OF ILLUSTRATIONS

LIST OF APPENDICES

LIST OF SYMBOLS AND ABBREVIATIONS

%	:	Per cent
^{o}C	:	Degrees Celsius
@	:	at the rate of
±	:	Plus or minus
<	:	Less than
>	:	Greater than
=	:	is equal to
/	:	per
i.e.,	:	that is
h.	:	Hour
etc.	:	and so on
cv.	:	Cultivar
µm.	:	Micro meter
M ha.	:	Million hectares
viz.,	:	Namely
kg ha^{-1}	:	Kilograms per hectare
et al.	:	and others
ml.	:	Milli litre
S. No.	:	Serial Number
CD	:	Critical Difference
SE(m)	:	Standard Error of mean
No.	:	Number
min.	:	Minute
g	:	Gram
Na_2CO_3	:	Sodium carbonate
CMIE	:	Centre for Monitoring Indian Economy
cm	:	Centimeter
cm^2	:	Centimeter squares
CGR	:	Crop growth rate
cm day^{-1}	:	Centimeter per day
cm^2 gm^{-1}	:	Centimeter square per gram
DAS	:	Days after sowing
dm^2	:	Decimeter square
Day $^{-1}$	:	Per day
g m^{-2} day^{-1}	:	Gram per meter square per day
g dm^{-2} day^{-1}	:	Gram per decimetre square per day
g g-1 day-1	:	Gram per gram per day
h_1 & h_2	:	plant height at time t_1 & t_2
ha^{-1}	:	per hectare
HI	:	Harvest index
i.e	:	That is

K	:	Potassium
kg	:	Kilogram
L_A	:	Leaf area
L_w	:	Leaf dry weigtt
LAD	:	Leaf area duration
LAI	:	Leaf area index
LAR	:	Leaf area ratio
m^2	:	Meter square
m^{-2}	:	Per meter square
mg	:	Milligram (s)
mg cm^{-2}	:	Milligram per centimetre square
min	:	Minute (s)
MSL	:	Mean sea level
N	:	Nitrogen
NAR	:	Net assimilation rate
NS	:	Non significant
P	:	Phosphorous
Pp	:	Page number
PAR	:	photosynthetically active radiation
SPD	:	Split Plot Design
RF	:	Rainfall
RGR	:	Relative growth rate
RH	:	Relative humidity
RUE	:	Radiation use efficiency
SEm	:	Standard error mean
SLA	:	Specific leaf area
SLW	:	Specific leaf weight
SPAD	:	Soil plant analytical development
t	:	time
TDM	:	Total dry matter
viz,	:	Namely
W	:	Total plant dry weight

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ABSTRACT

The present investigation entitled "Identification of cotton growth stages and growth pattern studies in cotton genotypes*"* was conducted at the college farm, College of Agriculture, Rajendranagar, Hyderabad, during *kharif* 2015-2016. The field trial was conducted following split plot design with three replications and three cotton genotypes viz. ADB-542, Narasimha and Deltapine 9121 as main plots, three different levels of spacings viz. 75 x 10, 60 x 10 cm and 45 x 10 cm as sub plots. To determine the duration for growth phases in cotton, requirement for photo induction of flowering to maturity the growth phases, yield attributes and yield. In this experiment, phenological observations (days to squaring, flowering, boll initiation and peak boll burst), growing degree days require ment for (squaring, flowering and boll initiation), morphological parameters (plant height, leaf area, number of monopodia, number of sympodia and dry matter production per plant), physiological parameters (leaf pigments, spad chlorophyll meter readings (SCMR), photosynthetic rate, chlorophyll stability index and proline), growth parameters (crop growth rate, relative growth rate, net assimilation rate, specific leaf area and specific leaf weight) and yield parameters (number of bolls per plant, boll weight, seed cotton yield, lint yield and seed index) were evaluated at three different growth stages.

Results of phenological characteristics showed that in 75 x 10 cm spacing, for square, flower and boll initiation minimum days were required (42.1, 66.8 and 93.4 respectively). Among the genotypes Deltapine 9121 recorded early square, flower and boll initiation i.e at 41.1, 66.6 and 92.3 days respectively. Minimum days were required for peak boll burst in Deltapine 9121 at 75 x 10 cm (114.0 days). In 75 x 10 cm minimum growing degree days (GDD) were required for squaring (740), flowering (1148) and boll initiation (1588). Among the genotypes Deltapine 9121 recorded minimum GDD for early squaring (722), flowering (1144) and boll initiation (1570).

Morphological parameters showed that Deltapine 9121 recorded maximum plant height (78.1 cm) in 75 x 10 cm spacing and Narasimha recorded minimum plant height (48.3 cm) in 45 x 10 cm at boll initiation stage. Significantly maximum leaf area (3489 cm^2) in 75 x 10 cm was recorded in Deltapine 9121 while, Narasimha showed minimum leaf area at boll initiation stage (773 cm^2). Deltapine 9121 showed significantly maximum number of sympodia at 75 x 10 cm spacing (17.3), while, Narasimha at 45 x

10 cm spacing recorded minimum sympodia (11.6). Deltapine 9121 also showed significantly maximum number of monopodia at 75 x 10 cm spacing (1.3). Deltapine 9121 at 75 x 10 cm spacing had recorded maximum dry matter production (90.1 g).

In respect of physiological parameters Deltapine 9121 recorded maximum leaf chl-a (1.11 mg g^{-1}), chl-b (1.77 mg g^{-1}), chl-t (3.11 mg g^{-1}) and carotenoids (0.68 mg g^{-1}), SCMR values (29.1), photosynthetic rate (23.6 µ mol CO_2 m^{-2} s^{-1}), chlorophyll stability index (49.3 %) and proline (933 µg g^{-1} fresh weight) in 75 x 10 cm spacing at boll initiation stage. While, Narasimha recorded minimum leaf chl-a (0.43 mg g^{-1}), chl-b (0.46 mg g^{-1}), chl-t (0.91 mg g^{-1}) and carotenoids (0.20 mg g^{-1}), SCMR values (39.2), photosynthetic rate (13.2 µ mol CO_2 m^{-2} s^{-1}), chlorophyll stability index (25.2 %) and proline (281 µg g^{-1} fresh weight) in 45 x 10 cm respectively at boll initiation stage.

At 60-90 DAS the crop growth rate (CGR) was significantly maximum in Deltapine 9121 at 75 x 10 cm spacing (1.81 g day^{-1}). Narasimha at 60 x 10 cm spacing showed maximum RGR i.e. 0.037 g g^{-1} day^{-1} at 40-60 DAS. At 40-60 DAS maximum NAR (0.001 g cm^{-2} d^{-1}) was recorded in 75 x 10 cm spacing in genotype Narasimha (0.001 g cm^{-2} d^{-1}), 60 x 10 cm spacing all the tested genotypes and in 45 x 10 cm spacing all the tested genotypes recorded the similar rate of assimilates. Specific leaf area was maximum in Deltapine 9121 at 75 x 10 cm spacing (126 cm^2 g^{-1}) and minimum in Narasimha at 75 x 10 cm spacing (80 cm^2 g^{-1}) at 90 DAS. Specific leaf weight was maximum in Narasimha at 75 x 10 cm spacing (0.012 g cm^{-2}) and minimum in Deltapine 9121 at 75 x 10 cm spacing (0.008 g cm^{-2}) at 90 DAS.

Deltapine 9121 at 75 x 10 cm spacing recorded maximum number of bolls i.e. 7.9, boll weight 2.90 g, seed cotton yield 23.17 g $plant^{-1}$ and lint yield 826 kg ha^{-1}.

CHAPTER-I

INTRODUCTION

CHAPTER I

INTRODUCTION

India ranks first in acreage of cotton crop and is third in total production in world only after Russia and America. Cotton is the most important cash crop of India. Cotton is primarily cultivated for its lint, which is used for textile and several other industrial uses. Cotton lint export from India occupies prime position in the world. Total cotton area in India in 2013-14 is 116.14 lakh ha, with a total production is 375 lakh bales and productivity of 552 kg ha^{-1} (CCI, 2016). Telangana state contributes to an area in 2014-15 about 16.93 lakh ha, total production of 103.47 lakh MT and productivity of 1039 kg ha^{-1} (Agrisnet.tg.nic.in, 2015).

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 per m^2 (Kerby *et al*. 1990) resulting in a population of 50,000 to 1,50,000 plants ha^{-1}. 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^{-1}, while conventional cotton is planted in rows 90 to 100 cm apart and has a plant population of about 1,00,000 plants ha^{-1}. In India, the recommended plant density for cotton seldom exceeded 55,000 plants ha^{-1}. The UNR system is popular in several countries like Brazil, China, Australia, Spain, Uzbekistan, Argentina, USA and Greece (Rossi *et al*. 2004).

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 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). 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 with the current cotton production system in India.

Cotton area in the state is mostly covered by *Bt.* hybrids. Owing to its high production potential, farmers sow the crop every season but have to procure the seed from external sources, which is proving to be a costly input. The present hybrids though high yielding, have become susceptible to insect sucking pests and certain boll worms. The coverage under *Bt.* hybrids in India is almost saturated and further improvement in cotton yield is not possible (Rao and Alapati, 2007). All the *Bt* hybrids are Gossypium hirsutum which constitute 87 per cent in the world. This increase was between 2002 to 2009. The yield increased by 8 to 10 per cent from BG II than BG I and non *Bt.* (Sudha *et al*. 2011).

Increase of plant density with decreasing cotton row spacing has been suggested as an alternative strategy to optimize cotton productivity, reduce production costs and increased farmer profit. Availability of most suitable cultivars, more efficient options of weed, pest and disease control to modify morpho physiological frame, planting and harvesting equipments has rekindled an interest in high density cotton planting. The optimum plant density under parabolic relationship will depend upon the genotype characteristics, soil, climatic, physiological parameters and management regime. High density planting system (HDPS) with short duration, compact varieties is an alternative approach for improving cotton productivity. Several research and development issues need to be redressed before this technology can be commercially adopted. Central Institute of Cotton Research (CICR) is investigated that HDPS to emerge as a boon to farmers particularly those cultivating cotton on marginal soils.

The increase in yield alone could not benefit the cotton growers as quality of cotton fibre is the primary concern for fetching higher price (Srinivasan, 2004). Also multi location and multi seasonal testing of genotypes is required for identification of region specific high yielding genotypes for recommending to farmers (Sarang *et al.* 2011). Knowledge of association between yield and its component characters themselves is also essential before resorting to selection for desirable genotypes (Adarsha *et al.* 2004).

Cotton is an indeterminate plant exhibiting overlapping vegetative and reproductive growth phases and these phases cannot be clearly demarcated. The duration of the different phases depends upon the variety, climate and management practices (Venugopalan, 1999-2000). Hybrids come to maturity earlier than the varieties. As a result the phenology of varieties under HDPS is also not documented.

Hence the growth stages need to be identified so as to give inputs efficiently to the crop to obtain superior yields. To improve the production potential the crop is sown by adopting different spacings which would facilitate high density planting system (HDPS) which is amenable to mechanical harvest. This practice of HDPS which demands compact types so far has not been tested for straight varieties and no suitable hybrids have been advocated.

Varieties belong to *Gossypium hirsutum* L. type, their branching pattern (monopodial and sympodial) to fit to HDPS has been altered to make it compact. The variation in phenology with respect to its influence on growth pattern of the crop is also not well understood. The present investigation is therefore taken up to understand the changes in phenology in hybrids as compared to varieties with the following objectives.

1. To determine the duration for growth phases in cotton.

2. To find out the requirement for photo induction of flowering to maturity.

3. To find out the growth phases, yield attributes and yield.

CHAPTER-II

REVIEW OF LITERATURE

CHAPTER II

REVIEW OF LITERATURE

2.1 Phenological observations

2.1.1 Days to squaring

Saleem *et al.* (2009) conducted a field experiment with three cotton cultivars viz., NIAB-111, CIM-496 and FH-901 and three row spacings viz., 60 cm (5.55 plants m^{-2}), 75 cm (4.44 plants m^{-2}) and 90 cm (3.70 plants m^{-2}). Results showed that number of days from planting to first floral bud initiation (squaring) were significantly affected by row spacing while varieties have no significant effect on this character. 35.3 days were recorded in 90 cm row space as against 34.4 days with narrow rows of 60 cm.

Ban *et al.* (2015) studied the number of days required for 50% squaring in normal sowing (11 July) and late sowing (2 August) in different cotton genotypes under 120 x 45 cm spacing. The results indicated that the number of days required for 50 % squaring was significantly increased under late sowing compared to normal sowing. The non-*Bt* hybrid, LHH-144 required significantly more days to 50 % squaring (59.7 days), while G. Cot Hy.-8 BG-II was earliest and took significantly less days, viz., 52.1 days for 50% squaring.

2.1.2 Days to peak flowering

Tomar and Singh (1992) crossing 20 genotypes with three well adapted varieties (Lohit, Shyamali, and G-27) as testers (male) in a line x tester mating design. 60 hybrids and their 23 parents were planted in randomized block design with three replications. The number of days recorded in all crosses for flower initiation varied between of 66 – 81 days Shymali recorded 66 days, while RG-8 x Lohit cross breed recorded 81 days.

Saleem *et al.* (2009) conducted a field experiment to determine the effect of row spacing on earliness in cotton. Three cotton cultivars viz., NIAB-111, CIM-496 and FH-901 were grown with three row spacings of 60, 75 and 90 cm. They recorded the number of days taken from planting to appearance of first flower. Results showed that the varieties and row spacing significantly affected the number of days taken for appearance of first flower. Maximum of 46.1 days were recorded with 90 cm row spacing and minimum of 43.7 days with 60 cm spacing. Genotypes NIAB-III took

significantly less days (44.2) for the appearance of first flower than CIM-496 and FH-901 (45.2) which were on par with respect to first flower appearance.

Aziz *et al.* (2011) recorded the number of days required for flowering in six cotton genotypes (NAM-77, C-2602, BC-0342, BC-0406, CB-10 and CB-9) sown at three different population densities viz. 90 × 45 cm (24,692 plants ha^{-1}), 75 × 45 cm (29,630 plants ha^{-1}) and 60 × 45 cm (37,037 plants ha^{-1}). Results indicated interaction of genotypes and spacings. Minimum number of days (55.33) for flowering was reported with the spacing of 60 × 45 cm in the genotype C-2602 and was identical to Namangan-77 and the maximum number of days (65.6) was reported with 60 ×45 cm in CB-9.

Vineela *et al.*, (2013) reported the number of days for 50 % flowering in American cotton (*Gossypium hirsutum* L.). Average number of days required for 50 % flowering in cotton genotypes was 55.17 days with the spacing of 90 x 60 cm.

Ban *et al.* (2015) recorded the number of days required for 50% flowering in normal sowing (11 July) and late sowing (2 August) in different cotton genotypes under 120 x 45 cm spacing. Findings indicated that the number of days for 50 % flowering was significantly decreased under late sowing. Genotype DHH-263 required significantly more days (81.5) to 50 % flowering, and was statistically at par with LHH-144 (81.2 days). G. Cot Hy.-8 BG-II flowered in less number of days (72.5).

2.1.3 Days to boll initiation

Saleem *et al.* (2009) conducted a field study to determine the effect of row spacing on earliness in cotton, cultivars viz., NIAB-111, CIM-496 and FH-901 were grown with three row spacings of 60, 75 and 90 cm. Number of days were recorded from planting to appearance of first boll splitting. Results indicated that varieties and row spacing significantly affected the number of days required for appearance of first boll splitting. Maximum of 89.9 days were recorded with 90 cm row spacing and minimum of 86.7 days were reported with 60 cm row spacing. NIAB-III recorded significantly less days (86.5) for the appearance of first boll split than CIM-496 (88.5) and FH-901 (89.8).

Singh *et al.* (2011) evaluated twenty cotton genotypes to study early maturity in cotton- wheat cropping system. Duration of maturity ranged from 130 to 180 days. The

genotype AAH-1 reached maturity early (130 days) and Pusa 8-6 genotype reached to maturity late (185 days).

Ban *et al.* (2015) identified the effect of different environments on crop phenology of cotton (*Gossypium hirsutum* L.) genotypes. Number of days required for maturity was recorded in normal sowing (11 July) and late sowing (2 August) in different cotton genotypes under 120 x 45 cm spacing. Number of days required for maturity was significantly decreased under late sowing. Non-Bt hybrid, LHH-144 reported maximum days to maturity (167.1 days), while G. Cot Hy.-8 BG-II took a minimum days for maturity (152.7).

2.1.4 Days to peak boll burst

Saleem *et al.* (2009) conduct a field study to determine the effect of row spacing on earliness in cotton. Three cotton cultivars viz., NIAB-111, CIM-496 and FH-901 were grown with three row spacings of 60, 75 and 90 cm. Results recorded showed increased maturity with increased row spacing in all the cultivars. Maximum mean maturity days (155) were recorded in wider row spacing of 90 cm, followed by 75cm and then 60 cm row spacing. Varieties also significantly differed in maturity days. Maximum maturity days (156.1) were reported in FH-901 and minimum days (151.5) were reported in NIAB-111.

Aziz *et al.* (2011) recorded the number of days required for boll bursting in six cotton genotypes (NAM-77, C-2602, BC-0342, BC-0406, CB-10 and CB-9) with respect of three different population densities viz. 90 × 45 cm (24692 plants ha^{-1}), 75 × 45 cm (29630 plants ha^{-1}) and 60 × 45 cm (37037 plants ha^{-1}). Results indicated interaction. C-2602 recorded minimum of 97.0 days for boll splitting in 60 × 45 cm, where as CB-9 recorded maximum of 129.7 days for boll splitting in 90 ×45 cm spacing.

Ban *et al.* (2015) identified the effect of crop phenology of cotton (*Gossypium hirsutum* L.) genotypes as influenced by different environments. They recorded the number of days required for 50% boll burst in normal sowing (11 July) and late sowing (2 August) in different cotton genotypes under 120 x 45 cm spacing. Non–*Bt* hybrid, LHH-144 reported significantly maximum days (130.5) for 50 % boll bursting, while G. Cot Hy.-8 BG II was reported as earlier, took significantly less days (72.5) for 50 % boll bursting.

2.2 Growing degree days (Heat units)

Hutmacher *et al.* (2002) reported that approximate number of heat units (degree days 60F) from emergence to specific phenological (growth) stages in San Joaquin Valley cotton and are given below.

Growth period	Heat units (60 F/ 15.5˚C)
Emergence to1st square	425-500
Emergence to peak bloom	1350-1500
Emergence to 1st open Boll	1650-1850
Emergence to 60% open Boll	2200-2350

Robertson *et al*., (2007) reported the minimum growing degree-days of 425 to 475 heat units for emergence to first square appearance and 775 to 850 heat units for planting to first flower initiation.

Munir *et al.* (2015) evaluated the growth, yield and earliness response of cotton to row spacing and nitrogen management. Three row spacings of 60, 75 and 90 cm were established with four nitrogen fertilizer rates of 0, 60, 120 and 180 kg N ha^{-1}. Number of degree-days required from planting to first square and flower appearance was recorded with different row spacings. The maximum number of growing degree-days was reported in wider rows of 90 cm (846), minimum number of growing degree-days was reported in narrow rows of 60 cm (820).

2.3 Morphological observations

2.3.1 Plant height

Plant height plays an important role in determining the morphological frame work relating to plant type and canopy development in cotton. It is one of the important

characters of growth and yield of cotton and is influenced by both genetic and environmental factors.

Gao and Jein (1989) reported that changes in leaf production is associated with changes in plant height.

Arshad *et al.* (1993) reported that plant height, number of bolls per plant and sympodial branches were positively correlated with seed cotton yield per plant. The number of bolls per plant was also positively correlated with plant height.

Meena *et al.* (2007) reported variation in plant height from 107 to 148 cm in undescriptive cultivars. The variety Ganeshgarhia had maximum plant height (148 cm) followed by Whitegold-1 (147 cm) while minimum plant height was observed in Sikander Sultan (107 cm).

Pendharkar *et al.* (2010) reported that plant height was positively correlated with the spacing. Maximum plant height of 130 cm was observed in 180 x 30 cm spacing while, minimum of 123 cm was observed in 90 x 60 cm spacing.

Bhalerao and Gaikwad (2010) reported that the plant height differed significantly with different plant spacings. Maximum plant height of 83.5 cm was recorded with narrow spacing of 90 x 60 cm and the minimum plant height of 82.1 cm was recorded with wider spacing of 90 x 90 cm.

Hensh *et al.* (2011) reported maximum plant height (119.76 cm) in 45 x 30 cm spacing, which was significantly higher than 60 x 30 cm spacing (106.78 cm) and concluded that decrease of row spacing caused plants to grow taller.

Singh *et al.* (2012) reported variation in plant height from 59.3-75.1 cm in undescriptive cultivars from four different locations across India in a spacing 45 x 15 cm. Results showed maximum plant height was reported in NH-630 genotype (75.1 cm) at Akola, while minimum plant height was reported in Narasimha genotype (59.3 cm) at Nandyal location.

Ganvir *et al.* (2013) reported that plant height was positively correlated with the plant spacing. Maximum plant height of 96.45 cm was observed in 60 x 10 cm, medium plant height of 87.96 cm was observed in 60 x 15 cm spacing and minimum plant height of 79.22 cm was recorded in 60 x 30 cm.

Nalwade *et al.* (2013) reported the plant height varied from 97.26 to 106.93 cm in undescriptive cultivars. The hybrid Akka *Bt* recorded maximum plant height (106.93) followed by MRC 7301 *Bt* (101.39 cm) and Bramha *Bt* (107 cm).

Deotalu *et al.* (2013) reported that plant height was positively correlated with plant spacing. The variety NDLH 1938 recorded maximum plant height (75.27 cm) followed by AKH 9916 (74.71 cm) and minimum plant height was observed in BS 79 (62.78 cm) under 60 x 30 cm spacing.

Singh *et al.* (2014) reported that the *Bt* cotton plant height related to the intercropping systems in different plant geometries. Maximum plant height (107.7 cm) was recorded in *Bt* cotton + summer mungbean (1:1) in 67.5 x 75 cm, while the minimum plant height (77.8 cm) was recorded in *Bt* cotton + fodder bajra (1:1) in 67.5 x 75 cm spacing.

Baskaran and kavimani (2015) reported variation in the plant height in relation to different types of conservation tillage practices. Maximum plant height (109.2 cm) was recorded in minimum tillage with crop residue application @ 5 t ha^{-1}, while minimum plant height (98.3 cm) was recorded in minimum tillage without crop residue application.

2.3.2 Leaf area $plant^{-1}$

Kudachikar *et al.* (1999) upon evaluation of 9 hirsutum cotton genotypes for higher productivity under rainfed condition revealed that there was a marked difference in growth parameters and yield attributes among the genotypes where high yielding genotypes were associated with low leaf area, higher amount of total dry matter, high leaf efficiency, higher harvest index and more bolls numbers. These attributes formed the physiological basis for higher productivity of *G. hirsutum* cotton under rainfed condition.

Adarsha *et al.* (2004) reported significantly higher leaf area at 120 days after sowing than at harvest in DHH-542 (5913 cm^2 $plant^{-1}$) and DHB-105 (3487 cm^2 $plant^{-1}$) compared to CPD-448 (2387 cm^2 $plant^{-1}$) and Anjali (1031 cm^2 $plant^{-1}$).

Pendharkar *et al.* (2010) reported that leaf area per plant was positively correlated with spacings. Maximum leaf area per plant was reported with closer spacing of 90 x 60 cm (3740 cm^2 $plant^{-1}$) followed by 120 x 45 cm (3570 cm^2 $plant^{-1}$), 180 x 30

cm (3348 cm^2 $plant^{-1}$) and minimum leaf area (3530 cm^2 $plant^{-1}$) was recorded in 150 x 30 cm spacing.

Tayade *et al.* (2011) they showed the importance of source (leaf area) in yield formation in transgenic *Bt* cotton.

Nalwade *et al.* (2013) reported significantly higher leaf area at 120 DAS than at 90 DAS in Akka *Bt* (6852 cm^2 $plant^{-1}$) and Super Maruti *Bt* (5289 cm^2 $plant^{-1}$) as compared to Bramha *Bt* (4721 cm^2 $plant^{-1}$), Bunny *Bt* (4536 cm^2 $plant^{-1}$) and MRC 7301 *Bt* (3712 cm^2 $plant^{-1}$) under 90 x 45 cm spacing.

2.2.3 Numbers of monopodia $plant^{-1}$

Channaveeraiah (1983) observed that for selection of high yielding genotypes under rainfed condition, cultivars are more preferred which posses moderate duration, moderate LAI, LAD (80-85 days) and with medium size of monopodial branches.

Meena *et al.* (2007) reported that the numbers of monopodia varied from 1.4 to 1.8 in undescriptive cultivars.

Pendharkar *et al.* (2010) reported that in *Bt* cotton hybrids number of monopodial branches per plant were not significantly influenced by the different plant spacings. Results indicated that maximum number of monopodial branches per plant with closer spacing of 90 x 60 cm (1.69) and minimum number of monopodia per plant was reported with wider spacing of 180 x 30 cm (1.42).

Joshi *et al.* (2011) evaluated the JK-Durga *Bt* and reported maximum number of monopodial branches per plant (3.80).

Nalwade *et al.* (2013) identified the numbers of monopodial branches per plant in *Bt* cotton cultivars to vary from 2.40 to 3.40. Akka *Bt* recorded maximum number of monopodia per plant (3.40) followed by Super Maruti *Bt* (2.90) and minimum number in Bramha *Bt* (2.40) in 90 x 45 cm spacing.

Ganvir *et al.* (2013) revealed the effect of spacings on monopodials. Maximum monopodial branches per plant were recorded under lower plant densities. Maximum number of monopodial branches per plant (2.08) was recorded in 60 x 30 cm (55,555 plants ha^{-1}) spacing and the minimum number of monopodia per plant (1.37) was recorded in 60 x 10 cm (1,66,666 plants ha^{-1}) spacing..

Singh *et al.* (2014) reported that the monopodial branches per plant in *Bt* cotton as influenced by different intercropping systems in relation to planting geometries to vary from 1.5 to 3.0. The results showed that the maximum number of monopodial branches per plant (3.0 plant^{-1}) in *Bt* cotton were recorded in the treatment of *Bt* cotton + long melon (1:1) at 67.5 x 75 cm, minimum number of monopodial branches per plant (1.5 plant^{-1}) in *Bt* cotton were recorded in the treatment of *Bt* cotton + fodder bajra (1:2) at 135 x 37.5 cm spacing.

2.3.4 Numbers of sympodia plant^{-1}

Hallikeri *et al.* (2004) noted 10 % higher number of sympodial branches per plant in *Bt* genotypes than non-*Bt* types.

Sankarnarayanan *et al.* (2004) reported *Bt* cotton hybrid MECH-162 as compared to non-*Bt* hybrids to possess higher seed cotton yield, number of sympodial branches per plant and number of bolls per plant.

Gite *et al.* (2006) observed that number of sympodia per plant had positive and significant genotypic and phenotypic correlations with seed cotton yield.

Meena *et al.* (2007) reported the numbers of sympodia per plant to vary from 8.2 to 12.8 in undescriptive cultivars.

Giri *et al.* (2008) reported *Bt* cotton hybrid NCS-145 to record significantly higher number of sympodia per plant (20.63) and seed cotton yield per plant (166 gm) as against RCH-2 *Bt* hybrid which recorded lower sympodia per plant (16.7) and seed cotton yield (127 gm).

Phad *et al.* (2010) found that *Bt* cotton hybrids to contribute to more seed cotton yield by increased number of sympodia, number of bolls per plant and boll weight (g).

Pendharkar *et al.* (2010) found closer spacing to produce maximum number of sympodial branches per plant. Maximum number of sympodial branches per plant (19.99) was recorded in closer spacing of 90 x 60 cm and the minimum number of sympodial branches per plant (18.23) with wider spacing of 180 x 30 cm.

Bhongle and Patil (2011) reported that the numbers of sympodia per plant varied from 14.2 to 18.0 in undescriptive *Bt* cotton hybrids. Maximum number of sympodia

per plant were recorded by the hybrid NECH- 14 *Bt* (18.9), followed by MRC 6301 *Bt* (18.8), while minimum number was recorded in the hybrid RCH- 138 *Bt* (14.2).

Joshi *et al.* (2011) found that the main yield contributing factor for cotton was sympodial branches per plant.

Nalwade *et al.* (2013) recorded the number of sympodia at harvest time in different hybrids. Akka BG II hybrid showed maximum number of sympodia per plant (27.42) among all hybrids and the hybrid Bramha *Bt* showed minimum sympodia (20.04).

Deotalu *et al.* (2013) recorded a positive correlation of the number of sympodial branches per plant with spacing. The number of sympodia per plant was 9.53 in closer spacing of 60 x 30 cm and maximum of 10.79 in wider spacing of 60 x 45 cm.

Ganvir *et al.* (2013) observed a positive correlation of the number of sympodial branches per plant with spacing. Maximum number of sympodia per plant (11.18) was recorded in wider spacing of 60 x 30 cm, as compared to narrow spacing of 60 x 15 cm (9.09) and in ultra narrow spacing of 60 x 10 cm (8.06).

Singh *et al.* (2014) studied the effect of different intercropping systems on the number of sympodial branches per plant in *Bt* cotton hybrids at two plant spacings. Results showed the maximum number of sympodial branches per plant (21.4) in *Bt* cotton + long melon intercropping system at 67.5 x 75 cm and minimum number of sympodial branches per plant (12.3) in *Bt* cotton + fodder bajra intercropping system at 135 x 37.5 cm.

Shukla *et al.* (2014) conducted field experiment to study the production potential of sympodial branches per plant of cotton hybrids under different plant spacings and NPK levels. Results indicated that plant spacings were negatively correlated but the NPK levels were positively correlated with the number of sympodial branches. Maximum number of sympodia per plant (16.3) was recorded in closer pacing of 60 x 60 cm, as compared to wider spacing of 90 x 60 cm the number of sympodia was minimum (13.7).

Baskar and Jagannathan (2014) conducted a field experiment to study the effect of crop geometry on the number of sympodial branches per plant in inter specific hybrid *Bt* cotton. The results indicated the maximum number of sympodia per plant (27.4) with

wider spacing of 150 x 90 cm by using 125 % RDF water soluble fertilizer (WSF) over other spacings.

2.3.5 Dry matter production plant^{-1}

Senthivelu *et al.* (2009) studied the effect of dry matter production in wet seeded rice-cotton cropping sequence under integrated nutrient management practices. Maximum amount of dry matter (3.93 t ha^{-1}) was recorded at harvest with application of FYM @ 12.5 t ha^{-1} + 100 % RDF treatment, while a minimum amount of dry matter (0.18 t ha^{-1}) was recorded at squaring stage with Glyricidi a leaf manure @ 6.25 t ha^{-1} + 100 % RDF treatment.

Pendharkar *et al.* (2010) conducted a field experiment to understand dry matter production in *Bt* cotton hybrids under different plant spacings in rainfed condition. Negative correlation of dry matter production with spacings was observed. Maximum amount of dry matter per plant (147.22 g) was recorded in Ajit-155 *Bt* under closer plant spacing of 90 x 60 cm and the minimum amount of dry matter per plant (128.0 g) was recorded in RCH-2 *Bt* under wider plant spacing of 180 x 30 cm.

Bhalerao and Gaikwad (2010) conducted a field experiment to examine the dry matter productivity per plant in *Bt* cotton under various plant geometry and fertilizer levels. Results showed that the dry matter production per plant (g) was positively correlated with the plant spacings. Maximum amount of dry matter per plant (99.6 g) was recorded in wider spacing of 90 x 90 cm while, the minimum dry matter per plant (89.4 g) was recorded in closer spacing of 90 x 45 cm.

Hensh *et al.* (2011) studied the effect of dry matter production in cotton under different spacings at lateritic belt of West Bengal. At 150 DAS, the maximum dry matter accumulation per plant (489.33 g m^{-2}) occurred when plants were grown at 45 x 30 cm spacing which was significantly higher than that observed at spacing of 75 x 30 cm (446.67 g m^{-2}) and 60 x 30 cm (458.33 g m^{-2}). The same trend was observed in other growth stages. Reduction in dry matter under wider inter-row spacing of 75 cm and 60 cm can be attributed to inefficient use of radiation, because under wider spacing much of radiation may even be wasted by falling on ground during major part of growing period. The amount of dry matter production per plant recorded at different intervals under closer spacing of 45 x 30 cm increased from 30 DAS (39.77 g m^{-2}), 60 DAS

(111.67 g m^{-2}), 90 DAS (215.62 g m^{-2}), 120 DAS (344.27 g m^{-2}) to 150 DAS (489.33 g m^{-2}).

Shukla *et al.* (2013) evaluated the effect of spacings and fertility levels on dry matter production in cotton hybrids under rainfed condition. Findings indicated that the dry matter production per plant was positively correlated with the spacings. In wider spacing of 90 x 60 cm maximum amount dry matter per plant was recorded at 120 DAE (43.78 g) as compared to closer spacing of 60 x 60 cm at 120 DAE where dry matter per plant reported was minimum (37.83 g).

Nalwade *et al.* (2013) revealed the morpho-physiological traits *of Bt* cotton (BG II) hybrids under rainfed condition. Data on dry matter production in hybrid Akka BG II was maximum i.e., 30.80 g at 60 DAS, 102.75 g at 90 DAS, 225.65 g at 120 DAS and 269.16 g at harvest) followed by Super Maruti BG II under 90 x 45 cm spacing.

Deotalu *et al.* (2013) reported the growth of hirsutum varieties as influenced by plant spacing and fertilizer levels under rainfed condition. Findings showed that the amount of dry matter production per plant was positively correlated with plant spacings and fertilizer levels. In closer spacing of 60 x 30 cm, 100 % RDF (50:25:25 kg NPK ha^{-1}) amount dry matter production per plant recorded was minimum (56.71, 60.95 g) but in wider plant spacing of 60 x 45 cm, 125 % RDF (62.5:31.25:31.25 kg NPK ha^{-1}) amount of dry matter per plant recorded was maximum (71.04, 66.80 g).

Baskaran and Kavimani (2015) conducted a field experiment to study the effect of conservation tillage on growth of *Bt* cotton. Maximum dry matter production was recorded at harvesting stage. Results indicated dry matter production was not significantly influenced with conservation tillage practices. Maximum amount of dry matter (5230 kg ha^{-1}) was recorded in minimum tillage with crop residue @ 5 t ha^{-1} and the minimum amount of dry matter with convention tillage (4670 kg ha^{-1}).

2.4 Physiological observations

2.4.1 Leaf pigments

Gur *et al.* (2010) investigated the diurnal gradual heat stress effects on antioxidant enzymes, proline accumulation and some physiological components in cotton. Cotton (*Gossypium hirsutum* L.) cultivar Stoneville-453 was used in this study. At squaring stage (4 -5 squares) heat stress treatments were applied at 30°C (control),

38°C (moderate heat stress) and 45°C (high heat stress). Results recorded was an increase in the quantity of chlorophyll-a, chlorophyll-b and total chlorophyll contents in the leaves of the plants at 38°C, but the chlorophyll content of the plants treated 45°C dropped with respect to control plants. Total chlorophyll values were 2.38, 2.74 and 2.31 mg g^{-1} fw; chlorophyll-a values were 1.77, 2.05 and 1.72 mg g^{-1} fw; and chlorophyll-b values were 0.61, 0.69 and 0.59 mg/g fw for the control (30^0C), 38 and 45°C treated plants, respectively.

Li *et al.* (2012) investigated physiological characteristics of photosynthesis at different stages of growth under drought conditions. The chlorophyll content of drought-stressed leaves changed over time and decreased earlier than that of control plants. In the early stages of growth, no obvious differences in the chlorophyll a/b values were seen between the drought or well-watered control. These results showed that the stacking of the thylakoids was weakened and the light harvesting competence and the photosynthetic capability of the chloroplasts deteriorated. The chlorophyll a/b values of the drought-stressed leaves were all significantly lower than those of control, except on August 3 when it was significantly higher, showing the reduction in thylakoid stacking in drought-stressed plants which resulted in decreased photosynthesis.

Dinakaran *et al.* (2010) investigated the efficacy of *Bt* and conventional non *Bt* cotton in terms of biochemical parameters viz., photosynthetic pigments (chlorophyll and carotenoids). Results showed that photosynthetic pigments of *Bt* cotton were higher than that of non *Bt* cotton, which indicates the mobilization of resources for synthesis of pigments in *Bt* cotton.

Byale *et al.* (2014) found the effect of nutrients on total chlorophyll and anthocyanin contents in *Bt* cotton under rainfed condition. Maximum total chlorophyll content was recorded in the leaves due to the application of recommended dose of nitrogen + phosphorus + potassium + sulphur + magnesium + zinc +boron at square (3.25 mg g^{-1}), boll formation (3.53 mg g^{-1}) and boll bursting stages (3.42 mg g^{-1}) while lower total chlorophyll content at square (1.42 mg g^{-1}), boll formation (1.86 mg g^{-1}) and boll bursting stages (1.36 mg g^{-1}) was recorded in control conditions. Also, maximum anthocyanin content (4.87, 18.8 & 44.07 mg g^{-1} at square, boll formation and boll bursting) was recorded when no fertilizers were applied.

Singh *et al.* (2015) studied the chlorophyll effect on three different levels of plant spacing of 60, 50 and 40 cm with a consistent row width of 210 cm. Results

showed that significant effect of spacings on the chlorophyll content. Maximum content was recorded in optimum spacing of 50 cm during all the three growth stages i.e., square formation (0.80 mg g^{-1}), peak flowering (0.90 mg g^{-1}) and boll bursting (0.70 mg g^{-1}). Higher level of RWC in narrow spacing of 50 cm was understood to have influenced the pigment levels.

2.4.2 Spad chlorophyll meter readings (SCMR)

Jahedi *et al.* (2013) determined the effect of row spacing on the yield of cotton cultivars. Experiment treatments included row spacing three levels of 30, 50 and 70 cm as main plot. Sub plots included three cultivars Varamin, Khordad and Sepid. Findings showed a negative correlation of SCMR with plant spacing and non significant results between spacings and genotypes. Maximum SCMR (48.60) was recorded with closer row spacing of 30 cm, intermittent SCMR (48.10) with medium row spacing of 50 cm and minimum SCMR readings was recorded under wider row spacing of 70 cm. In case of genotypes, maximum SCMR was recorded by Sepid (52.70) followed by Varamin (45.90) and Khordad (45.50).

2.4.3 Photosynthetic rate

Zhao *et al.* (2004) reported leaf and canopy photosynthetic characteristics of cotton under elevated CO_2 concentration and UV-B radiation. Findings showed a positive correlation of photosynthetic rate with elevated CO_2 concentration and negative correlation of photosynthetic rate with UV-B radiation. Maximum photosynthetic rate (41.9 µ mol CO_2 m^{-2} s^{-1}) was recorded at 720 CO_2 (µL L^{-1}), UV-B at 0 (kJ m^{-2} d^{-1}) followed by 40.5 µ mol CO_2 m^{-2} s^{-1} at 720 CO_2 (µL L^{-1}), UV-B at 8 (kJ m^{-2} d^{-1}) and minimum (17.1 µ mol CO_2 m^{-2} s^{-1}) recorded at 360 CO_2 (µL L^{-1}), UV-B at 16 (kJ m^{-2} d^{-1}).

Cottee *et al.* (2012) evaluated the impact of tents on photosynthesis using a Li-6400 portable photosynthesis system (Li-Cor Ltd, Lincoln, NE) with a pulse-amplitude modulated (PAM) leaf chamber fluorometer sensor head. Results indicated genotypic differences for all physiological measurements taken on leaves under ambient field conditions and under the tents. Photosynthesis rate decreased under tents compared with ambient field conditions. The decrease in photosynthesis was greater for cotton variety Sicala-45 (34.0 µ mol CO_2 m^{-2} s^{-1}) compared with Sicot-53 (37.0 µ mol CO_2 m^{-2} s^{-1}).

Liu *et al.* (2008) reported that under drought during the flowering and boll-setting periods, photosynthetic index apparently decreased but the photosynthetic pigment content increased.

Levi *et al.* (2009) showed that variation in photosynthetic rates has been used to distinguish water deficit tolerance and sensitive genotypes in various species, including cotton.

Li *et al.* (2012) observed that the fv/fm decreased during later stages of growth (boll set) under water stress and also their result suggests that regulating photosynthetic system at crucial stage was the defense response of cotton plant to drought.

Liu *et al.* (2015) investigated effect of photosynthetic characteristics of the subtending leaf of cotton boll at different fruiting branch nodes and their relationships with lint yield and fiber quality. Findings showed photosynthesis rate was significantly affected by different days after anthesis and sowing date. Maximum photosynthetic rate (23.7 μ mol CO_2 m^{-2} s^{-1}) was recorded in Kemian-1at $FB_{10–11}$ sowing date at 17 days after anthesis followed by (22.9 μ mol CO_2 m^{-2} s^{-1}) in Sumian-15 at $FB_{10–11}$ sowing date at 17 days after anthesis and minimum (7.5 μ mol CO_2 m^{-2} s^{-1}) in Sumian-15 at $FB_{10–11}$ sowing date at 45 days after anthesis.

2.4.4 Chlorophyll stability index (CSI)

Zhu *et al.* (2005) postulated that increase in chlorophyll was an indicator of the primary reactions of photosynthesis.

Jahedi *et al.* (2013) determined effect of row spacing on the yield of cotton cultivars. Experiment treatments including row spacing were carried out at three levels of 30, 50 and 70 cm as main plot. Subplots were considered with three cultivars Varamin, Khordad and Sepid. The effect of row spacing on chlorophyll index wasn't significant. Maximum chlorophyll index was obtained in 30 cm spacing (48.6%) and the minimum chlorophyll index was obtained in 70 cm spacing (47.4%). The effect of cultivar on chlorophyll index was significant. The maximum amount of chlorophyll index was obtained in Sepid with 52.7%. Chlorophyll maintenance and consequently photosynthetic durability in stressful conditions are among physiological indicators of stress resistance.

2.4.5 Proline accumulation

Parida *et al.* (2008) reported the differential responses of the enzymes involved in proline biosynthesis and degradation in drought tolerant and sensitive cotton genotypes during drought stress and recovery. Free proline levels were studied in drought tolerant (Ca/H 680) and drought sensitive (Ca/H 148) genotypes of cotton (*Gossypium hirsutum* L.). Results indicated proline contents of leaves increased significantly with progression of drought stress in both the genotypes. Proline level increased slowly in early stages (200 μg g^{-1} dry weight) of drought induction (3-7 days), as where it increased steadily after 7 days of stress (500 μg g^{-1} dry weight). After 14 days of drought stress, proline level increased by 22-fold in the genotype Ca/H 680 (5000 μg g^{-1} dry weight), and 14 fold in Ca/H 148 (2000 μg g^{-1} dry weight). After recovery from drought, the proline contents of both the genotypes decreased significantly and tend to be equal to their respective control.

Gur *et al.* (2010) investigated the diurnal gradual heat stress affects antioxidant enzymes, proline accumulation and some physiological components in cotton. Cotton (*Gossypium hirsutum* L.) cultivar Stoneville-453 was used in this study. At squaring stage (4 -5 squares) heat stress treatments were applied at 30°C (control), 38°C (moderate heat stress) and 45°C (high heat stress). Results indicated a decline in the level of proline content in the leaves of plants subjected to 38 and 45°C as compared to the control plants. Proline values were 1.04, 0.86 and 0.27 μ mol g^{-1} fresh weight for control, 38 and 45°C treated plants, respectively. As compared to the control plants, proline content dropped by 17.36 and 74 % in the plants subjected to 38 and 45°C.

Singh *et al.* (2015) evaluated the effects of different levels of spacing on biophysical and biochemical parameters in cotton. Study was pertaining to the effect of three different levels of plant spacing 60, 50 and 40 cm with a consistent row width of 210 cm during growth stages like square formation, peak flowering and boll bursting stages of cotton crop. The Results showed significant effect of spacings on the proline (mg/gm). Spacing had significant effect on proline accumulation. Results highlighted square formation stage exhibited maximum proline (19 mg gm^{-1}) content at spacing of 60 cm, whereas during peak flowering (20 mg gm^{-1}) and boll bursting stage (18 mg gm^{-1}) it was maximum at spacing of 50 cm.

2.5 Computation of growth parameters

2.5.1 Crop growth rate (CGR)

In terms of total dry matter production by a crop or by a crop community, leaf area index and photosynthetic rate appear to be the major determinants to crop growth rate. Increase in yield potential of a variety is not associated with an increase in photosynthetic rate and it is difficult to find out clear cut evidence that a variety with high leaf photosynthesis rate was measured in cotton.

Godoy *et al.* (2000) reported that transgenic cultivars showed significant increase in biomass (crop growth rate) during 84-105 days after sowing. All the cultivars evaluated in this study had the same efficiency for rate of dry matter accumulation (Relative growth rate) Paymaster genotype had the maximum net growth rate value.

Ali *et al.* (2009) determined effect of sowing dates and plant spacing on growth in cotton (*Gossypium hirsutum* L.). Cotton crop was sown on three sowing dates; May 10, June 01 and June 20 with three plant spacing 15, 30 and 45cm. Results indicated crop growth rate after 50 days of sowing (CGR50) was the maximum (3.8 $g/m^2/day$) in crop sown at earlier dates (10-May) as compared to other sowing dates and at high plant density of 15 cm. Non significant differences were observed for CGR after 100 days (CGR100) at all plant spacings. Crop growth rate after 150 days (CGR150) was the maximum (2.3 $g\ m^{-2}\ day^{-1}$) for crop sown on 1st June at high density of 15 cm. However, late sown crop (1-June) showed the minimum (0.5 $g\ m^{-2}\ day^{-1}$) CGR150 at low plant density of 45cm.

Hameed *et al.* (2013) studied quantitative physiological, vegetative, and reproductive analysis in *Gossypium hirsutum* L. under influence of cultivars and nitrogen levels. Treatments of nitrogen were Zero, 60, 110 and 160 kg ha^{-1} applied in splits to the soil along with high yielding cotton cultivars (CIM-496, CIM-506, and CIM-534). All the cultivars and various nitrogen doses increased CGR significantly. CGR was enhanced significantly with each increment in nitrogen application rate i.e. from zero to 160 kg ha^{-1} from crop sowing to the crop harvest. However, the maximum (6.0 $g\ m^{-2}\ day^{-1}$) CGR was obtained by the treatment (160 kg nitrogen ha-1) against control (5.1 $g\ m^{-2}\ day^{-1}$). Similarly, cultivar CIM-496 achieved the top position in production of the maximum CGR.

Shukla *et al.* (2013) evaluated the effect of spacing and fertility levels on growth parameters of cotton hybrids under rainfed condition. Findings revealed CGR was positively correlated with plant spacings and genotypes. Maximum CGR (0.39 g day^{-1} $plant^{-1}$ at 120 DAE, 1.35 g day^{-1} $plant^{-1}$ at 150 DAE) was recorded with wider row spacing of 90 x 60 cm and minimum CGR (0.35 g day^{-1} $plant^{-1}$ at 120 DAE, 1.20 g day^{-1} $plant^{-1}$ at 150 DAE) with closer row spacing of 60 x 60 cm. Among the genotypes MLCH-318 recorded maximum (0.46 g day^{-1} $plant^{-1}$ at 120 DAE, 1.38 g day^{-1} $plant^{-1}$ at 150 DAE) CGR followed by PKV Hy-2 (0.35 g day^{-1} $plant^{-1}$ at 120 DAE, 1.30 g day^{-1} $plant^{-1}$ at 150 DAE) and VBCH-2231 (0.30 g day^{-1} $plant^{-1}$ at 120 DAE, 1.15 g day^{-1} $plant^{-1}$ at 150 DAE).

Vineela *et al.* (2013) investigated physio-morphological and yield components traits in American cotton. Material used in the present study consisted of 84 intra-hirsutum derived from 12 lines i.e RAH 100-32, SC 7, RAH 370, GCOT 16, RAH 178-4, RACH 99-152, SM 1, RAH 97- 612, RAH 111, NAWAB, RAH 178, RAC 99152 and 7 testers SC 68, SC7-IPS, SC 40, SC 79, C11, NAWAB 8, SC 31 which were isolated from new heterotic gene pools through line x tester fashion along with two checks i.e., Mallika *Bt* and RAHH 95. Wider variability was observed in case of CGR at peak flowering stage (0.83 g m^{-2} day^{-1}), CGR at boll formation stage (2.06 g m^{-2} day^{-1}) and CGR at maturity stage (0.37 g m^{-2} day^{-1}) which indicated their amenability towards directional selection.

2.5.2 Relative growth rate (RGR)

Patil *et al.* (2002) reported that the RGR increased from 30 to 60 DAS and declined rapidly there after.

Ali *et al.* (2009) determined the effect of sowing dates and plant spacing on growth in cotton. Crop was sown on three sowing dates; May 10, June 01 and June 20 with three-plant spacing 15, 30 and 45cm. Only early sown crop (10-May) showed the maximum RGR (4.6 g g^{-1} day^{-1}) relative growth rate after 50 days (RGR50) at high plant density of 15 cm. 20-June, sowing showed the maximum RGR (RGR100) at all plant spacings (1.4 g g^{-1} day^{-1} at 15 cm, 1.6 g g^{-1} day^{-1} at 30 cm and 1.5 g g^{-1} day^{-1} at 45 cm spacing respectively) while crop sowing on 1-June showed the maximum (0.1 g g^{-1} day^{-1}) RGR after 150 days (RGR150) at plant spacing of 15cm.

Hameed *et al.* (2013) studied quantitative physiological, vegetative, and reproductive analysis in *Gossypium hirsutum* L. under influence of cultivars and nitrogen levels. Treatments of nitrogen were Zero, 60, 110 and 160 kg ha^{-1} applied in splits to the soil along with high yielding cotton cultivars (CIM-496, CIM-506, and CIM-534). Relative growth rate (RGR) was altered significantly by the cultivars and nitrogen fertilizer throughout the crop growth. 160 kg nitrogen ha^{-1} treatment produced significantly the maximum RGR (6.0 g m^{-2} day^{-1}) against control treatment from seedling emergence to the crop final harvest while, the RGR was maximum after 90 DAS and then continuously decreased till crop harvest. As compared to CIM-506 and CIM-534, cultivar CIM-496 appeared with the maximum value of RGR (0.04 g g^{-1} day^{-1} @ 30 DAS, 0.06 g g^{-1} day^{-1} @ 60 DAS,).062 g g^{-1} day^{-1} @ 90 DAS, 0.055 g g^{-1} day^{-1} @ 120 DAS and 0.02 g g^{-1} day^{-1} @ 150 DAS) throughout the crop growing period.

Shukla *et al.* (2013) evaluated the effect of spacing and fertility levels on growth parameters of cotton hybrids under rainfed condition. Findings revealed positive RGR with plant spacings and genotypes. Maximum RGR (0.014 g g^{-1} day^{-1} $plant^{-1}$ at 120 DAE, 0.025 g g^{-1} day^{-1} $plant^{-1}$ at 150 DAE) was recorded with wider row spacing of 90 x 60 cm and minimum RGR (0.009 g g^{-1} day^{-1} $plant^{-1}$ at 120 DAE, 0.019 g g^{-1} day^{-1} $plant^{-1}$ at 150 DAE) with closer row spacing of 60 x 60 cm. Among the genotypes MLCH-318 was recorded maximum (0.016 g g^{-1} day^{-1} $plant^{-1}$ at 120 DAE, 0.028 g g^{-1} day^{-1} $plant^{-1}$ at 150 DAE) RGR followed by PKV Hy-2 (0.009 g g^{-1} day^{-1} $plant^{-1}$ at 120 DAE, 0.020 g g^{-1} day^{-1} $plant^{-1}$ at 150 DAE) and VBCH-2231 (0.007 g g^{-1} day^{-1} $plant^{-1}$ at 120 DAE, 0.018 g g^{-1} day^{-1} $plant^{-1}$ at 150 DAE).

2.5.3 Net assimilation rate (NAR)

Patil *et al.* (2002) showed that NAR showed increased trend up to 60 to 90 DAS.

Singh *et al.* (2008) studied the effect of crop geometry and planting methods on growth and yield of *Bt* and non-*Bt* cotton hybrids in cotton-wheat system under north western plain zones. MECH-162 *Bt* and non-*Bt*, LHH-144, AAH-1cotton hybrids were sown under raised and flat bed planting methods at normal (67.5 x 60 cm) and wider (100 x 60 cm) spacing. Findings showed a negative correlation of net assimilation rate (NAR) with plant spacings. NAR was recorded maximum under normal row spacing (9.35 mg dm^{-2} day^{-1}) than wider row spacing (7.84 mg dm^{-2} day^{-1}).

Hameed *et al.* (2013) studied quantitative physiological, vegetative, and reproductive analysis in *Gossypium hirsutum* L. under influence of cultivars and nitrogen levels. Treatments of nitrogen were Zero, 60, 110 and 160 kg ha^{-1} applied in splits to the soil along with high yielding cotton cultivars (CIM-496, CIM-506, and CIM-534). Cultivars and fertilizer nitrogen affected significantly cotton crop NAR from 30 to 150 DAS. Maximum amount of nitrogen given to crop produced the maximum significant NAR. However, it was observed that cotton NAR was the maximum during early crop growth stages then after it started to decrease as crop matured. Similarly, NAR of all the cultivars was the maximum during vegetative crop growth stages and then as fruit load increase it continuously decreased till crop final harvest. Cultivar CIM-496 produced the maximum value of NAR (8 g cm^{-2} day^{-1} @ 30 DAS, 7.2 g cm^{-2} day^{-1} @ 60 DAS, 6.0 g cm^{-2} day^{-1} @ 90 DAS, 5.5 g cm^{-2} day^{-1} @ 120 DAS and 1.5 g cm^{-2} day^{-1} @ 150 DAS) against CIM-506 (7.6 g cm^{-2} day^{-1} @ 30 DAS, 6.8 g cm^{-2} day^{-1} @ 60 DAS, 5.0 g cm^{-2} day^{-1} @ 90 DAS, 4.2 g cm^{-2} day^{-1} @ 120 DAS and 1.0 g cm^{-2} day^{-1} @ 150 DAS) during the whole crop growing season.

2.5.4 Specific leaf area (SLA)

Reddy *et al.* (1989) studied seasonal leaf area-leaf weight relationships in the cotton canopy. This experiment was designed to study changes in SLA in various parts of a cotton canopy throughout the growing season. The main stem of the cotton plant was divided into five-node segments. Leaf area was measured for each segment throughout the growing season. The mean seasonal SLAs for the segments from the bottom to the top of the canopy were 26.2, 25.6, 20.9, 19.4, and 18.1 m^2 kg^{-1}. Except for the upper most segment, SLA increased from 43 to 90 DAE and declined from 100 DAE. Decline coincided with boll maturation but also with canopy defoliation. It was possible to account for 93% of the variation in SLA for all segments by plotting SLA against light flux density within the cotton canopy.

Yao *et al.* (2016) reported cotton response to different plant population densities by adjusting SLA to optimize canopy photosynthetic use efficiency of light and nitrogen. Specific leaf area is affected by changes in light conditions as plants develop. SLA in all three PPD (plant population density) treatments increased as PAR decreased from the top to the bottom of the cotton canopy. PPDs were 7.5, 19.5, and 31.5 plants m^{-2} (referred to as low-PPD, medium-PPD, and high-PPD, respectively). Results recorded was in upper-canopy SLA 11.16, 10.83 and 12.47 m^2 kg^{-1} (referred to as low-

PPD, medium-PPD, and high-PPD SLA respectively), at mid-canopy SLA recorded was 14.64, 14.73 and 15.48 m^2 kg^{-1} (referred to as low-PPD, medium-PPD, and high-PPD SLA respectively) and at lower-canopy SLA recorded was 16.92, 19.34 and 20.88 m^2 kg^{-1} (referred to as low-PPD, medium-PPD, and high-PPD SLA respectively).

2.5.5 Specific leaf weight (SLW)

Bharadwaj and Singh (1988) reported a new ideotype in upland cotton based on foliage characteristics such as small and thick leaves (higher SLW) with more number of bolls and higher boll weight.

Singh *et al.* (1990) concluded that varieties with small thick leaves are usually drought resistant.

Adarsha *et al.* (2004) reported that specific leaf weight increased at 120 DAS and decreased at harvest.

Singh *et al.* (2008) studied the effect of crop geometry and planting methods on growth and yield of *Bt* and non-*Bt* cotton hybrids in cotton-wheat system under north western plain zones. MECH-162 *Bt* and non-*Bt*, LHH-144, AAH-1cotton hybrids were sown under raised and flat bed planting methods at normal (67.5 x 60 cm) and wider (100 x 60 cm) spacing. Findings revealed a negative correlation of SLW with plant spacings. SLW was maximum under normal row spacing (0.409 g dm^{-2}) than wider row spacing (0.363 g dm^{-2}).

Ratnakumari *et al.* (2012) reported higher yield of cotton due to SLW under rainfed condition.

Koler *et al.* (2013) revealed the effect of plant growth regulators on yield, morpho physiological and biochemical parameters in hybrid cotton. Among the treatments, significantly maximum SLW was recorded with CCC (80 ppm) sprayed at 70 DAS (1018 mg dm^{-2}) followed by CCC (60 ppm) sprayed at 70 + 90 DAS (1007 mg dm^{-2}) as compared to all growth retardants sprayed at 90 DAS, NAA at all the concentrations, water spray (808 mg dm^{-2}) and control (808 mg dm^{-2}).

Haritha *et al.* (2014) studied 40 germplasm lines genetic divergence morpho physiological traits under 120 x 60 cm spacing in upland cotton. Results recorded for SLW at 60 DAS varied between 5.227- 6.787 mg cm^{-2}. Maximum SLW at 60 DAS was

recorded in cluster IV and minimum in cluster VI. SLW at 120 DAS varied between 5.380- 6.320 mg cm^{-2}. Maximum SLW at 120 DAS was recorded in cluster IV and minimum in cluster III.

2.6 Yield and yield attributes

2.6.1 Number of bolls $plant^{-1}$

Mayee *et al.* (2004) reported the difference among *Bt* hybrids for yield contributing characters as well as fiber properties. Maximum yield of 2.13 t ha^{-1} was recorded by MECH 162 (*Bt*) followed by MECH 184 (*Bt*). The yield of MECH 12 (*Bt*) was only 1.77 t ha^{-1}. All the three non *Bt* cotton counter parts attributed to higher retention of bolls from the first flush of flowers that resulted to lesser boll damage.

Rauf *et al.* (2004) found that among three yield component number of bolls per plant was the first important contributor to seed cotton yield, followed by boll weight.

Singh *et al.* (2006) revealed that biomass accumulation was significantly lower in all *Bt*-hybrids as compared to non–*Bt* cotton hybrids. In fact better retention of early fruiting parts in *Bt* hybrids could have led to more efficient translocation of photosynthates into reproductive fruiting bodies and consequently more overall growth attained got reduced in *Bt* as compared to non- *Bt*.

Srinivasulu *et al.* (2006) studied effect of spacing on growth and yield of cotton hybrids under rainfed conditions of coastal Andhra Pradesh. 36 treatment combinations consisted of 6 hybrids (PSCH-504, PRCHH-5, RAHH-99, NSPHH-7, Ankur-5642 and Bunny as check) with three plant spacings of 120 x 60 cm, 120 x 90 cm and 90 x 90 cm. Maximum number of bolls (40.5) was recorded in 120 x 60 cm, followed by (39.3) in 120 x 90 cm and minimum number was (35.6) in 90 x 90 cm.

Rajakumar and Gurumurthy (2008) reported lowest plant density of 9,259 plants ha^{-1} recorded the maximum number of bolls per plant (32.87) compared to high plant density of 13,888 plants ha^{-1}, which registered 30.78 bolls per plant. Yield was reduced significantly in wider spacing (31.74 m^{-2}) than the closer spacing (43.97 m^{-2}) when compared on unit area basis. Direct seeding recorded a boll setting percentage of 30.29 as against 33.43 per cent under planting through poly bag seedlings.

Bhalerao and Gaikwad (2010) conducted an experiment to find out the impact of plant geometry and levels of N, P and K fertilization on performance of *Bt* cotton. It was observed that 90 x 45 cm spacing recorded 17.7% higher seed cotton yield than 90 x 90 cm and 90 x 60 cm spacing. Wider spacing of plants had more bolls plant^{-1} (23.1) than closer spaced (20.8 bolls plant^{-1}). Application of 125% RDF was at par with RDF i.e. 50-25-25 kg N-P-K ha^{-1} and significantly higher than 75% RDF. Increase in yield was due to improvement in bolls plant^{-1}.

Alse and Jadhav (2011) reported that the sympodia and green bolls per plant were significantly more in Dhroov *Bt* than Dhroov non *Bt*, Kashinath *Bt* and Nathbaba non *Bt.* Apparently better retention of early formed fruiting parts in Dhroov *Bt* has led to more efficient translocation of photosynthates into the reproductive sink component and consequently, the overall growth attainment got reduced in it as compared to other cultivars.

Lekharam and Shastry (2011) found that *Bt* cotton hybrids which possessed higher sympodia, bolls per plant and also the boll weight which contributed more towards seed cotton yield.

Sudha *et al.* (2011) reported that *Bt* cotton genotypes recorded higher total number of bolls per plant compared to non- *Bt* hybrid. Total number of bolls per plant was significantly higher in RCH-708 *Bt* (37.95) compared to all other cotton genotypes.

Singh *et al.* (2012) studied on the seed cotton yield, growth and yield contributing characters of new *Bt* cotton hybrids under varied agronomic manipulations. The treatments comprised three *Bt* cotton hybrids (MRC 7361, Bioseed 6488 and RCH 134), two plant geometries (67.5 x 75 cm & 67.5 x 90 cm). Findings showed a positive correlation of number of bolls per plant with plant geometries. Maximum number of bolls per plant (55.5) was recorded at wider spacing of 67.5 x 90 cm and minimum number of bolls per plant (51.3) with closer spacing of 67.5 x 75 cm.

Ahmed *et al.* (2014) conducted a field experiment to compare the seed cotton yield and its components in *Gossypium hirsutum* L. on inter plant densities. Number of bolls per plant is an important yield contributing parameter. Number of bolls per plant increased with increasing plant spacing. Maximum number of bolls per plant (47) was recorded in case of wider plant spacing of 60 cm against the minimum (14) in closer plant spacing of 15 cm of VH-306. Similarly, VH-311 recorded maximum number of

bolls per plant (43) in wider plant spacing of 60 cm. Increase in number of bolls per plant with increased plant spacing can be attributed to more availability of space and less intra plant competition.

Kumara *et al.* (2014) reported a positive response on growth and yield of *Bt* cotton hybrids with increased planting density. Treatments consisted of four levels of spacing (120 x 120 cm, 120 x 90 cm, 90 x 60 cm and 90 x 45 cm) with two *Bt* cotton hybrids viz., Rasi-530 *Bt* (H x H) and MRC-6918 *Bt* (H x B). Maximum number of bolls per plant was recorded (83.7) at wider spacing of 120 x 120 cm followed by 120 x 90 cm (76.0) and the minimum bolls (38.6) were recorded with closer spacing of 90 x 45 cm.

Rao *et al.* (2015) conducted field experiment to study the response of transplanted *Bt* cotton to different plant geometry. Methods of sowing were worked with varied plant densities. Transplanting at 90 x 45 cm, 90 x 60 cm, 90 x 90 cm, 120 x 45 cm and 120 x 60 cm and dibbling at 90 x 60 cm and 120 x 45 cm spacings. The cotton variety MRC-7351 (Mahyco) BG-II was used. Number of bolls per plant varied from 25.73-50.51. Maximum number of bolls (50.51) per plant was recorded in the treatment of transplanting 90 x 90 cm spacing and minimum number (25.73) was in treatment of dibbling 120 x 45 cm.

Singh *et al.* (2015) studied the effect of agronomic manipulations on growth, yield attributes and seed cotton yield of American cotton under semi-arid conditions. Performance of three hirsutum genotypes (Bihani251, CSH3129 and LH2076) in two plant geometries (67.5 x 60 cm and 67.5 x 75 cm) was evaluated. Findings revealed a negative correlation of number of bolls per plant with plant geometries. Maximum number bolls (44.6) were recorded at closer spacing of 67.5 x 60 cm and minimum number of bolls (40.9) with wider spacing of 67.5 x 75 cm.

2.6.2 Boll weight

Nehra *et al*. (2004) observed that the *Bt* cotton hybrid produced significantly higher seed cotton yield in comparison to their respective non-*Bt* hybrids and local check. This increase in seed cotton yield has been attributed to more number of bolls per plant and boll weight per plant.

Srinivasan (2006) found that among the hybrids MECH 184 *Bt* recorded heaviest (3.59 g) boll and was significantly superior to the rest of the hybrids.

Khadi *et al.* (2008) reported that increase in lint yield was because of increased boll weight and boll number, which clearly indicated that *Bt* gene offers protection against boll worm damage and which in turn contributes to the development of a number of healthy bolls.

Rao *et al.* (2009) found that the high number of bolls per plant and boll weight increased the seed cotton yield.

Sarang *et al.* (2011) stated that cotton hybrids which had high boll number per plant and boll weight gave higher seed cotton yield.

Tayade *et al.* (2011) noted that the multiple regression and path analysis studies revealed that picked bolls and boll weight was more beneficial for increased seed cotton yield of MECH-184 Bt.

Thakare *et al*., (2011) found that among the four Bt hybrids JKCH 99 recorded maximum seed cotton yield because of more number of fruiting forms (i.e. square, flower and bolls), boll weight and biomass.

Singh *et al.* (2012) studied on the seed cotton yield, growth and yield contributing characters of new *Bt* cotton hybrids under varied agronomic manipulations. The treatments comprised three *Bt* cotton hybrids (MRC 7361, Bioseed 6488 and RCH 134), two plant geometries (67.5 x 75 cm & 67.5 x 90 cm). Findings showed a positive correlation of boll weight with plant geometries. Maximum boll weight (4.71 g) was recorded at wider spacing of 67.5 x 90 cm and minimum boll weight (4.5 g) with closer spacing of 67.5 x 75 cm.

Jadhav *et al.* (2015) studied the influence of plant geometry on performance of cotton hybrid Bunny *Bt* (NCS-145 Bt) under irrigated condition. The treatments of plant geometry included S_1: 90 x 60 cm, S_2: 120 x 45 cm, S_3: 150 x 36 cm and S_4: 180 x 30 cm. Boll weight was significantly influenced by plant geometries. Maximum boll weight (3.48 g) was recorded in wider spacing of 150 x 36 cm followed by (3.28 g) in 120 x 45 cm and the minimum boll weight (3.10 g) was recorded in 180 x 30 cm.

Singh *et al.* (2015) studied the effect of agronomic manipulations on growth, yield attributed and seed cotton yield of American cotton under semi-arid conditions. Performance of three hirsutum genotypes (Bihani251, CSH3129 and LH2076) in two plant geometries (67.5 x 60 cm and 67.5 x 75 cm) was evaluated. Findings showed a

negative correlation of boll weight with plant geometries. Maximum boll weight (3.17 g) was recorded at closer spacing of 67.5 x 60 cm and minimum boll weight (3.12 g) with wider spacing of 67.5 x 75 cm.

2.6.3 Seed cotton yield

Singh *et al*. (2007) noted that the Rashi hybrid RCH-134 recorded significantly maximum seed cotton yield per plant (247.7 g) over Ankur 651, Ankur 2534 and MRC 6301.

Aziz *et al.* (2011) conducted the experiment to find out the maximum yield potential in three different spacings viz. 90 × 45 cm (24,692 plants ha^{-1}), 75 × 45 cm (29,630 plants ha^{-1}) and 60 × 45 cm (37,037 plants ha^{-1}). Maximum seed cotton yield of 2.93 t ha^{-1} was recorded for all the genotypes when the spacing was 75 × 45 cm. Minimum cotton yield (0.96 t ha^{-1}) was obtained in genotype with 90 × 45 cm spacing.

Joshi *et al*. (2011) concluded that higher yield per ha^{-1} was supported by higher yield per plant which ranged between 179.03 g per plant (JK-CH 99 *Bt*) to 114.81 g per plant (DCH-32).

Singh *et al.* (2012) studied the seed cotton yield, growth and yield contributing characters of new *Bt* cotton hybrids under varied agronomic manipulations. The treatments comprised three *Bt* cotton hybrids (MRC 7361, Bioseed 6488 and RCH 134), two plant geometries (67.5 x 75 cm & 67.5 x 90 cm). Findings showed a positive correlation of seed cotton yield with plant geometries. Maximum seed cotton yield (2387 kg ha^{-1}) was recorded at wider spacing of 67.5 x 90 cm and minimum seed cotton yield (2218 kg ha^{-1}) with closer spacing of 67.5 x 75 cm.

Rao *et al.* (2015) conducted field experiment to study the response of translated *Bt* cotton to different plant geometry. He worked on methods of sowing with varied plant densities. Transplanting at 90 x 45 cm, 90 x 60 cm, 90 x 90 cm, 120 x 45 cm and 120 x 60 cm and dibbling at 90 x 60 cm and 120 x 45 cm spacings. The cotton variety MRC-7351 (Mahyco) BG-II was used. Seed cotton yield (g) per plant varied from 109.47-211.82. Maximum seed cotton yield (211.82 g) per plant was recorded in the treatment of transplanting 90 x 90 cm spacing and minimum number (109.47 g) was in treatment of dibbling 120 x 45 cm. Seed cotton yield kg ha^{-1} varied from 2095-2828. Maximum seed cotton yield (2828 kg ha^{-1}) was recorded in the treatment of

transplanting 90 x 60 cm spacing and minimum seed cotton yield (2095 kg ha^{-1}) was in treatment of dibbling 120 x 45 cm.

Venugopalan *et al.* (2014) reported 25-30% high yield over the recommended spacing on shallow to medium deep soils under rainfed condition using appropriate genotypes like PKV 081, NH-615, SURAJ, KC3, Anjali, F2383 and ADB-39 at high densities viz., 1.5 to 2.5 lakh plants ha^{-1} at 45 or 60 cm spacing depending upon the soil type.

Jadhav *et al.* (2015) studied the influence of plant geometry on performance of cotton hybrid Bunny *Bt* (NCS-145 Bt) under irrigated condition. The treatments of plant geometry S_1: 90 x 60 cm, S_2: 120 x 45 cm, S_3: 150 x 36 cm and S_4: 180 x 30 cm. Mean seed cotton yield was significantly influenced by plant geometries. Maximum mean seed cotton yield 36.36 q ha^{-1} was recorded in wider spacing of 150 x 36 cm followed by 34.11 q ha^{-1} in 120 x 45 cm and 31.11 q ha^{-1} in 180 x 30 cm.

Singh *et al.* (2015) studied the effect of agronomic manipulations on growth, yield attributes and seed cotton yield of American cotton under semi-arid conditions. Performance of three hirsutum genotypes (Bihani251, CSH3129 and LH2076) in two plant geometries (67.5 x 60 cm and 67.5 x 75 cm) was evaluated. Findings showed a negative correlation of seed cotton yield with plant geometries. Maximum seed cotton yield (2258.7 kg ha^{-1}) was recorded at closer spacing of 67.5 x 60 cm and minimum seed cotton yield (1958.1 kg ha^{-1}) with wider spacing of 67.5 x 75 cm.

2.6.4 Lint yield

Singh *et al.* (2012) studied effect on the seed cotton yield, growth and yield contributing characters of new *Bt* cotton hybrids under varied agronomic manipulations. The treatments comprised three *Bt* cotton hybrids (MRC 7361, Bioseed 6488 and RCH 134), at two plant geometries (67.5 x 75 cm & 67.5 x 90 cm). Findings showed a positive correlation of lint yield with plant geometries. Maximum lint yield (823.3 kg ha^{-1}) was recorded at wider spacing of 67.5 x 90 cm and minimum lint yield (761.1 kg ha^{-1}) with closer spacing of 67.5 x 75 cm.

Shukla *et al.* (2014) done a field experiment for study the production potential of lint yield kg ha^{-1} of cotton hybrids under different plant spacings and NPK levels. Results indicated that the lint yield was negatively correlated with plant spacings but had a positive correlation with NPK levels. Maximum lint yield (345 kg ha^{-1}) was

recorded in closer pacing of 60 x 60 cm, but in wider spacing of 90 x 60 cm lint yield was minimum (301 kg ha^{-1}).

Singh *et al.* (2015) studied the effect of agronomic manipulations on growth, yield attributed and seed cotton yield of American cotton under semi-arid conditions. He evaluated the performance of three hirsutum genotypes (Bihani251, CSH3129 and LH2076) in two plant geometries (67.5 x 60 cm and 67.5 x 75 cm). Findings showed a negative correlation of lint yield with plant geometries. Maximum lint yield (777.8 kg ha^{-1}) was recorded at closer spacing of 67.5 x 60 cm and minimum lint yield (684.6 kg ha^{-1}) with wider spacing of 67.5 x 75 cm.

2.6.7 Seed index

Pendharkar *et al.* (2010) revealed response of *Bt* cotton hybrids to different plant spacings under rainfed condition. The experiment consists of four spacings viz., 90 x 60 cm, 120 x 45 cm, 150 x 30 cm and 180 x 30 cm and three cotton hybrids viz., Bunny *Bt*, Ajit 155 *Bt* and RCH 2 *Bt*. Findings showed a significant effect of spacings and genotypes on the seed index. Seed index was varied 7.14-7.50 g between the spacings and among the genotypes varied 7.34-7.39 g. Maximum seed index (7.50 g) was recorded at closer spacing of 90 x 60 cm followed by 7.47 g in 120 x 45 cm and 7.14 g in wider spacing of 180 x 30 cm. While, in genotypes Ajit 155 *Bt* was recorded maximum seed index (7.39 g) followed by Bunny *Bt* (7.36 g) and RCH 2 *Bt* (7.34 g).

Aziz *et al.* (2011) studied yield and fibre quality of some cotton genotypes as affected by population density. Five short durated and short statured cotton genotypes (NAM-77, C-2602, BC-0342, BC-0406 and CB-10) along with cultivar CB-9 were evaluated in three different spacings viz. 90 × 45cm (24692 plants ha^{-1}), 75 × 45 cm (29630 plants ha^{-1}) and 60 × 45cm (37037 plants ha^{-1}). Seed index varied insignificantly among the different genotypes of cotton. Genotype CB-9 produced the maximum seed index (10.10 g) but BC-0406 genotype was minimum (8.00 g).

Bharathi *et al.* (2014) reported quality of *Bt* cotton varied under plant geometry in rainfed vertisols. The treatments consist of two cotton hybrids NCS 145 *Bt* and NCS 145 non *Bt* (Non *Bt*), two spacings 120 x 60 cm and 90 x 45 cm. Results showed a significant effect of spacings and genotypes on the seed index. Seed index was varied 10.35-10.76 g between the spacings and among the genotypes varied 10.46-10.62 g. Maximum seed index (10.76 g) was recorded at wider spacing of 120 x 60 cm and

minimum seed index (10.46 g) in closer spacing of 90 x 45 cm. While, in genotypes NCS 145 *Bt* was recorded maximum seed index (10.62 g) and NCS 145 non *Bt* was recorded minimum (10.46 g).

Singh *et al.* (2014) reported the productive potential of hybrid *Bt* cotton inter cropping system under irrigated condition in different plant spacings. Results showed the maximum seed index (8.30 g) was recorded in sole *Bt* cotton at 67.5 x 75 cm spacing and the minimum seed index (7.88 g) was recorded in *Bt* cotton + fodder bajra (1:2) intercropping system at 135 x 37.5 cm spacing.

2.7 To Study the correlation between physiological traits for seed cotton yields and its attributes

Girase and Mehetre (2002) reported that the boll number, boll weight, sympodial number, total dry matter exhibited significant positive association with seed cotton yield.

Gite *et al.* (2006) observed that the number of sympodial per plant had positive and significant genotypic and phenotypic correlations with seed cotton yield.

Annapurve *et al.* (2007) reported that the number of sympodial had high positive correlation with seed cotton yield at both phenotypic and genotypic levels. The characters days to 50 % flowering and boll bursting had highly positive correlation with number of seed/boll at both phenotypic and genotypic levels and the number of boll/plant showed highly positive significant correlation with number of seed boll^{-1} at both phenotypic and genotypic levels.

Tayade *et al.* (2011) showed that hybrid MECH 184 *Bt* seed cotton yield per plant was positively and significantly correlated with independent characters namely leaf area and dry matter accumulation. Multiple regression and path analysis studies revealed that picked bolls and boll weight was more beneficial in increasing the seed cotton yield of MECH-184 *Bt*.

CHAPTER-III

MATERIAL AND METHODS

CHAPTER III

MATERIAL AND METHODS

The investigation entitled **"Identification of growth stages and growth pattern studies in cotton genotypes"** was carried out during *Kharif,* 2015-16. The details of materials used and methodologies adopted during the course of investigation are elucidated in this chapter.

3.1 Location of the experimental site

The present investigation was carried out at College Farm, College of Agriculture, Professor Jayashankar Telangana State Agricultural University, Rajendra nagar, Hyderabad. The farm is geographically situated at an altitude of 542.6 m above mean sea level at 17º 19' N latitude and 78º 28' E longitude and falls under the Southern Telangana agro-climatic zone of Telangana.

3.2 Weather condition during the crop growth period

Weather data on rain fall, maximum and minimum temperature, relative humidity, wind speed and sunshine hours during crop period was recorded at the meteorological observatory of Agricultural Research Institute, Rajendranagar, Hyderabad and furnished (Appendix-A).

The weekly mean maximum and minimum temperature during the crop growth period were 28.4 ^{0}C to 33.6 ^{0}C and 16.0 ^{0}C to 23.6 ^{0}C respectively. The weekly mean relative humidity during the crop growth period ranged from 40.0 to 95.0 per cent. The total rain fall received during crop growth period was 375.3 mm. The mean sunshine hours ranged from 2.4 hrs to 9.3 hrs per day and mean evaporation ranged from 3.0 to 7.8 mm per day. The mean wind speed ranged from 0.2 to 11.0 km hr^{-1}.

3.2 Cropping history of the experiment site

The crop grown in the field for the previous two years were

Year	*Kharif*	*Rabi*
2013-14	Cotton	Fallow
2014-15	Cotton	Fallow
2015-16	Present investigation	

3.4 Experimental details

Name of crop : Cotton (*Gossypium hirsutum* L.)

Genotypes : Three

Experimental design : Split Plot Design

Main plots : Three genotypes
I. ADB-542
II. Narasimha
III. Deltapine 9121

Sub plots : Three spacings
I.75 x10 cm
II. 60 x 10 cm
III. 45 x 10 cm

Number of treatments : Nine

Number of replications : Three

Season : Kharif 2015-2016

Plot size : 9.0 x 2.0 m

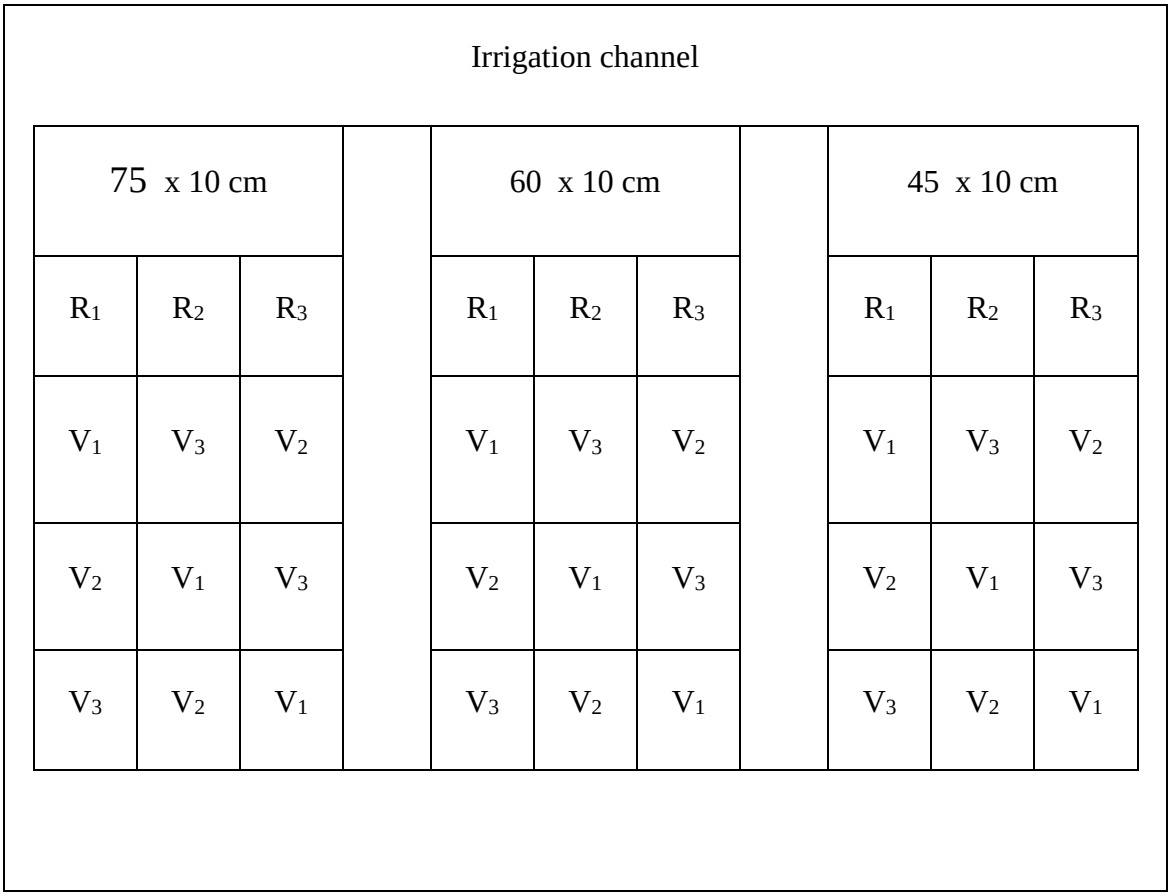
Fertilizer : N: 90 kg ha^{-1}, P: 45 kg ha^{-1} and K: 45 kg ha^{-1}

Date of Sowing : 14^{th} July 2015

Sowing method : Dibbling

3.4.1 Layout

Figure 3.1: Layout plan of the experiment field



Design : Split plot design

Main plots : 3

Sub plots : 3

Replications : 3

Treatments : 9

Plot size : 9.0 x 2.0 m

3.5 CULTIVATION DETAILS

3.5.1 Field studies

3.5.1.1 Preparatory cultivation and lay out

The experiment field was prepared for sowing by ploughing the field with a tractor drawn cultivator followed by harrowing with a cattle drawn harrow. The land was finally levelled with a wooden plank and plots were laid out manually according to the layout plan. The gross plot size for each treatment was 9.0 × 2.0 m^2.

3.5.1.2 Assessment of nutrient requirements *vis-a-vis* fertilizer practices in vogue

A recommended dose of 90 N, 45 P_2O_5 and 45 K_2O kg ha^{-1} was applied in the form of Urea, SSP and MOP respectively. The entire dose of P_2O_5 was applied as a basal dose at the time of sowing. K_2O was applied in two splits and nitrogen was applied in three splits. First was at the time of sowing, second was at maximum vegetative stage and last dose was applied at boll initiation stage.

3.5.1.3 Sowing

The crop was sown on 14th July 2015 by dibbling seeds in opened holes with a hand hoe at a depth of 4 to 5 cm in recommended spacings of 75 × 10 cm, 60 × 10 cm and 45 × 10 cm. Healthy and bold seeds were used for sowing.

3.5.1.4 Thinning

The crop was thinned at 14 days after sowing, retaining one healthy seedling.

3.5.1.5 Weed management

Pre emergence herbicide pendimethalin @ 2.5 ml l^{-1} was sprayed to prevent growth of weeds. Hand weeding was carried out three times at 15 days interval to maintain the crop in weed free condition.

3.5.1.6 Plant protection

Monocrotophos 1.6 ml l^{-1}, Acephate 1.5 g l^{-1} and Chlorpyrifos 2.5 ml l^{-1} were sprayed alternatively against white fly and other sucking pests during the crop growth period as and when required.

3.5.1.7 Irrigation

No irrigations were given to the crop as the rainfall during the crop growth period was sufficient with well distribution.

3.6 Harvesting

The seed cotton was harvested three times when the bolls were fully burst. Seed cotton from plants of border rows was first harvested and treated as bulk. The seed cotton in the remaining rows was harvested separately at each picking and it was weighed on a sensitive balance. The total seed cotton yield was quantified.

3.7 Phenological observation

3.7.1 Days to squaring

Total number of days from the date of sowing to the date on which 50 percent of the plants initiated squaring in a plot was recorded.

3.7.2 Days to flowering

Total number of days from the date of sowing to the date on which 50 percent of the plants initiated flowering in a plot was recorded

3.7.3 Days to boll initiation

Total number of days from the date of sowing to the date on which 50 percent of the plants initiated bolls in a plot was recorded.

3.7.4 Days to peak boll burst

Total number of days from the date of sowing to the date on which 50 percent of the plants opened bolls in a plot was recorded.

3.8 Growing degree days (Heat Units) calculation

A degree-day or a heat unit is the mean temperature above base temperature. Mathematically, it can be expressed as (Reddy, 1995).

$$\text{Growing degree-days (GDD)} = \sum_{i=1}^{n} \left\{ \left(\frac{T_{max} + T_{min}}{2} - T_b \right) \right\}$$

Where, T_{max} is maximum temperature of the day

T_{min} is minimum temperature and

T_b is the lowest temperature at which there is no growth which is also called as base temperature (10^0c).

3.8.1 Degree days to squaring

Squaring was recorded when 50 % plants initiated squares and the degree-days were calculated from germination to the particular growth stage.

3.8.2 Degree days to flowering

Flowering was recorded when 50 % plants initiated flowers and the degree-days were calculated from germination to the particular growth stage.

3.8.3 Degree days to boll initiation

Boll formation was recorded when 50 % plants initiated bolls and the degree-days were calculated from germination to the particular growth stage.

3.9 Morphological observations

Biometric observations on the morpho – physiological parameters were recorded on five representative plants from each replicated treatment tagged in each plot and the mean values were recorded.

3.9.1 Plant height (cm)

Plant height from the ground surface to the top most growing point was measured in cm at 40, 60 and 90 DAS.

3.9.2 Leaf area plant^{-1} (cm^2)

Observation on leaf area per plant (cm^2) was recorded at 40, 60, and 90 DAS. Leaf area of selected five plants from each replication and treatment was measured by using LI-3100 Leaf area meter (LICOR- Lincoln, Nebraska, USA).

3.9.3 Number of monopodial branches per plant

The monopodial branch is an exact replica of the main stem. These branches are formed at the base of the plant and do not bear flowers and bolls directly. Fruiting bodies are formed on further branches monopodial. These were counted from tagged plants at 40, 60 and 90 DAS and average number of monopodial per plant was worked out.

3.9.4 Number of sympodial branches per plant

The branches formed above the growing shoots inside the axils of 4^{th} or 5^{th} leaf which bear flowers at each node and grow horizontally are called sympodia. These were counted from tagged plants at 40, 60 and 90 DAS and average number of sympodials per plant was worked out.

3.9.5 Dry matter production plant^{-1} (g plant^{-1})

The representative plants were destructively sampled from each plot at 40 DAS (squaring stage), 60 DAS (flowering stage), 90 DAS (boll formation stage) and 120 DAS (harvesting stage) by cutting at the base. The plants were initially dried in the shade and later dried in a hot air oven at 65^{o}C. The weight of the oven dried plants was recorded and the mean value was recorded as dry matter accumulation (g) per plant of cotton.

3.10 Physiological observation

3.10.1 Estimation of leaf pigments (mg g^{-1} of fresh tissue)

Chlorophyll content in leaves was estimated colorimetrically by 80 % Acetone method as described by Arnon (1949).

$$\text{Chlorophyll-a (mg/g)} = 12.7\,(D.663) - 2.69\,(D.645) \times \frac{V}{1000 \times W}$$

$$\text{Chlorophyll-b (mg/g)} = 22.9\,(D.645) - 4.68\,(D.663) \times \frac{V}{1000 \times W}$$

$$\text{Carotenoids (mg/g)} = 7.6\,(D.480) - 1.49\,(D.510) \times \frac{V}{1000 \times W}$$

$$\text{Total chlorophyll (mg/g)} = \frac{D.652 \times 1000}{34.5} \times \frac{V}{1000 \times W}$$

Where, D = Optical density at 480, 510, 645,652, 663 nm

V=Final volume of DMSO

W = Fresh weight of sample taken

$$\text{Chl a / Chl b} = \frac{\text{Chlorophyll } \mathbf{a} \text{ content}}{\text{Chlorophyll } \mathbf{b} \text{ content}}$$

3.10.2 Estimation of proline accumulation (μg g^{-1} fresh weight)

Proline content in the leaves was determined by following the method of Bates *et al.* (1973).

Reagents

A. 3 % sulphosalicyclic acid

B. Glacial acetic acid

C. Acid ninhydrin [Acidninhydrin was prepared by dissolving 2.5 g of ninhydrin powder in 60 mL of Glacial acetic acid and 40 mL of Ortho phosphoric acid].

D. Toluene

Procedure:

One gm of fresh leaf material was weighed and homogenised in 10 mL of 3 % sulphosalicyclic acid. The homogenized mixture was filtered and the volume of the filterate was made up to 25 mL. Two mL of the extract was taken in a test tube and 2 mL of Glacial acetic acid was added to it and thoroughly mixed. To that solution 2 mL of Acid nin-hydrin was added and kept in a boiling water bath maintained at 100^0C for 60 minutes. The test tube was brought to room temperature and to it 4 mL of Toluene was added. After through shaking the toluene fraction was separated and the final optical density was measured at 520 nm using Systronics Spectrophotometer model 106. The proline content was computed using the following formula.

$$\text{Proline (μg g}^{-1}\text{ fresh weight)} = \frac{\text{OD} \times 36.231 \times \text{V}}{\text{Y} \times \text{W}}$$

Where, O.D. = Optical density at 520 nm

V = Final volume of the extract

Y = Volume of the aliquot taken

W = Weight of the plant material

3.10.3 Spad Chlorophyll Meter Readings (SCMR) Values

The SPAD-502 (Soil Plant Analytical Development) meter was used for measuring the relative chlorophyll content of leaves. The chlorophyll content was measured from fully expanded leaves. Mean of five values from five leaves was obtained. This meter enables obtaining instant readings without destroying the plant tissue.The observations were recorded at 40, 60 and 90 DAS.

3.10.4 Photosynthetic rate (μ mol CO_2 m^{-2} s^{-1})

The photosynthetic rate was measured using Infra Red Gas Analyser (Model TPS-1) from leaves that had fully expanded recently. The net exchange of CO_2 between a leaf and the atmosphere was measured by enclosing the leaf in closed chamber and monitoring the rate at which the CO_2 concentration in the chamber changed over a fairly short time interval. The observations were recorded at 40, 60 and 90 DAS.

3.10.5 Chlorophyll stability index (CSI) (%)

The CSI was used as a measuring method to differentiate between drought resistant and drought susceptible variety. The laboratory method was described by Kaloyereas (1958) that determine the drought hardiness based on the thermo-stability of chlorophyll pigments when kept in a hot water bath for an hour. The more stable the chlorophyll, the hardier the plant.

$$\text{CSI} = \frac{\text{OD value at 652 nm of heated sample}}{\text{OD value of unheated sample}} \times 100$$

3.11 Computation of growth parameters

In the main field, five plants were randomly selected and labelled separately in each plot for collecting data to measure CGR, RGR, NAR, SLA, SLW and yield attributing characters like number of bolls per plant, boll weight and seed cotton yield (g).

3.11.1 Crop growth rate (CGR) (g m^{-2} d^{-1})

The crop growth rate was calculated to estimate the production efficiency of a crop. It is calculated by using formula given by Watson (1952) and expressed as gram per square meter per day. The observations were recorded at 40, 60, 90, 120 DAS.

$$\mathbf{CGR} = \frac{(\boldsymbol{W_2} - \boldsymbol{W_1})}{(\boldsymbol{t_2} - \boldsymbol{t_1})}$$

Where,

W_1 and W_2 are the dry weights of the plants at time t_1 and t_2 respectively.

3.11.2 Relative growth rate (RGR) (g g^{-1} d^{-1})

RGR is the increase in dry weight per unit dry weight per unit time and is expressed as grams per gram per day and calculated by the formula of Blackman (1919). The observations were recorded at 40, 60, 90, 120 DAS.

$$\text{RGR} = \frac{(\text{Loge } \mathbf{W_2} - \text{Loge } \mathbf{W_1})}{(\mathbf{t_2} - \mathbf{t_1})}$$

Where,

W_1 and W_2 = Total dry weight of plants at time t_1 and t_2 respectively.

3.11.3 Net assimilation rate (NAR) (g cm^{-2} d^{-1})

Net assimilation rate is the rate of increase in dry weight per unit leaf area per unit time (Watson 1952) and is expressed as grams per dm^2 per day. It was calculated by the formula of Radford (1967). The observations were recorded at 40, 60, 90, 120 DAS.

$$\text{NAR} = \frac{(\mathbf{W_2} - \mathbf{W_1})\ (\mathbf{loge\ A_2} - \mathbf{loge\ A_1})}{(\mathbf{t_2} - \mathbf{t_1})\ (\mathbf{A_2} - \mathbf{A_1})}$$

3.11.4 Specific leaf area (SLA) (cm^2 g^{-1})

The specific leaf area on all the sampling days was calculated by using the formula suggested by kvet *et al.,* (1971) and expressed in cm^{-2} g^{-1}.

$$SLA = \frac{(L_A)}{(L_W)}$$

Where, L_A is Leaf area L_W is Leaf dry weight

3.11.5 Specific leaf weight (g cm^{-2})

The specific leaf area on all the sampling days was calculated by using the formula and expressed in g cm^{-2}.

$$SLW = \frac{(L_W)}{(L_A)}$$

Where, L_A is the leaf area and L_W is leaf dry weight.

3.12 Yield parameters

3.12.1 Number of bolls $plant^{-1}$

The number of bolls per plant was calculated to estimate the yielding efficiency of a crop. It was calculated by counting the number of bolls for each plant. Five plants data was recorded from each treatment. The average value was calculated.

3.12.2 Boll weight (g)

The boll weight of each treatment was calculated to estimate the yielding efficiency of a crop. It was calculated by weighing the each boll from five plants from each treatment by using electric weighing machine. The average value was calculated.

3.12.3 Seed cotton yield (kg ha^{-1})

The cumulative yield of seed cotton from three pickings in each treatment plot was weighed and expressed in kg ha^{-1}.

3.12.4 Lint yield (kg ha^{-1})

The cumulative yield lint from three pickings in each treatment plot was weighed and expressed in kg ha^{-1}.

3.12.4 Seed index (g)

The weight of 100 cotton seed is termed as seed index. Seeds were separated by delinting of the seed cotton. This was carried out by soaking the kapas in concentrated H_2SO_4, by which the fuzz gets burnt and left over seeds were immediately washed 3- 4 times with fresh water followed by lime water again with fresh water to neutralize the acid residues and dried under shade.

3.19 Statistical Analysis

The field experiment data recorded on various parameters during the course of investigation were statistically analyzed duly following the analysis of variance technique for split plot design as suggested by Panse and Sukhame (1978). The statistical significance was tested with 'F' test at 0.05 level of probability and where ever the 'P' value was found significant, critical (CD) was worked out to test the significance.

Plate 1: View of the different genotypes under 75 x 10 cm spacing (ADB-542, Narasimha and Deltapine 9121 Left to Right)

Plate 2: View of the different genotypes under 60 x 10 cm spacing (ADB-542, Narasimha and Deltapine 9121 Left to Right)

Plate 3: View of the different genotypes under 45 x 10 cm spacing (ADB-542, Narasimha and Deltapine 9121 Left to Right)

CHAPTER-IV

RESULTS AND DISCUSSION

CHAPTER IV

RESULTS AND DISCUSSION

Observations were recorded on various parameters viz., morphological, phenological, physiological, yield and yield attributes. The observations recorded during the course of investigation are presented and discussed.

4.1 Phenological observations

4.1.1 Days to squaring

Number of days required for each stage to be distinctly distinguished in field was significantly influenced by different high density plant spacings (Table 4.1). Square stage was attained between 42.1 – 43.1 days in different plant spacings. Squares appeared early in 75 x 10 cm spacing (42.1 days) followed by 60 x 10 (42.4 days) and 45 x 10 cm (43.1 days). The treatments 75 x 10 and 60 x 10 cm were on par. Flower stage in different plant spacings appeared between 66.8 – 69.1 days. Flower formation in 75 x 10 cm spacing occurred early (66.8 days) followed by 60 x 10 (68.3 days) and 45 x 10 cm (69.1 days). Bolls appeared between 93.4 – 95.5 days in different plant spacings. Bolls were recorded early in 75 x 10 cm spacing (93.4 days) followed by 60 x 10 (94.2 days) and 45 x 10 cm (95.5 days). Saleem *et al.* (2009) reported the effect of row spacing on earliness. Number of days to first floral bud initiation (squaring) in 90 cm (3.70 plants m^{-2}) took 35.3 days as against 34.4 days with narrow rows of 60 cm (5.55 plants m^{-2}). Earliness was attributed to maximum solar radiation interception in wider row spacing of 90 cm. Genotypic variation was recorded with respect to earliness. Square stage in different genotypes was attained in 41.1 – 43.4 days. Deltapine 9121 took minimum days. ADB 542 and Narasimha which were on par, recorded square stage in 43.1 and 43.4 days.

4.1.2 Days to flowering

Number of days required to attain flower stage in different genotypes ranged from 66.6 – 69.3 days. Deltapine 9121 recorded minimum days to initiate flowers i.e., 66.6 days. ADB 542 and Narasimha recorded in 68.3 and 69.3 days.

4.1.3 Days to boll initiation

Boll formation was recorded in different genotypes between 92.3 – 96.4 days. Deltapine 9121 took minimum days to boll formation (92.3 days). ADB 542 and Narasimha took in 94.4 and 96.4 days. Aziz *et al.* (2011) reported that the quality of cotton genotypes was affected by population density. The number of days required for flower initiation varied significantly with interaction of genotypes and spacing of cotton. Minimum time was required (55.33 days) for flowering with the spacing 60 × 45 cm in genotype C 2602. The maximum time was required by CB-9 (65.6 days) in 60 × 45 cm. Days to flower initiation varied as per the genetic nature of the genotype.

Spacing x genotype interaction for phenological observations was found non – significant. Saleem *et al.* (2009) reported spacings and genotypes to affect the number of days taken for first boll splitting. Maximum of 89.9 days were needed with 90 cm row spacing. Minimum of 86.7 days were needed with 60 cm row spacing. The difference between the spacings and cloudiness during the crop period were attributed to cause the early or late boll splitting.

Among all the tested treatments 75 × 10 cm spacing and the genotype Deltapine 9121 are superior for phenological observations. Deltapine 9121 recorded minimum days throughout the crop growth period for each stage.

Table 4.1: Number of days required for each growth stage in cotton genotypes under different plant spacings.

Squaring					Flowering					Boll initiation				
Spacings	Genotypes			Mean	Spacings	Genotypes			Mean	Spacings	Genotypes			Mean
	G_1	G_2	G_3			G_1	G_2	G_3			G_1	G_2	G_3	
S_1	42.6	43.0	40.6	42.1	S_1	67.3	67.6	65.6	66.8	S_1	93.6	95.3	91.3	93.4
S_2	43.0	43.3	41.0	42.4	S_2	68.6	69.6	66.6	68.3	S_2	94.3	96.3	92.0	94.2
S_3	43.6	44.0	41.6	43.1	S_3	69.0	70.6	67.6	69.1	S_3	95.3	97.6	93.6	95.5
Mean	43.1	43.4	41.1		Mean	68.3	69.3	66.6		Mean	94.4	96.4	92.3	

Comparison	Std. Error	C.D.
Si – Sj	0.17	0.68
Gi – Gj	0.20	0.64
SiGi – SiGj	0.36	NS
SiGi – SjGi	0.34	NS

Comparison	Std. Error	C.D.
Si – Sj	0.28	1.11
Gi – Gj	0.18	0.55
SiGi – SiGj	0.31	NS
SiGi – SjGi	0.38	NS

Comparison	Std. Error	C.D.
Si – Sj	0.15	0.59
Gi – Gj	0.28	0.87
SiGi – SiGj	0.49	NS
SiGi – SjGi	0.42	NS

S_1 means 75 x 10 cm, S_2 means 60 x 10 cm and S_3 means 45 x 10 cm

G_1 means ADB 542, G_2 means Narasimha and G_3 Deltapine 9121 (Where C.D. is significant P = 0.05 %)

4.1.4 Days to peak boll burst

Data on days to peak boll burst in all spacings and genotypes differ significantly with each other (Fig. 4.1, table 4.2)

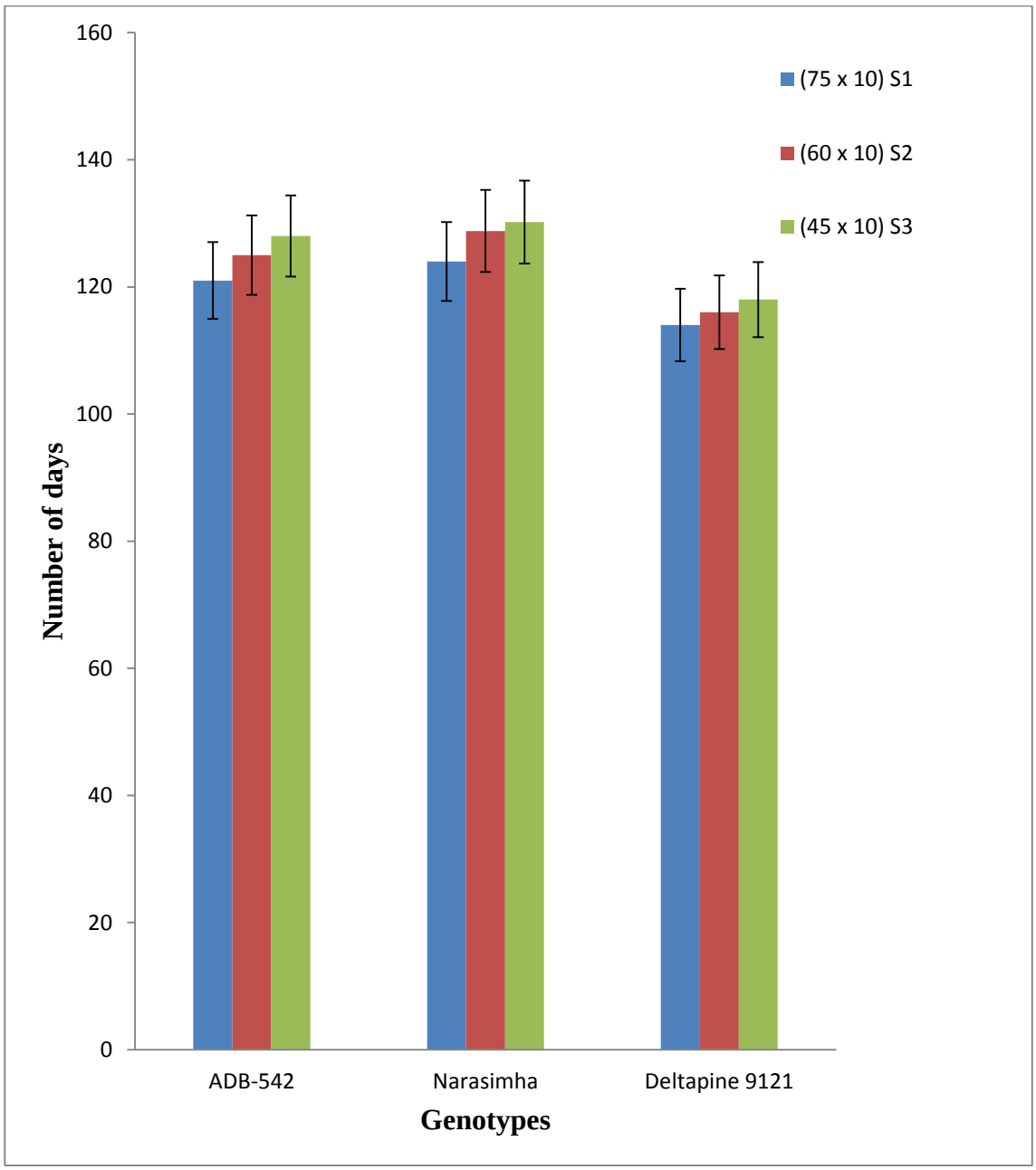
Number of days required for peak boll burst was significantly influenced by different high density plant spacings and genotypes. Interaction revealed less days were required in the genotype Deltapine 9121 for boll burst with wider spacing of 75 x 10 cm (114.0), followed by 116.0 days required for boll burst with medium spacing of 60 x 10 cm in the same genotype Deltapine 9121 (116.0) and maximum days required for boll burst with closer spacing of 45 x 10 cm in the genotype Narasimha (130.2). Minimum days were one of the important tool for mechanical harvesting. Minimum days were reported under wider row spacing. It may be probably because of high solar interception on leaves leading to fast translocation of assimilates. Maturity days increased with increasing of row spacing in all the cultivars. Maximum mean maturity days (155) were recorded in wider row spacing of 90 cm, followed by 75cm and then 60 cm row spacing. The varieties also significantly differed in maturity days. Maximum maturity days (156.1) were reported in FH-901 and minimum days (151.5) were reported in NIAB-111 (Saleem *et al.* 2009). Genotypes along with spacing interaction was significantly influenced the number of days required for boll splitting of the crop. Genotype C-2602 reported minimum of 97.0 days for boll splitting in 60 × 45 cm where as CB-9 was reported maximum of 129.7 days for boll splitting in 90 ×45 cm spacing (Aziz *et al.* 2011). The non–*Bt* hybrid, LHH-144 reported significantly maximum days (130.5) for 50 % boll bursting, while G. Cot Hy.-8 BG II was reported as earlier, took significantly less days (72.5) for 50 % boll bursting (Ban *et al.* 2015).

Table 4.2: Number of days required for peak boll burst in cotton genotypes under different plant spacings.

Spacings	Genotypes			Mean
	G_1	G_2	G_3	
S_1	121.0	124.0	114.0	119.7
S_2	125.0	128.8	116.0	123.3
S_3	128.0	130.2	118.0	125.4
Mean	124.6	127.6	116.0	

Comparison	Std. Error	C.D.
Si – Sj	0.03	0.13
Gi – Gj	0.04	0.12
SiGi – SiGj	0.07	0.21
SiGi – SjGi	0.06	0.21

Fig. 4.1: Number of days required for peak boll burst in cotton genotypes under different plant spacings.



4.2 Growing degree days (Heat units) calculation

The heat unit (or) growing degree-day (GDD) concept was proposed to explain the relationship between growth duration and attainment of required temperature. This concept assumes a direct and linear relationship between growth and temperature. A degree-day (or) a heat unit is the mean temperature above base temperature. (Reddy, 1995)

Number of degree days required to attain each stage was significantly influenced by different high density plant spacings (Table 4.3). 740-756 degree-days were required for squaring. The requirement of degree days increased with decreasing in row spacing adopted. 740.0 degree-days were recorded for squaring in 75 x 10 cm followed by 745.0 and 756.0 degree-days in 60 x 10 and 45 x 10 cm. The treatment 45 x 10 cm was significantly different. 1148.0-1185.0 degree-days were required for flowering. 1148.0 degree-days were recorded for flowering in 75 x 10 cm followed by 1172.0 and 1185.0 degree-days in 60 x 10 and 45 x 10 cm. The treatments 60 x 10 and 45 x 10 cm were on par. 1588.0-1622.0 degree-days were recorded for boll formation. 1588.0 degree-days were recorded for boll formation in 75 x 10 cm spacing followed by 1601.0 and 1622.0 degree-days in 60 x 10 and 45 x 10 cm. Number of degree-days required from planting to first square and flower appearance differed with different row spacings. The maximum number of growing degree-days were reported in wider rows of 90 cm, minimum number of growing degree-days were reported in narrow rows of 60 cm (Munir *et al.* 2015).

Genotypic variation was recorded with respect to growing degree days. 722-762 degree-days were required for squaring. 722 degree-days were recorded for squaring in Deltapine 9121followed by 757 and 762 degree-days in ADB 542 and Narasimha which were on par. 1144-1188 degree-days were required for flowering. 1144 degree days were recorded for flowering in Deltapine 9121 followed by 1172 and 1188 degree-days in ADB 542 and Narasimha. 1570-1636 degree-days were recorded for boll formation. 1570 degree-days were recorded for bolls formation in Deltapine 9121 followed by 1604 and 1636 degree-days in ADB 542 and Narasimha. Robertson *et al.* (2007) updated the minimum heat units required for each stage in cotton. They reported the minimum growing degree-days of 425 to 475 heat units for emergence to first square appearance and 775 to 850 heat units for planting to first flower initiation.

Spacing x genotype interaction for GDD was found non-significant. Among all the tested treatments 75 × 10 cm spacing and the genotype Deltapine 9121 are superior. They recorded minimum GDD. The degree-days difference between the spacings may be due to the difference in the number of plant population stand per unit area while, difference among the genotypes may be the genetic nature.

Table 4.3: Degree-days (Heat units) requirement for each growth stage in cotton genotypes under different plant spacings.

Square stage					Flower stage					Boll initiation stage				
Spacings	Genotypes			Mean	Spacings	Genotypes			Mean	Spacings	Genotypes			Mean
	G_1	G_2	G_3			G_1	G_2	G_3			G_1	G_2	G_3	
S_1	749	755	715	740	S_1	1155	1161	1128	1148	S_1	1591	1619	1553	1588
S_2	755	760	721	745	S_2	1177	1194	1144	1172	S_2	1603	1635	1564	1601
S_3	766	771	732	756	S_3	1183	1210	1161	1185	S_3	1619	1656	1591	1622
Mean	757	762	722		Mean	1172	1188	1144		Mean	1604	1636	1570	

Comparison	Std. Error	C.D.
Si – Sj	2.93	11.5
Gi – Gj	3.45	10.6
SiGi – SiGj	5.97	NS
SiGi – SjGi	5.69	NS

Comparison	Std. Error	C.D.
Si – Sj	4.67	18.3
Gi – Gj	2.98	9.18
SiGi – SiGj	5.16	NS
SiGi – SjGi	6.29	NS

Comparison	Std. Error	C.D.
Si – Sj	2.42	9.53
Gi – Gj	4.53	13.9
SiGi – SiGj	7.86	NS
SiGi – SjGi	6.86	NS

4.3 Morphological parameters

4.3.1 Plant height (cm)

Plant height is an important morphological character in cotton which provides seat for nodes and internodes from where monopodial and sympodial branches emerge and thus play an important role in determining morphological framework relating to productivity (Eaton, 1955).

Plant height was recorded at different crop growth stages. All the cotton genotypes increased in plant height and were recorded at 40, 60 and 90 DAS representing square, flower and boll initiation stages of the crop. Height of cotton genotypes was found significant (Table 4.4, fig 4.2).

Plant height was significantly influenced by different high density plant spacings. Height recorded ranged from 28.1 – 30.4 cm at square stage. In 75 x 10 cm spacing, maximum plant height was recorded (30.4 cm) followed by 60 x 10 (30.3 cm) and 45 x 10 cm (28.1 cm). 75 x 10 and 60 x 10 cm are on par. Plant height recorded ranged from 39.8 – 46.2 cm at the time of initiation of flowering. In 75 x 10 cm spacing, the maximum plant height was recorded (46.2 cm) followed by 60 x 10 (42.4 cm) and 45 x 10 cm (39.8 cm). Plant height recorded ranged from 54.2 – 66.2 cm at boll initiation stage. In 75 x 10 cm spacing, the maximum plant height was recorded (66.2 cm) followed by 60 x 10 (59.8 cm) and 45 x 10 cm (54.2 cm).

Genotypic variation was recorded with respect to plant height. 28.5 – 31.7 cm height was recorded at square stage. Deltapine 9121 recorded maximum plant height. ADB 542 and Narasimha which were on par recorded 28.6 and 28.5 cm. Plant height varied from 39.4 – 49.4 cm at the time of flowering in genotypes which followed the same trend as that of square stage. Deltapine 9121 recorded maximum plant height of 49.4 cm. ADB 542 and Narasimha were on par and recorded 39.4 and 39.5 cm. Plant height increased to 57.2 – 69.8 cm at the time of boll initiation. Deltapine 9121 recorded the maximum plant height of 69.8 cm. ADB 542 and Narasimha recorded 57.2 and 53.1 cm. ADB 542, Narasimha and Deltapine 9121 were significantly different in the plant height (table 4.4).

Spacing x genotype interaction effect revealed maximum plant height in 75 x 10 cm spacing at different growth stages in the genotype Deltapine 9121 (32.6, 56.3, 78.1 cm).

High density planting pattern with 75 x 10 cm recorded optimum height than other plant populations. (Deotalu *et al.* 2013), recorded plant height of 75.27 cm under closer spacing of 60 x 30 cm as compared to the wider plant spacing 60 x 45 cm where 62.78 cm was recorded. Height increase could be due to competition for solar radiation, water and nutrient uptake among the plants. Besides leaf production was associated with plant height changes (Gao and Jein, 1989). Height was related to the intercropping systems in different plant geometries (Singh *et al.* 2014) and varied with conservation tillage practices (Baskaran and Kavimani, 2015). Plant height and seed cotton yield was positively correlated with the plant spacing (Ganvir *et al.* 2013).

Table 4.4: Plant height (cm) at different growth stages of cotton genotypes under different plant spacings.

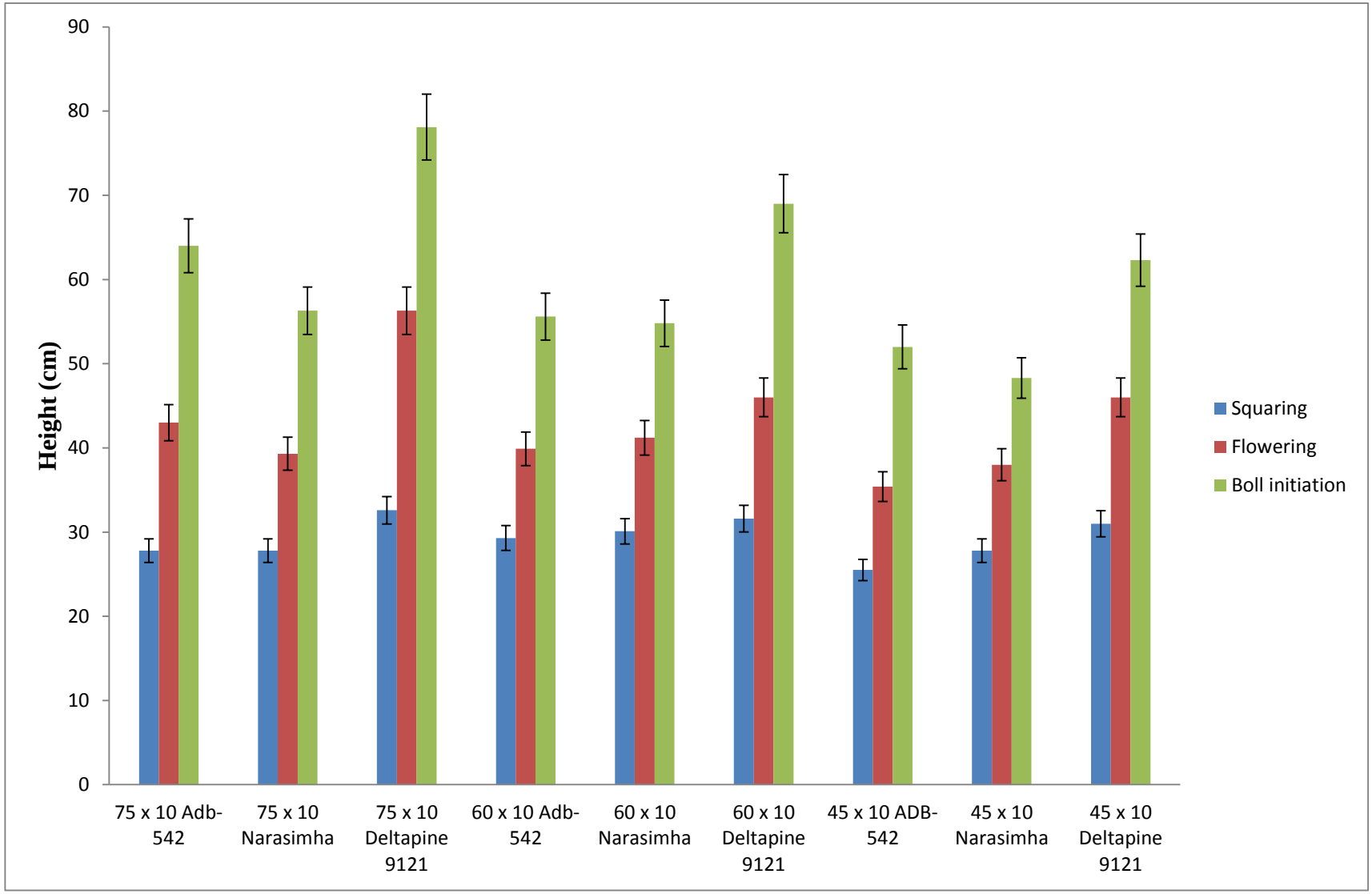
Square stage					Flower stage					Boll initiation stage				
Spacings	Genotypes			Mean	Spacings	Genotypes			Mean	Spacings	Genotypes			Mean
	G_1	G_2	G_3			G_1	G_2	G_3			G_1	G_2	G_3	
S_1	27.8	27.8	32.6	30.4	S_1	43.0	39.3	56.3	46.2	S_1	64.0	56.3	78.1	66.2
S_2	29.3	30.1	31.6	30.3	S_2	39.9	41.2	46.0	42.4	S_2	55.6	54.8	69.0	59.8
S_3	25.5	27.8	31.0	28.1	S_3	35.4	38.0	46.0	39.8	S_3	52.0	48.3	62.3	54.2
Mean	28.6	28.5	31.7		Mean	39.4	39.5	49.4		Mean	57.2	53.1	69.8	

Comparison	Std. Error	C.D.
Si – Sj	0.17	0.70
Gi – Gj	0.33	1.04
SiGi – SiGj	0.58	1.80
SiGi – SjGi	0.51	1.63

Comparison	Std. Error	C.D.
Si – Sj	0.64	2.51
Gi – Gj	0.49	1.53
SiGi – SiGj	0.86	2.65
SiGi – SjGi	0.95	3.29

Comparison	Std. Error	C.D.
Si – Sj	0.56	2.22
Gi – Gj	0.71	2.19
SiGi – SiGj	1.23	3.80
SiGi – SjGi	1.15	3.79

Fig. 4.2: Plant height (cm) at different growth stages of cotton genotypes under different plant spacings.



4.3.2 Leaf area plant^{-1} (cm^2)

Leaf area is fundamentally important as a parameter. This variable represents the amount of leaf material in ecosystems and controls the links between biosphere and atmosphere through various processes such as photosynthesis, respiration, transpiration and rain interception.

Grand mean leaf area values per plant recorded were 798.4 cm^2 at square stage, 1334.5 cm^2 at flower stage and 1652.6 cm^2 at boll initiation stage. The values showed an increase in leaf area with the advancement of crop growth stages (Table 4.5, fig 4.3).

Leaf area was significantly influenced by different high density plant spacings and genotypes. Interaction revealed maximum plant leaf area at square stage with 75 x 10 cm spacing in the genotype Deltapine 9121 (1764 cm^2). At flower formation stage maximum leaf area recorded the same trend of square stage at 75 x 10 cm spacing in the genotype Deltapine 9121 (2796 cm^2). At boll initiation stage leaf area showed the same trend as in square and flower formation. Maximum value at 75 x 10 cm spacing in the genotype Deltapine 9121 (3489 cm^2) was recorded. Maximum leaf area increase as reported at wider row spacing was probably because of less competition for solar radiation. Pendharkar *et al.* (2010) reported a maximum leaf area under closer spacing of 90 x 60 cm (3740 cm^2) as compared to the wider plant spacing 180 x 30 cm (3348 cm^2) for the reason that under closer spacing light interception was high leading to taller plants that produce more number of leaves.

Tayade *et al.* (2011) reported higher yields in genotypes with maximum leaf area in *Bt* cotton types. Adarsha *et al.* (2004) reported maximum leaf area in DHH-542 (5913 cm^2). Bhatt (1987) reported that leaf area differs in the varieties. Kudachikar *et al.* (1999) reported differences in growth parameters and yield attributes among the genotypes sown under rainfed condition where high yielding genotypes were associated with low leaf area. Nalwade *et al.* (2013) reported that maximum leaf area in Akka-*Bt* (6852 cm^2) in 90 x 45 cm spacing.

Table 4.5: Leaf area (cm^2) at different growth stages of cotton genotypes under different plant spacings.

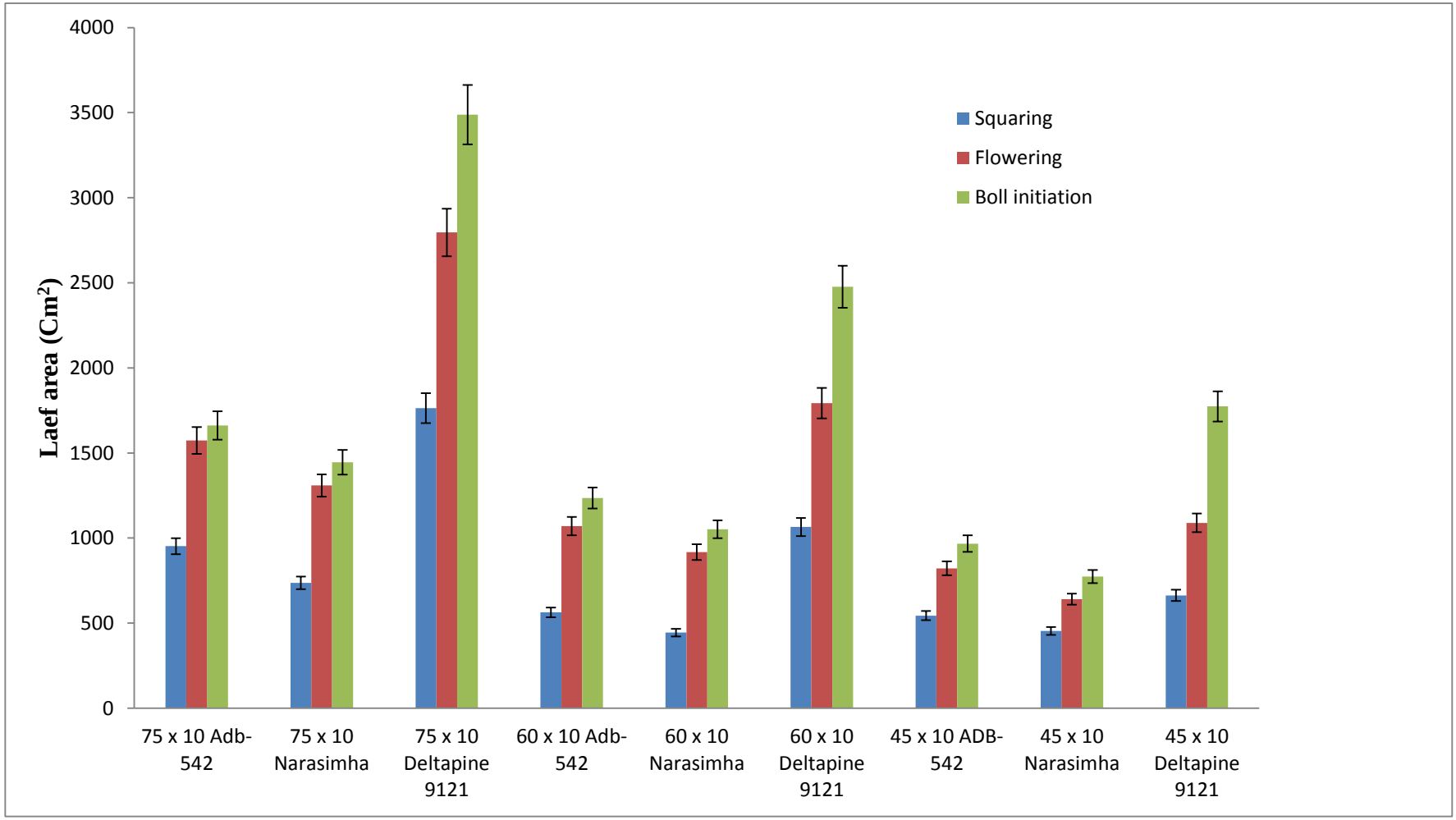
Square stage					Flower stage					Boll initiation stage				
Spacings	Genotypes			Mean	Spacings	Genotypes			Mean	Spacings	Genotypes			Mean
	G_1	G_2	G_3			G_1	G_2	G_3			G_1	G_2	G_3	
S_1	952	737	1764	1151	S_1	1574	1309	2796	1893	S_1	1662	1445	3489	2199
S_2	563	444	1065	691	S_2	1070	917	1793	1260	S_2	1236	1051	2477	1588
S_3	544	454	663	554	S_3	822	641	1089	851	S_3	967	773	1774	1171
Mean	687	545	1164		Mean	1155	956	1893		Mean	1288	1090	2580	

Comparison	Std. Error	C.D.
Si – Sj	1.48	5.83
Gi – Gj	3.42	10.55
SiGi – SiGj	5.93	18.27
SiGi – SjGi	5.06	15.97

Comparison	Std. Error	C.D.
Si – Sj	2.93	11.52
Gi – Gj	4.73	14.60
SiGi – SiGj	8.20	25.29
SiGi – SjGi	7.31	23.54

Comparison	Std. Error	C.D.
Si – Sj	3.33	13.07
Gi – Gj	4.73	18.82
SiGi – SiGj	10.58	32.60
SiGi – SjGi	9.26	29.54

Fig. 4.3: Leaf area (cm^2) at different growth stages of cotton genotypes under different plant spacings.



4.3.3 Number of monopodia plant^{-1}

The branches that do not bear fruit directly are the monopodial branches. Monopodial branches are also called vegetative branches and are always formed at the base of the cotton plant. Monopodial branches give the plant a bushy look. Plant spacing has a great influence on the number of monopodial branches. Closer spacing reduces the appearance of monopodial branches.The number of monopodia determines the seed cotton yield. Mean number of monopodial branches per plant, is given (Table 4.6).

Monopodial branches were significantly influenced by different high density plant spacings and genotypes. Interaction revealed maximum number of monopodia per plant at square stage with 75 x 10 cm spacing in the genotype Deltapine 9121 (2.0). At flower formation stage maximum number of monopodials per plant were recorded in 75 x 10 and 60 x 10 cm spacing in the same genotype Deltapine 9121 (1.6). At boll initiation stage monopodial number showed the same trend as in flower formation. Maximum monopodials per plant were recorded in Deltapine 9121 (1.6). Maximum monopodials as reported at wider row spacing was probably because of less competition for spread. Pendharkar *et al.* (2010) reported in *Bt* cotton hybrids that number of monopodial branches per plant were not significantly influenced by the different plant spacings. Ganvir *et al.* (2013) revealed the monopodial effect on spacings. Maximum monopodial branches per plant were recorded under lower plant densities. Maximum number of monopodial branches per plant (2.08) was recorded in 60 x 30 cm (55,555 plants ha^{-1}) spacing and the minimum number of monopodia per plant (1.37) was recorded in 60 x 10 cm (1,66,666 plants ha^{-1}) spacing.

The numbers of monopodia varied from 1.4 to 1.8 in undescriptive cultivars (Meena *et al.* 2007). Nalwade *et al.* (2013) reported that the number of monopodial branches per plant varied from 2.40 to 3.40 in *Bt* cotton cultivars in 90 x 45 cm spacing. Singh *et al.* (2014) recorded monopodials that varied with the intercropping systems. The maximum number of monopodial branches per plant (3.0) in *Bt* cotton were recorded in the treatment of *Bt* cotton + long melon (1:1) at 67.5 x 75 cm, minimum number of monopodial branches per plant (1.5) in *Bt* cotton were recorded in the treatment of *Bt* cotton + fodder bajra (1:2) at 135 x 37.5 cm spacing.

Table 4.6: Monopodia per plant at different growth stages of cotton genotypes under different plant spacings.

Square stage					Flower stage					Boll initiation stage				
Spacings	Genotypes			Mean	Spacings	Genotypes			Mean	Spacings	Genotypes			Mean
	G_1	G_2	G_3			G_1	G_2	G_3			G_1	G_2	G_3	
S_1	1.3	1.6	2.0	1.6	S_1	1.0	1.3	1.6	1.3	S_1	0.6	1.0	1.3	1.0
S_2	1.0	1.3	1.6	1.3	S_2	0.6	1.0	1.6	1.1	S_2	0.3	0.6	1.3	0.7
S_3	1.0	1.0	1.3	1.1	S_3	0.6	0.6	1.0	0.7	S_3	0.3	0.3	1.0	0.5
Mean	1.1	1.3	1.6		Mean	0.7	1.0	1.4		Mean	0.4	0.6	1.2	

Comparison	Std. Error	C.D.
Si – Sj	0.003	0.012
Gi – Gj	0.001	0.006
SiGi – SiGj	0.003	0.010
SiGi – SjGi	0.004	0.015

Comparison	Std. Error	C.D.
Si – Sj	0.003	0.012
Gi – Gj	0.002	0.007
SiGi – SiGj	0.004	0.013
SiGi – SjGi	0.004	0.016

Comparison	Std. Error	C.D.
Si – Sj	0.002	0.010
Gi – Gj	0.002	0.008
SiGi – SiGj	0.004	0.014
SiGi – SjGi	0.004	0.015

4.3.4 Number of sympodia plant^{-1}

Sympodial branches bear fruit directly, so they are called fruiting branches. The secondary branches on monopodial branches are also sympodial as they bear fruit directly. Number of sympodial branches per plant are important component of the cotton plant. Once a sympodial branch has formed at a main stem node, the plant is no longer able to produce monopodial branches above that node. It influences the yield of cotton crop. The number of sympodial branches recorded at different growth stages are expressed as mean number of sympodia per plant (Table 4.7, fig 4.4).

Sympodial branches were significantly influenced by different high density plant spacings and genotypes. At square stage, maximum number of sympodia was recorded with 75 x 10 cm spacing in genotype Deltapine 9121 (13). At flower formation stage maximum number of sympodia was also recorded at 75 x 10 cm spacing in the genotype Deltapine 9121 (13.6). At boll initiation stage sympodial number showed the same trend as in square and flower formation. At 75 x 10 cm spacing in the genotype Deltapine 9121 maximum value was recorded (17.3). Maximum number of sympodial was reported at wider row spacing was probably because of high light interception leading to taller plants that produce more number of sympodial branches. Deotalu *et al.* (2013) observed a positive correlation of the number of sympodial branches per plant with spacing. The maximum number of sympodia per plant (9.53) was recorded in closer spacing of 60 x 30 cm but in wider spacing of 60 x 45 cm the number of sympodia was maximum (10.79). This higher number may be probably because of wider spacing in plants leading to less competition for nutrients and other resources.

Shukla *et al.* (2014) reported a negative correlation where in a maximum sympodial number per plant (16.3) was recorded in closer spacing of 60 x 60 cm and less number in wider row spacing of 90 x 60 cm (13.7) owing to less amount of rainfall during the crop growth period. However, Buttar and Singh (2006) obtained significantly higher seed cotton yield in *Bt* hybrids which might be due to significantly higher number of sympodia and bolls per plant as compared to non-*Bt* hybrid. This shows the superiority of *Bt* cotton hybrids over non-*Bt* hybrid.

Table 4.7: Sympodia per plant at different growth stages of cotton genotypes under different plant spacings.

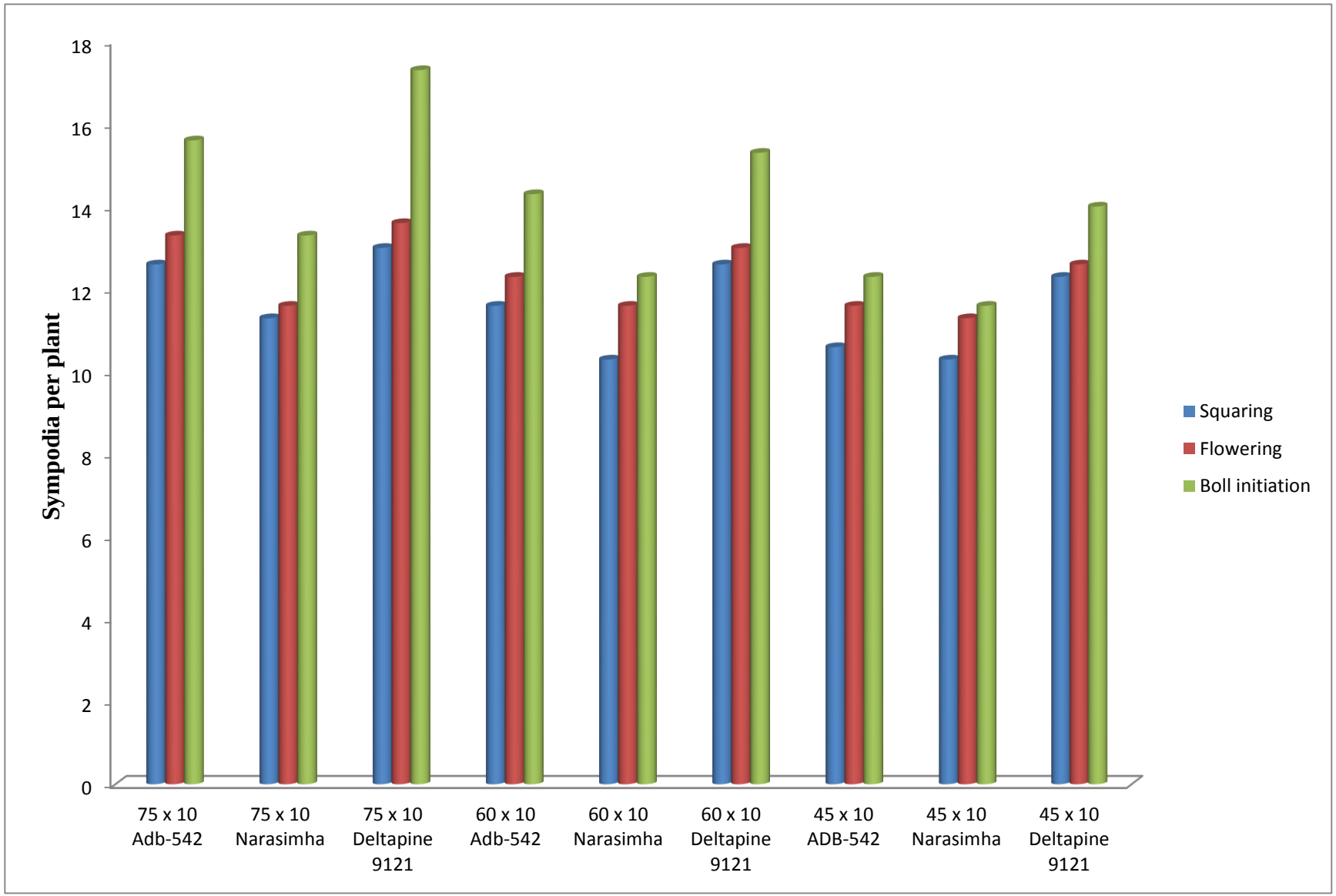
Square stage					Flower stage					Boll initiation stage				
Spacings	Genotypes			Mean	Spacings	Genotypes			Mean	Spacings	Genotypes			Mean
	G_1	G_2	G_3			G_1	G_2	G_3			G_1	G_2	G_3	
S_1	12.6	11.3	13	12.3	S_1	13.3	11.6	13.6	12.8	S_1	15.6	13.3	17.3	15.4
S_2	11.6	10.3	12.6	11.5	S_2	12.3	11.6	13.0	12.3	S_2	14.3	12.6	15.3	14.1
S_3	10.6	10.3	12.3	11.1	S_3	11.6	11.3	12.6	11.8	S_3	12.3	11.6	14.0	12.6
Mean	11.6	10.6	12.6		Mean	12.4	11.5	13.1		Mean	14.1	12.5	15.5	

Comparison	Std. Error	C.D.
Si – Sj	0.010	0.042
Gi – Gj	0.010	0.032
SiGi – SiGj	0.018	0.055
SiGi – SjGi	0.018	0.061

Comparison	Std. Error	C.D.
Si – Sj	0.008	0.034
Gi – Gj	0.008	0.025
SiGi – SiGj	0.014	0.044
SiGi – SjGi	0.014	0.049

Comparison	Std. Error	C.D.
Si – Sj	0.024	0.094
Gi – Gj	0.015	0.048
SiGi – SiGj	0.027	0.083
SiGi – SjGi	0.032	0.115

Fig. 4.4: Number of sympodia at different growth stages of cotton genotypes under different plant spacings.



4.3.5 Dry matter production plant^{-1} (g)

The dry matter produced by leaves, stem and the reproductive parts (i.e. flower, bolls) at various stages of growth are presented as mean dry matter production per plant (Table in 4.8 with fig 4.5).

Dry matter production per plant was significantly influenced by different high density plant spacings and genotypes. At square stage maximum amount of dry matter production was recorded in 75 x 10 cm spacing in genotype Deltapine 9121 (17.2 g). At flower formation stage maximum amount of dry matter were also recorded at 75 x 10 cm spacing in the genotype Deltapine 9121 (35.6 g). At boll initiation stage dry matter production showed the same trend as in square and flower formation. At 75 x 10 cm spacing in the genotype Deltapine 9121 maximum value was recorded (90.1 g). Maximum amount of dry matter production as reported at wider row spacing was probably because of high photosynthetic rate. The present findings are in agreement with the findings of Shukla *et al.* (2013) who reported that the amount of dry matter production per plant was positively correlated with row spacing. The amount of dry matter production per plant (43.78 g) was recorded in wider row spacing of 90 x 60 cm but in closer row spacing 60 x 60 cm the amount of dry matter per plant was minimum (37.83 g). This lower number may be probably because of less photosynthetic rate at closer row spacing leading to less transportation of photosynthetic assimilates to the plant parts. They were responsible for maximum dry matter.

Deotalu *et al.* (2013) reported a positive correlation where in maximum dry matter production per plant (71.04 g) was recorded in wider row spacing of 60 x 45 cm and less number in narrow plant spacing of 60 x 30 cm (56.71 g). Owing to less photosynthetic rate in narrow plant spacing dry matter production per plant was not significantly influenced with plant spacings (Baskaran and Kavimani, 2015).

Table 4.8: Dry matter production (g) per plant at different growth stages of cotton genotypes under different plant spacings.

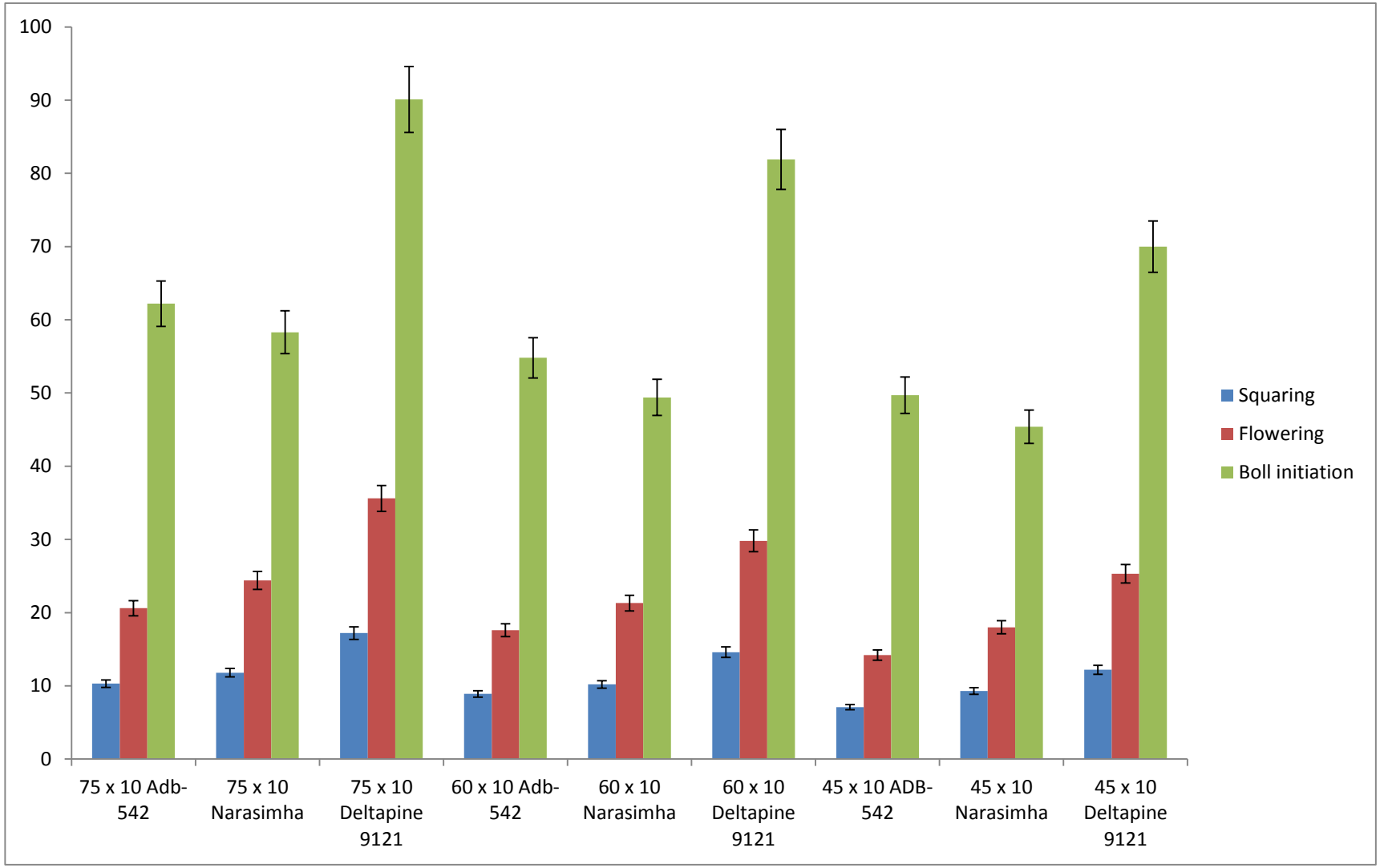
Square stage					Flower stage					Boll initiation stage				
Spacings	Genotypes			Mean	Spacings	Genotypes			Mean	Spacings	Genotypes			Mean
	G_1	G_2	G_3			G_1	G_2	G_3			G_1	G_2	G_3	
S_1	10.3	11.8	17.2	13.1	S_1	20.6	24.4	35.6	26.8	S_1	62.2	58.3	90.1	70.2
S_2	8.9	10.2	14.6	11.2	S_2	17.6	21.3	29.8	22.9	S_2	54.8	49.4	81.9	62.1
S_3	7.1	9.3	12.2	9.5	S_3	14.2	18.0	25.3	19.2	S_3	49.7	45.4	70.0	55.1
Mean	8.8	10.4	14.6		Mean	17.5	21.2	30.2		Mean	55.5	51.0	80.7	

Comparison	Std. Error	C.D.
Si – Sj	0.036	0.141
Gi – Gj	0.044	0.135
SiGi – SiGj	0.076	0.235
SiGi – SjGi	0.072	0.237

Comparison	Std. Error	C.D.
Si – Sj	0.110	0.434
Gi – Gj	0.110	0.340
SiGi – SiGj	0.191	0.589
SiGi – SjGi	0.191	0.643

Comparison	Std. Error	C.D.
Si – Sj	0.262	1.029
Gi – Gj	0.322	0.993
SiGi – SiGj	0.558	1.720
SiGi – SjGi	0.526	1.731

Fig. 4.5: Dry matter production (g) per plant at different growth stages of cotton genotypes under different plant spacings.



4.4 Physiological parameters

4.4.1 Leaf pigments (mg g^{-1} of fresh tissue)

Chlorophyll is the pigment primarily responsible for photosynthesis. It absorbs energy from sunlight and helps converts it into chemical energy during the light dependent reactions of photosynthesis. Chlorophyll determines the photosynthetic capacity and influence the rate of photosynthesis, dry matter product and yield (Gitelson, 2003).

The chlorophylls, a and b are the pigments of photosynthesis. They are produced in chloroplasts in the photosynthetic tissues of the leaf. Chlorophyll is normally broken down towards the end of the leaf life span. Li *et al.* (2012) recorded no obvious differences in the chlorophyll a/b values between the drought or well-watered control. These results showed that the stacking of the thylakoids was weakened and the light harvesting competence and the photosynthetic capability of the chloroplasts deteriorated.

Chlorophyll b is an accessory pigment and acts indirectly in photosynthesis by transferring light it absorbs to Chl-a. Both Chl-a and Chl-b primarily absorb red and blue light, the most effective colours in photosynthesis. They reflect or transmit green light, which is why leaves appear green.

The ratio of chlorophyll a to chlorophyll b in the chloroplast is normally 3:1. It is known that the chlorophyll a to b ratio is higher in high-light growth conditions than in low-light growth conditions. (i.e, more chlorophyll b in shade plants).

Dinakaran *et al.* (2010) reported that photosynthetic pigments of *Bt* cotton were higher than that of non *Bt* cotton, which indicates the mobilization of resources for synthesis of pigments *Bt* cotton.

The leaf pigments present in leaves, stem and the reproductive parts (i.e. flower, bolls) at various stages of growth are presented as mean number of mg per g of fresh tissue (Table in 4.9.1- 4.9.5 and fig 4.6).

Leaf pigment components chlorophyll-a, chlorophyll-b, total chlorophyll, carotenoids (mg g^{-1} of fresh tissue) and chlorophyll-a/b ratio per plant was significantly influenced by different high density plant spacings and genotypes. At square stage with 75 x 10 cm spacing in genotype Deltapine 9121, maximum contents were recorded for

Chlorophyll-a (1.02 mg g^{-1}) (Table, 4.9.1), Chlorophyll-b (1.57 mg g^{-1}) (Table, 4.9.2), total chlorophyll (2.71 mg g^{-1}) (Table, 4.9.3) and Carotenoids (0.41 mg g^{-1}) (Table, 4.9.5). Chlorophyll-a/b ratio was maximum with 45 x 10 spacing in the same genotype Deltapine 9121 (0.89) (Table 4.9.4). Byale *et al.* (2014) recorded the effect of nutrients on total chlorophyll and anthocyanin contents in *Bt* cotton under rainfed condition. Higher total chlorophyll content was recorded in the leaves due to the application of recommended dose of nitrogen + phosphorus + potassium + sulphur + magnesium + zinc +boron at square (3.25 mg g^{-1}), boll formation (3.53 mg g^{-1}) and boll bursting stages (3.42 mg g^{-1}) as compared to lower total chlorophyll content (square 1.42 mg g^{-1}, boll formation 1.86 mg g^{-1} and boll bursting stages 1.36 mg g^{-1}) was recorded in the leaves in control conditions. However, maximum anthocyanin content (4.87, 18.8 & 44.07 at square, boll formation and boll bursting) was recorded when no fertilizers were applied. At flower formation stage maximum leaf pigments components concentration were also recorded at 75 x 10 cm spacing in the genotype Deltapine 9121 (Chlorophyll-a 1.19 mg g^{-1}, Chlorophyll-b 1.96 mg g^{-1}, Total chlorophyll 3.29 mg g^{-1} and Carotenoids 0.73 mg g^{-1}) but maximum Chlorophyll-a/b ratio was recorded with 60 x 10 spacing in the same genotype Deltapine 9121 (0.89).

At boll initiation stage leaf pigments concentration showed the same trend as in square and flower formation. At 75 x 10 cm spacing in the genotype Deltapine 9121 maximum values were recorded for Chlorophyll-a (1.11 mg g^{-1}) (Table, 4.9.1), Chlorophyll-b (1.77 mg g^{-1}) (Table, 4.9.2), total chlorophyll (3.11 mg g^{-1}) (Table, 4.9.3) and Carotenoids (0.68 mg g^{-1}) (Table, 4.9.5). Maximum Chlorophyll-a/b ratio was recorded with 45 x 10 spacing in the same genotype Deltapine 9121 (0.77) (Table, 4.9.4). Maximum concentration of leaf pigments presence was reported at wider row spacing and was probably because of higher leaf area. Singh *et al.* (2015) evaluated the effects of different levels of spacing on biophysical and biochemical parameters in cotton (*Gossypium spp.*). Results showed that significant effect of spacings on the chlorophyll. Maximum content was observed in optimum spacing of 50 cm during all the three growth stages i.e., square formation (0.80 mg g^{-1}), peak flowering (0.90 mg g^{-1}) and boll bursting (0.70 mg g^{-1}). It may be probably because of higher level of relative water content in narrow spacing of 50 cm.

Table 4.9.1: Chlorophyll-a (mg g^{-1} fresh tissue) at different growth stages of cotton genotypes under different plant spacings.

Square stage					Flower stage					Boll initiation stage				
Spacings	Genotypes			Mean	Spacings	Genotypes			Mean	Spacings	Genotypes			Mean
	G_1	G_2	G_3			G_1	G_2	G_3			G_1	G_2	G_3	
S_1	0.64	0.54	1.02	0.73	S_1	0.81	0.64	1.19	0.88	S_1	0.72	0.55	1.11	0.79
S_2	0.53	0.47	0.90	0.63	S_2	0.72	0.62	1.16	0.84	S_2	0.61	0.52	1.07	0.73
S_3	0.42	0.44	0.79	0.55	S_3	0.67	0.55	1.09	0.77	S_3	0.52	0.43	1.03	0.66
Mean	0.53	0.48	0.90		Mean	0.73	0.60	1.15		Mean	0.62	0.50	1.07	

Comparison	Std. Error	C.D.
Si – Sj	0.000	0.001
Gi – Gj	0.000	0.001
SiGi – SiGj	0.001	0.003
SiGi – SjGi	0.000	0.003

Comparison	Std. Error	C.D.
Si – Sj	0.000	0.001
Gi – Gj	0.000	0.002
SiGi – SiGj	0.001	0.004
SiGi – SjGi	0.001	0.003

Comparison	Std. Error	C.D.
Si – Sj	0.000	0.001
Gi – Gj	0.000	0.002
SiGi – SiGj	0.001	0.004
SiGi – SjGi	0.001	0.003

Table 4.9.2: Chlorophyll-b (mg g^{-1} fresh tissue) at different growth stages of cotton genotypes under different plant spacings.

Square stage					Flower stage					Boll initiation stage				
Spacings	Genotypes			Mean	Spacings	Genotypes			Mean	Spacings	Genotypes			Mean
	G_1	G_2	G_3			G_1	G_2	G_3			G_1	G_2	G_3	
S_1	0.87	0.70	1.57	1.05	S_1	1.14	0.77	1.96	1.29	S_1	1.04	0.66	1.77	1.16
S_2	0.56	0.42	1.05	0.68	S_2	0.84	0.68	1.79	1.10	S_2	0.72	0.56	1.50	0.93
S_3	0.37	0.35	0.88	0.53	S_3	0.75	0.61	1.86	1.08	S_3	0.59	0.46	1.34	0.80
Mean	0.60	0.49	1.17		Mean	0.91	0.69	1.87		Mean	0.79	0.56	1.54	

Comparison	Std. Error	C.D.
Si – Sj	0.001	0.004
Gi – Gj	0.001	0.003
SiGi – SiGj	0.001	0.005
SiGi – SjGi	0.001	0.006

Comparison	Std. Error	C.D.
Si – Sj	0.000	0.002
Gi – Gj	0.001	0.005
SiGi – SiGj	0.002	0.009
SiGi – SjGi	0.002	0.007

Comparison	Std. Error	C.D.
Si – Sj	0.000	0.003
Gi – Gj	0.001	0.004
SiGi – SiGj	0.002	0.007
SiGi – SjGi	0.002	0.006

Table 4.9.3: Total chlorophyll (mg g^{-1} fresh tissue) at different growth stages of cotton genotypes under different plant spacings.

Square stage					Flower stage					Boll initiation stage				
Spacings	Genotypes			Mean	Spacings	Genotypes			Mean	Spacings	Genotypes			Mean
	G_1	G_2	G_3			G_1	G_2	G_3			G_1	G_2	G_3	
S_1	1.61	1.34	2.71	1.89	S_1	2.10	1.63	3.29	2.34	S_1	1.87	1.29	3.11	2.09
S_2	1.29	1.08	2.14	1.50	S_2	1.73	1.52	3.10	2.12	S_2	1.53	1.14	2.87	1.85
S_3	1.01	0.93	1.84	1.26	S_3	1.63	1.36	2.96	1.98	S_3	1.25	0.91	2.58	1.58
Mean	1.30	1.12	2.23		Mean	1.82	1.50	3.12		Mean	1.55	1.11	2.85	

Comparison	Std. Error	C.D.
Si – Sj	0.003	0.014
Gi – Gj	0.004	0.012
SiGi – SiGj	0.006	0.021
SiGi – SjGi	0.006	0.022

Comparison	Std. Error	C.D.
Si – Sj	0.000	0.003
Gi – Gj	0.002	0.007
SiGi – SiGj	0.004	0.012
SiGi – SjGi	0.003	0.010

Comparison	Std. Error	C.D.
Si – Sj	0.001	0.004
Gi – Gj	0.002	0.007
SiGi – SiGj	0.004	0.013
SiGi – SjGi	0.003	0.011

Fig. 4.6: Total chlorophyll (mg g^{-1} fresh tissue) at different growth stages of cotton genotypes under different plant spacings.

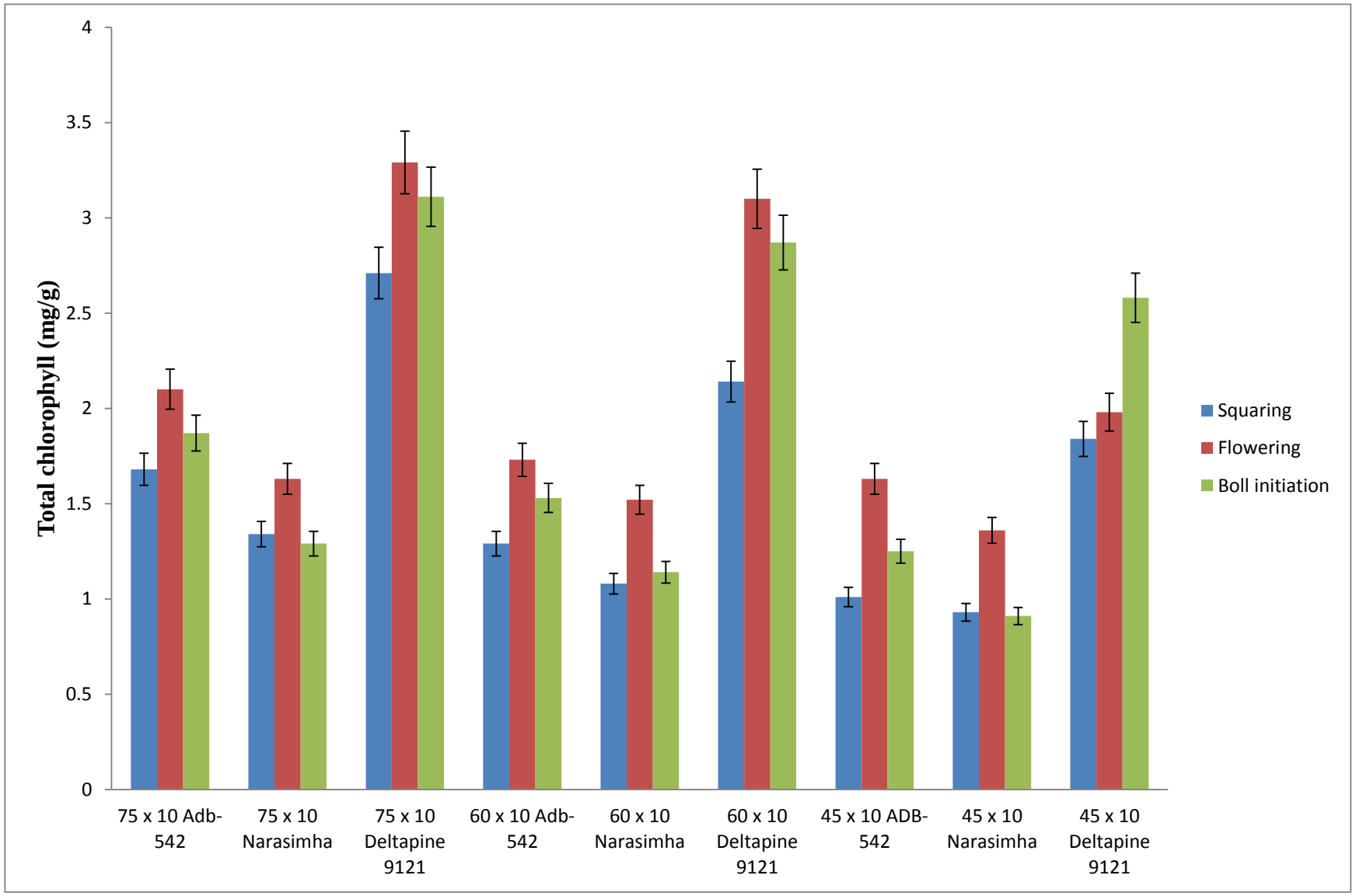


Table 4.9.4: Chlorophyll-a/b at different growth stages of cotton genotypes under different plant spacings.

Square stage					Flower stage					Boll initiation stage				
Spacings	Genotypes			Mean	Spacings	Genotypes			Mean	Spacings	Genotypes			Mean
	G_1	G_2	G_3			G_1	G_2	G_3			G_1	G_2	G_3	
S_1	0.74	0.76	0.65	0.71	S_1	0.71	0.82	0.61	0.71	S_1	0.68	0.83	0.62	0.71
S_2	0.94	1.10	0.85	0.96	S_2	0.86	0.91	0.65	0.80	S_2	0.85	0.91	0.71	0.82
S_3	1.13	1.22	0.89	1.08	S_3	0.89	0.90	0.58	0.79	S_3	0.88	0.92	0.77	0.86
Mean	0.94	1.03	0.80		Mean	0.82	0.87	0.61		Mean	0.80	0.89	0.70	

Comparison	Std. Error	C.D.	Comparison	Std. Error	C.D.	Comparison	Std. Error	C.D.
Si – Sj	0.000	0.000	Si – Sj	0.000	0.000	Si – Sj	0.000	0.000
Gi – Gj	0.000	0.000	Gi – Gj	0.000	0.000	Gi – Gj	0.000	0.000
SiGi – SiGj	0.000	0.000	SiGi – SiGj	0.000	0.000	SiGi – SiGj	0.000	0.000
SiGi – SjGi	0.000	0.000	SiGi – SjGi	0.000	0.000	SiGi – SjGi	0.000	0.000

Table 4.9.5: Carotenoids (mg g^{-1} fresh tissue) at different growth stages of cotton genotypes under different plant spacings.

Square stage					Flower stage					Boll initiation stage				
Spacings	Genotypes			Mean	Spacings	Genotypes			Mean	Spacings	Genotypes			Mean
	G_1	G_2	G_3			G_1	G_2	G_3			G_1	G_2	G_3	
S_1	0.24	0.20	0.41	0.28	S_1	0.46	0.36	0.73	0.52	S_1	0.41	0.28	0.68	0.46
S_2	0.19	0.16	0.32	0.23	S_2	0.38	0.33	0.68	0.47	S_2	0.34	0.25	0.63	0.41
S_3	0.15	0.14	0.28	0.19	S_3	0.36	0.30	0.65	0.44	S_3	0.27	0.20	0.57	0.35
Mean	0.19	0.17	0.34		Mean	0.40	0.33	0.69		Mean	0.34	0.24	0.63	

Comparison	Std. Error	C.D.
Si – Sj	0.001	0.007
Gi – Gj	0.002	0.006
SiGi – SiGj	0.003	0.011
SiGi – SjGi	0.003	0.012

Comparison	Std. Error	C.D.
Si – Sj	0.001	0.006
Gi – Gj	0.004	0.013
SiGi – SiGj	0.007	0.023
SiGi – SjGi	0.006	0.020

Comparison	Std. Error	C.D.
Si – Sj	0.002	0.009
Gi – Gj	0.004	0.014
SiGi – SiGj	0.008	0.024
SiGi – SjGi	0.006	0.022

4.4.2 Spad chlorophyll meter readings (SCMR)

SPAD meter is a simple, portable diagnostic tool that measures the greenness or relative chlorophyll content of leaves. Compared with the traditional destructive methods of chlorophyll extraction, the use of this equipment saves time, space, and resources. It is widely used for the rapid, accurate and non-destructive measurement of leaf chlorophyll concentrations. SCMR are proportional to the amount of chlorophyll present in the leaf. To convert these values into absolute units of chlorophyll concentration, calibration curves need to be derived and utilized.

SCMR per plant was significantly influenced by different high density plant spacings and genotypes (Table 4.10, fig 4.7). At square stage maximum SCMR values with 75 x 10 cm spacing were recorded in genotype Deltapine 9121 (28.0). At flower formation stage maximum SCMR values were also recorded at 75 x 10 cm spacing in the genotype Deltapine 9121 (29.4). At boll initiation stage SCMR values showed the same trend as in square and flower formation. At 75 x 10 cm spacing in the genotype Deltapine 9121 maximum value was recorded (39.2). Maximum SCMR values as reported at wider row spacing was probably because of higher concentration of leaf pigments present at wider row spacing. Jahedi *et al.* (2013) showed a negative correlation of SPAD readings with plant spacings and genotypes. Results recorded a maximum SPAD readings (48.60) was recorded with closer row spacing of 30 cm, intermittent SPAD readings (48.10) with medium row spacing of 50 cm and minimum SPAD readings (47.40) was recorded under wider row spacing of 70 cm. Among the genotypes maximum SPAD reading was recorded by Sepid (52.70) followed by Varamin (45.90) and Khordad (45.50). The difference among the genotypes may probably because of genetic nature.

Table 4.10: SCMR at different growth stages of cotton genotypes under different plant spacings.

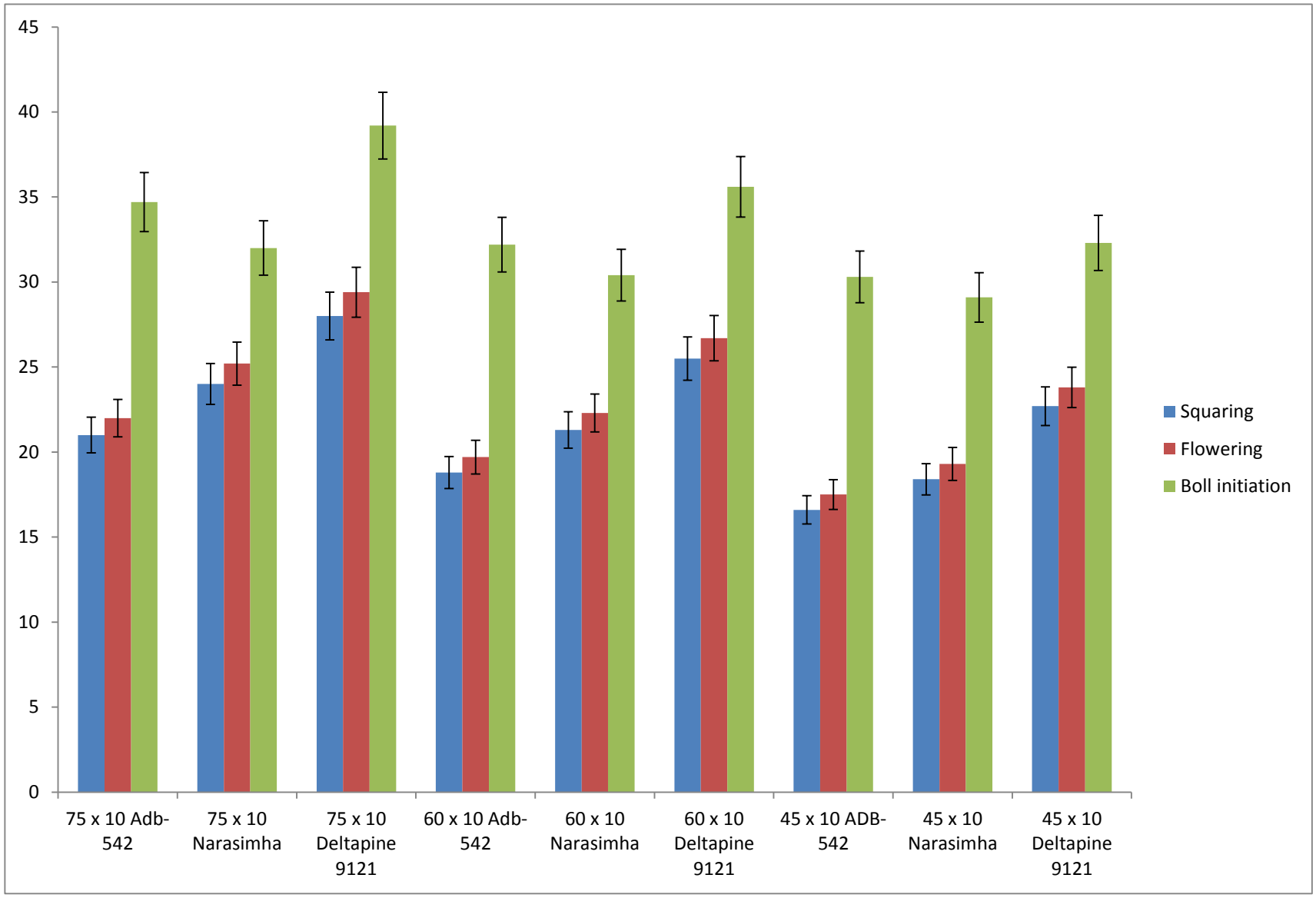
Square stage					Flower stage					Boll initiation stage				
Spacings	Genotypes			Mean	Spacings	Genotypes			Mean	Spacings	Genotypes			Mean
	G_1	G_2	G_3			G_1	G_2	G_3			G_1	G_2	G_3	
S_1	21.0	24.0	28.0	24.3	S_1	22.0	25.2	29.4	25.5	S_1	34.7	32.0	39.2	35.4
S_2	18.8	21.3	25.5	21.8	S_2	19.7	22.3	26.7	22.9	S_2	32.2	30.4	35.6	32.7
S_3	16.6	18.4	22.7	19.2	S_3	17.5	19.3	23.8	20.2	S_3	30.3	29.1	32.3	30.6
Mean	18.8	21.2	25.4		Mean	19.7	22.3	26.6		Mean	32.4	30.5	35.7	

Comparison	Std. Error	C.D.
Si – Sj	0.07	0.28
Gi – Gj	0.05	0.17
SiGi – SiGj	0.09	0.29
SiGi – SjGi	0.10	0.37

Comparison	Std. Error	C.D.
Si – Sj	0.07	0.30
Gi – Gj	0.05	0.17
SiGi – SiGj	0.10	0.31
SiGi – SjGi	0.11	0.39

Comparison	Std. Error	C.D.
Si – Sj	0.06	0.27
Gi – Gj	0.04	0.14
SiGi – SiGj	0.07	0.24
SiGi – SjGi	0.09	0.33

Fig. 4.7: SCMR at different growth stages of cotton genotypes under different plant spacings.



4.4.3 Photosynthetic rate (μ mol CO_2 m^{-2} s^{-1})

Photosynthesis is an integrated and regulated process highly sensitive to any change in environmental conditions, because it needs to balance the light energy absorbed by the photo systems with the energy consumed by the metabolic sinks of a plant (Ensminger *et al*. 2006). The photosynthesis of canopy is associated positively with chlorophyll content which decreases at late season (Wells, 2001). In addition, environmental stresses decrease the performance of the photo system, especially that of PS II; thus, chlorophyll fluorescence is considered a valuable tool to detect the influence of stress factors on plant photosynthesis (Singh *et al*. 2013). Photosynthetic rates have been used to distinguish water deficit tolerance and sensitive genotypes in various species, including cotton (Levi *et al.* 2009).

Photosynthetic rate per plant was significantly influenced by different high density plant spacings and genotypes (Table 4.11). At square stage maximum photosynthetic rate was recorded with 75 x 10 cm spacing in genotype Deltapine 9121 (11.8 μ mol CO_2 m^{-2} s^{-1}). At flower formation stage also maximum photosynthetic rate was recorded at 75 x 10 cm spacing in the genotype Deltapine 9121 (19.7 μ mol CO_2 m^{-2} s^{-1}). At boll initiation stage photosynthetic rate showed the same trend as in square and flower formation. At 75 x 10 cm spacing in the genotype Deltapine 9121 maximum rate was recorded (23.6 μ mol CO_2 m^{-2} s^{-1}). Photosynthesis rate decreased under tents compared with ambient field conditions. The decrease in photosynthesis was greater for cotton variety Sicala-45 (34.0 μ mol CO_2 m^{-2} s^{-1}) compared with Sicot-53 (37.0 μ mol CO_2 m^{-2} s^{-1}) (Cottee *et al.* 2006). Photosynthesis rate was significantly affected by different days after anthesis and sowing date (Liu *et al.* 2015). Maximum photosynthetic rate (23.7 μ mol CO_2 m^{-2} s^{-1}) was recorded in Kemian-1 17 days after anthesis followed by (22.9 μ mol CO_2 m^{-2} s^{-1}) in Sumian-15 17 days after anthesis and minimum (7.5 μ mol CO_2 m^{-2} s^{-1}) in Sumian-15 45 days after anthesis. Photosynthetic rate showed positive correlation with elevated CO_2 concentration and negative correlation with UV-B radiation (Zhao *et al.* 2004). Maximum photosynthetic rate (41.9 μ mol CO_2 m^{-2} s^{-1}) was recorded at 720 CO_2 (μL L^{-1}), UV-B at 0 (kJ m^{-2} d^{-1}) followed by 40.5 μ mol CO_2 m^{-2} s^{-1} at 720 CO_2 (μL L^{-1}), UV-B at 8 (kJ m^{-2} d^{-1}) and minimum (17.1 μ mol CO_2 m^{-2} s^{-1}) recorded at 360 CO_2 (μL L^{-1}), UV-B at 16 (kJ m^{-2} d^{-1}). Cotton under drought during the flowering and boll-setting periods, photosynthetic index apparently decreases but the photosynthetic pigment content increased (Liu *et al.* 2008).

Table 4.11: Photosynthetic rate (μ mol CO_2 m^{-2} s^{-1}) at different growth stages of cotton genotypes under different plant spacings.

Square stage					Flower stage					Boll initiation stage				
Spacings	Genotypes			Mean	Spacings	Genotypes			Mean	Spacings	Genotypes			Mean
	G_1	G_2	G_3			G_1	G_2	G_3			G_1	G_2	G_3	
S_1	9.3	8.1	11.8	9.7	S_1	16.2	14.8	19.7	16.9	S_1	20.3	17.8	23.6	20.5
S_2	8.2	7.0	10.4	8.5	S_2	14.7	13.5	16.9	15.0	S_2	17.3	16.0	20.5	17.9
S_3	7.0	6.8	8.9	7.5	S_3	12.2	10.7	14.4	12.4	S_3	14.9	13.2	16.8	15.0
Mean	8.2	7.3	10.3		Mean	14.3	13.0	17.0		Mean	17.5	15.6	20.3	

Comparison	Std. Error	C.D.
Si – Sj	0.03	0.14
Gi – Gj	0.03	0.09
SiGi – SiGj	0.05	0.16
SiGi – SjGi	0.05	0.20

Comparison	Std. Error	C.D.
Si – Sj	0.07	0.30
Gi – Gj	0.04	0.12
SiGi – SiGj	0.07	0.22
SiGi – SjGi	0.09	0.35

Comparison	Std. Error	C.D.
Si – Sj	0.09	0.38
Gi – Gj	0.04	0.14
SiGi – SiGj	0.08	0.25
SiGi – SjGi	0.11	0.43

4.4.4 Chlorophyll stability index (CSI) (%)

Chlorophyll stability is a function of temperature and it is found to correlate with drought tolerance. Chlorophyll stability index is a measure of integrity of membrane or heat stability of the pigments under stress conditions. The CSI is a single parameter used to measure frost (or) drought resistance of a plant.

Chlorophyll stability index was significantly influenced by different high density plant spacings and genotypes (Table 4.12). At square stage maximum CSI was recorded with 75 x 10 cm spacing in genotype Deltapine 9121 (31.0 %). At flower formation stage also maximum CSI was recorded at 75 x 10 cm spacing in the genotype Deltapine 9121 (47.0 %). At boll initiation stage CSI content showed the same trend as in square and flower formation. At 75 x 10 cm spacing in the genotype Deltapine 9121 maximum rate was recorded (49.3 %). Increase in chlorophyll was an indicator of the primary reactions of photosynthesis (Zhu *et al.* 2005). Jahedi *et al.* (2013) reported effect of row spacing on chlorophyll index wasn't significant. Maximum chlorophyll index was obtained in 30 cm treatment (48.6%) and the minimum chlorophyll index was obtained in 70 cm (47.4%). The effect of cultivar on chlorophyll index was significant. The maximum amount of chlorophyll index was obtained in Sepid with 52.7%. Chlorophyll maintenance and consequently photosynthesis durability in stressful conditions are among physiological indicators of stress resistance.

Table 4.12: Chlorophyll stability index (%) at different growth stages of cotton genotypes under different plant spacings.

Square stage					Flower stage					Boll initiation stage				
Spacings	Genotypes			Mean	Spacings	Genotypes			Mean	Spacings	Genotypes			Mean
	G_1	G_2	G_3			G_1	G_2	G_3			G_1	G_2	G_3	
S_1	28.0	23.8	31.0	27.6	S_1	33.8	32.6	47.0	37.8	S_1	37.6	36.5	49.3	41.2
S_2	25.2	20.6	27.5	24.4	S_2	29.0	26.5	38.8	31.4	S_2	32.5	30.6	43.8	35.6
S_3	21.0	18.3	23.0	20.8	S_3	25.3	20.6	29.2	25.0	S_3	27.2	25.2	35.8	29.4
Mean	24.7	20.9	27.1		Mean	29.3	26.5	38.3		Mean	32.4	30.7	43.0	

Comparison	Std. Error	C.D.
Si – Sj	0.17	0.69
Gi – Gj	0.09	0.29
SiGi – SiGj	0.16	0.51
SiGi – SjGi	0.22	0.80

Comparison	Std. Error	C.D.
Si – Sj	0.33	1.30
Gi – Gj	0.19	0.59
SiGi – SiGj	0.33	1.03
SiGi – SjGi	0.42	1.54

Comparison	Std. Error	C.D.
Si – Sj	0.20	0.80
Gi – Gj	0.13	0.41
SiGi – SiGj	0.23	0.71
SiGi – SjGi	0.27	0.98

Table 4.13: Proline (μg g^{-1} fresh weight) at different growth stages of cotton genotypes under different plant spacings.

Square stage					Flower stage					Boll initiation stage				
Spacings	Genotypes			Mean	Spacings	Genotypes			Mean	Spacings	Genotypes			Mean
	G_1	G_2	G_3			G_1	G_2	G_3			G_1	G_2	G_3	
S_1	303	236	476	339	S_1	385	331	693	469	S_1	466	444	933	614
S_2	226	198	403	275	S_2	303	231	598	377	S_2	394	308	738	480
S_3	186	163	326	225	S_3	249	186	435	290	S_3	326	281	625	411
Mean	239	198	402		Mean	312	249	575		Mean	396	344	765	

Comparison	Std. Error	C.D.
Si – Sj	1.96	7.71
Gi – Gj	2.18	6.72
SiGi – SiGj	3.77	11.64
SiGi – SjGi	3.65	12.16

Comparison	Std. Error	C.D.
Si – Sj	3.11	12.21
Gi – Gj	3.51	10.83
SiGi – SiGj	6.08	18.76
SiGi – SjGi	5.86	19.46

Comparison	Std. Error	C.D.
Si – Sj	3.58	14.09
Gi – Gj	4.66	14.36
SiGi – SiGj	8.07	24.88
SiGi – SjGi	7.50	24.58

4.4.5 Proline accumulation (μg g^{-1} fresh weight)

In plants, proline accumulation is a common physiological response to various stresses but is also part of the developmental program in generative tissues (e.g. pollen). Proline is a phosphorylation marker and is commonly found right before the amino acid serine and threonine to mark them as phosphorylation spots. As a result, proline proceeding these amino acids in an amino acid chain is highly evolutionarily conserved.

Proline (μg g^{-1} fresh weight) was significantly influenced by different high density plant spacings and genotypes (Table 4.13). At square stage maximum proline content was recorded with 75 x 10 cm spacing in genotype Deltapine 9121 (476 μ g g^{-1} fresh weight). At flower formation stage also maximum proline content was recorded at 75 x 10 cm spacing in the genotype Deltapine 9121 (693 μg g^{-1} fresh weight). At boll initiation stage proline content showed the same trend as in square and flower formation. At 75 x 10 cm spacing in the genotype Deltapine 9121 maximum rate was recorded (933 μg g^{-1} fresh weight). Proline contents of leaves increased significantly with progression of drought stress in both the genotypes. Proline level increased slowly in early stages (200 μg g^{-1} dry weight) of drought induction (3-7 days), where as it increased steadily after 7 days of stress (500 μg g^{-1} dry weight). After 14 days of drought stress, proline level increased by 22-fold in the genotype Ca/H 680 (5000 μg g^{-1} dry weight), and 14 fold in Ca/H 148 (2000 μg g^{-1} dry weight). After recovery from drought, the proline contents of both the genotypes decreased significantly and tend to be equal to their respective control (Parida *et al.* 2008). Singh *et al.* (2015) reported significant effect of spacings on the proline. Spacing had significant effect on proline accumulation. Results highlighted square formation stage exhibited maximum proline (19 mg g^{-1}) content at spacing of 60 cm, whereas during peak flowering (20 mg g^{-1}) and boll burst stage (18 mg g^{-1}) it was maximum at spacing of 50 cm. Gur *et al.* (2010) reported there was a decline in the level of proline content in the leaves of plants subjected to 38 and 45°C temperatures as compared to the control plants (30°C). Proline values were 1.04, 0.86 and 0.27 μ mol g^{-1} fresh weight for control, 38 and 45°C treated plants, respectively. As compared to the control plants, proline content dropped by 17.36 and 74.00 % in the plants subjected to 38 and 45°C.

4.5 Computation of growth parameters

4.5.1 Crop growth rate (CGR) (g m^{-2} d^{-1})

Biomass formed per unit area of land is then of more practical relevance than productivity per plant. Wide variability was observed in case of CGR at peak flowering stage (0.83 g m^{-2} day^{-1}), CGR at boll initiation stage (2.06 g m^{-2} day^{-1}) and CGR at maturity stage (0.37 g m^{-2} day^{-1}) indicated their amenability towards directional selection (Vineela *et al.* 2013). The crop growth rates at various stages are presented as mean number (Table in 4.14 with fig 4.8).

Crop growth rate per plant was significantly influenced by different high density plant spacings and genotypes. At 40-60 DAS maximum crop growth rate was with 75 x 10 cm spacing genotype Deltapine 9121 (0.91 g m^{-2} d^{-1}). At 60-90 DAS maximum crop growth rate was also recorded at 75 x 10 cm spacing in the genotype Deltapine 9121 (1.81 g m^{-2} d^{-1}). At 90-120 DAS crop growth rate does not show similar trend as in square and flower formation. At 60 x 10 cm spacing in the genotype Deltapine 9121 maximum crop growth rate was recorded (0.86 g m^{-2} d^{-1}). Maximum crop growth rate values as reported at wider row spacing was probably because of higher concentration of leaf pigments presented at wider row spacing leading to higher photosynthetic rate. Transgenic cultivars showed significant increase in biomass (crop growth rate) during 84-105 days after sowing (Godoy *et al.* 2000).

CGR 50 DAS (CGR50) was the maximum (3.8 g m^{-2} day^{-1}) in crop sown at earlier dates (10-May) as compared to other sowing dates and at high plant density of 15 cm. Non significant differences were observed for crop growth rate after 100 days (CGR100) at all plant spacings. Crop growth rate after 150 days (CGR150) was the maximum (2.3 g m^{-2} day^{-1}) for crop sown on 1^{st} June at high density of 15 cm. However, late sown crop (1-June) showed the minimum (0.5 g m^{-2} day^{-1}) CGR150 at low plant density of 45cm (Ali *et al.* 2009).

Table 4.14: Crop growth rate (g m^{-2} d^{-1}) at different interval days in cotton genotypes under different plant spacings.

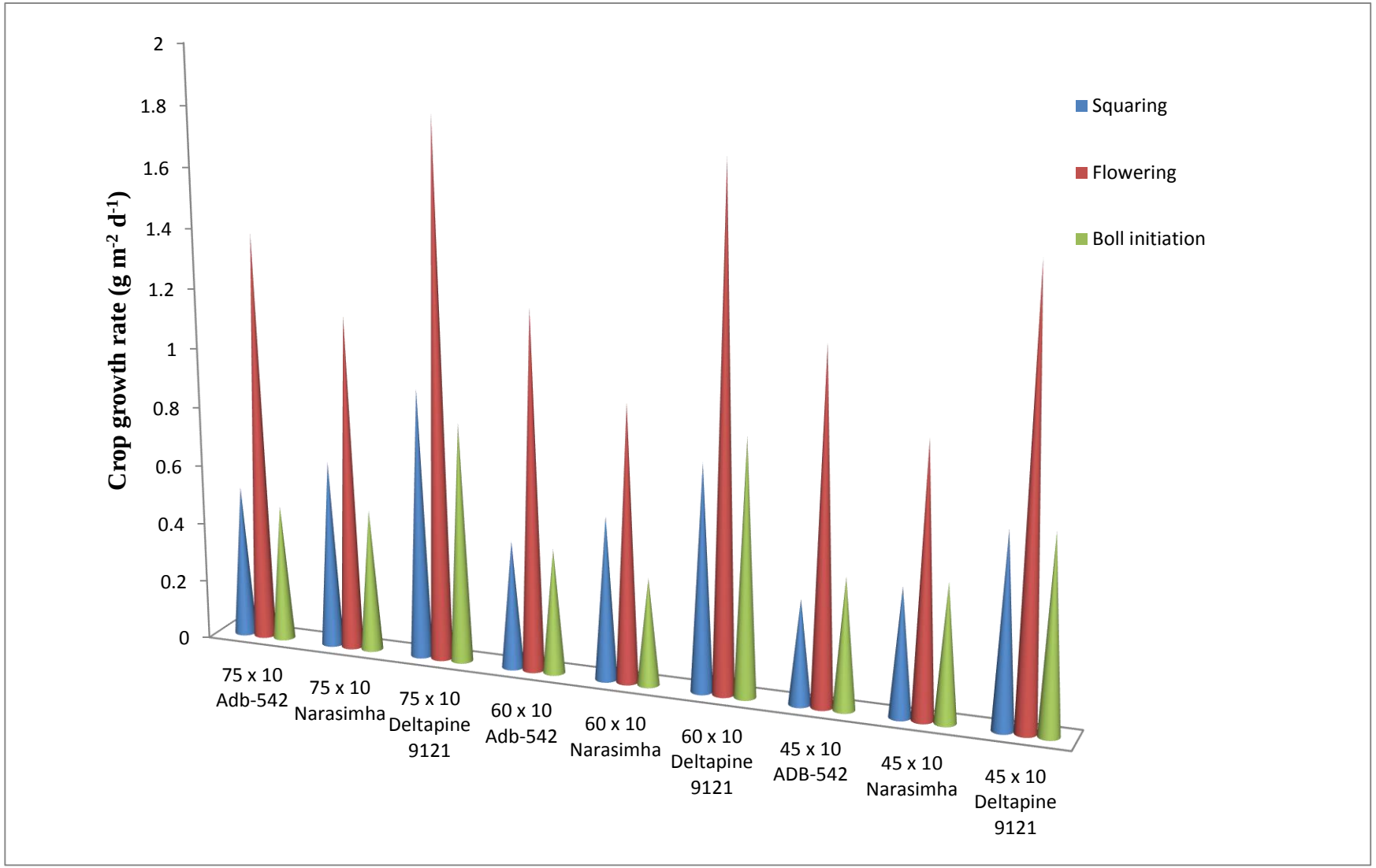
40-60 DAS					60-90 DAS					90-120 DAS				
Spacings	Genotypes			Mean	Spacings	Genotypes			Mean	Spacings	Genotypes			Mean
	G_1	G_2	G_3			G_1	G_2	G_3			G_1	G_2	G_3	
S_1	0.51	0.63	0.91	0.68	S_1	1.38	1.13	1.81	1.44	S_1	0.46	0.48	0.81	0.58
S_2	0.43	0.55	0.76	0.58	S_2	1.23	0.93	1.73	1.30	S_2	0.42	0.36	0.86	0.55
S_3	0.35	0.43	0.65	0.48	S_3	1.18	0.91	1.49	1.19	S_3	0.44	0.46	0.66	0.52
Mean	0.43	0.54	0.78		Mean	1.26	0.99	1.68		Mean	0.44	0.43	0.77	

Comparison	Std. Error	C.D.
Si – Sj	0.003	0.014
Gi – Gj	0.003	0.010
SiGi – SiGj	0.005	0.017
SiGi – SjGi	0.006	0.020

Comparison	Std. Error	C.D.
Si – Sj	0.005	0.019
Gi – Gj	0.007	0.023
SiGi – SiGj	0.013	0.040
SiGi – SjGi	0.011	0.038

Comparison	Std. Error	C.D.
Si – Sj	0.001	0.004
Gi – Gj	0.004	0.012
SiGi – SiGj	0.007	0.021
SiGi – SjGi	0.005	0.018

Fig. 4.8: Crop growth rate (g m^{-2} d^{-1}) at different interval days in cotton genotypes under different plant spacings.



4.5.2 Relative growth rate (RGR) (g g^{-1} d^{-1})

Relative growth rate (RGR) is the growth rate relative to the size of the population. It is also called the exponential growth rate or the continuous growth rate. RGR is a measure used to quantify the speed of plant growth. It is measured as the mass increase per above ground biomass per day. It is considered to be the most widely used way of estimating plant growth.

Relative growth rate per plant was significantly influenced by different high density plant spacings and genotypes (Table 4.15). At 40-60 DAS maximum relative growth rate was recorded with 60 x 10 cm spacing in genotype Narasimha (0.037 g g^{-1} d^{-1}). At 60-90 DAS maximum relative growth rate was also recorded at 45 x 10 cm spacing in the genotype ADB-542 (0.042 g g^{-1} d^{-1}). At 90-120 DAS relative growth rate does not show the similar trend as in square and flower formation. At 60 x 10 cm spacing in the genotype Deltapine 9121 maximum relative growth rate was recorded (0.013 g g^{-1} d^{-1}) at 90-120 DAS. Early sown crop (10-May) showed the maximum (4.6 g g^{-1} d^{-1}) relative growth rate after 50 days (RGR50) at high plant density of 15 cm. 20-June, sowing showed the highest relative growth rate (RGR100) at all plant spacings (1.4 g g^{-1} d^{-1} at 15 cm, 1.6 g g^{-1} d^{-1} at 30 cm and 1.5 g g^{-1} d^{-1} at 45 cm spacing respectively) while crop sowing on 1-June showed the maximum (0.1 g g^{-1} d^{-1}) relative growth rate after 150 days (RGR150) at plant spacing of 15cm (Ali *et al.* 2009). RGR was altered significantly by the cultivars and nitrogen fertilizer throughout the crop growth. 160 kg nitrogen ha^{-1} treatment produced significantly the maximum RGR (6.0 g m^{-2} day^{-1}) against control treatment from seedling emergence to the crop final harvest while, the RGR was maximum after 90 DAS and then continuously decreased till crop harvest. As compared to CIM-506 and CIM-534, cultivar CIM-496 appeared with the maximum value of RGR (0.04 g g^{-1} d^{-1} @ 30 DAS, 0.06 g g^{-1} d^{-1} @ 60 DAS,).062 g g^{-1} d^{-1} @ 90 DAS, 0.055 g g^{-1} d^{-1} @ 120 DAS and 0.02 g g^{-1} d^{-1} @ 150 DAS) throughout the crop growing period (Hameed *et al.* 2013). Relative growth rate was positively correlated with plant spacings and genotypes. Maximum RGR (0.014 g g^{-1} d^{-1} $plant^{-1}$ at 120 DAE, 0.025 g g^{-1} d^{-1} $plant^{-1}$ at 150 DAE) was recorded with wider row spacing of 90 x 60 cm and minimum RGR (0.009 g g^{-1} d^{-1} $plant^{-1}$ at 120 DAE, 0.019 g g^{-1} d^{-1} $plant^{-1}$ at 150 DAE) with closer row spacing of 60 x 60 cm (Shukla *et al.* 2013).

Table 4.15: Relative growth rate (g g^{-1} d^{-1}) at different interval days in cotton genotypes under different plant spacings.

40-60 DAS					60-90 DAS					90-120 DAS				
Spacings	Genotypes			Mean	Spacings	Genotypes			Mean	Spacings	Genotypes			Mean
	G_1	G_2	G_3			G_1	G_2	G_3			G_1	G_2	G_3	
S_1	0.034	0.036	0.036	0.036	S_1	0.037	0.029	0.031	0.032	S_1	0.008	0.010	0.010	0.009
S_2	0.034	0.037	0.036	0.035	S_2	0.038	0.028	0.034	0.033	S_2	0.009	0.008	0.013	0.010
S_3	0.034	0.033	0.036	0.035	S_3	0.042	0.031	0.034	0.035	S_3	0.010	0.012	0.011	0.011
Mean	0.034	0.035	0.036		Mean	0.039	0.029	0.033		Mean	0.009	0.010	0.011	

Comparison	Std. Error	C.D.	Comparison	Std. Error	C.D.	Comparison	Std. Error	C.D.
Si – Sj	0.000	0.000	Si – Sj	0.000	0.000	Si – Sj	0.000	0.000
Gi – Gj	0.000	0.000	Gi – Gj	0.000	0.000	Gi – Gj	0.000	0.000
SiGi – SiGj	0.000	0.000	SiGi – SiGj	0.000	0.000	SiGi – SiGj	0.000	0.000
SiGi – SjGi	0.000	0.000	SiGi – SjGi	0.000	0.000	SiGi – SjGi	0.000	0.000

4.5.3 Net assimilation rate (NAR) (g cm^{-2} d^{-1})

A useful measure of the photosynthetic efficiency of plants is net assimilation rate. Singh *et al.* (2008) reported a negative correlation of net assimilation rate (NAR) with plant spacings. NAR was recorded maximum under normal (67.5 x 60 cm) row spacing (9.35 mg dm^{-2} day^{-1}) than wider (100 x 60 cm) row spacing (7.84 mg dm^{-2} day^{-1}).

Patil *et al.* (2002) reported increased NAR to 60 to 90 days after sowing. NAR per plant was significantly influenced by different high density plant spacings and genotypes (Table 4.16). At 40-60 DAS maximum net assimilation rate (0.001 g cm^{-2} d^{-1}) was recorded in 75 x 10 cm spacing in genotype Narasimha (0.001 g cm^{-2} d^{-1}), 60 x 10 cm spacing all the tested genotypes and in 45 x 10 cm spacing all the tested genotypes recorded the similar rate of assimilates. At 60-90 DAS maximum NAR (0.001 g cm^{-2} d^{-1}) was also recorded similar in all the tested spacings and genotypes. At 90-120 DAS NAR recorded was zero (0.000 g cm^{-2} d^{-1}) in all the tested spacings and genotypes.

Table 4.16: Net assimilation rate (g cm^{-2} d^{-1}) at different interval days in cotton genotypes under different plant spacings.

40-60 DAS					60-90 DAS					90-120 DAS				
Spacings	Genotypes			Mean	Spacings	Genotypes			Mean	Spacings	Genotypes			Mean
	G_1	G_2	G_3			G_1	G_2	G_3			G_1	G_2	G_3	
S_1	0.000	0.001	0.000	0.000	S_1	0.001	0.001	0.001	0.001	S_1	0.000	0.000	0.000	0.000
S_2	0.001	0.001	0.001	0.001	S_2	0.001	0.001	0.001	0.001	S_2	0.000	0.000	0.000	0.000
S_3	0.001	0.001	0.001	0.001	S_3	0.001	0.001	0.001	0.001	S_3	0.000	0.000	0.000	0.000
Mean	0.000	0.001	0.001		Mean	0.001	0.001	0.001		Mean	0.000	0.000	0.000	
Comparison	Std. Error		C.D.		Comparison	Std. Error		C.D.		Comparison	Std. Error		C.D.	
Si – Sj	0.000		0.000		Si – Sj	0.000		0.000		Si – Sj	0.000		0.000	
Gi – Gj	0.000		0.000		Gi – Gj	0.000		0.000		Gi – Gj	0.000		0.000	
SiGi – SiGj	0.000		0.000		SiGi – SiGj	0.000		0.000		SiGi – SiGj	0.000		0.000	
SiGi – SjGi	0.000		0.000		SiGi – SjGi	0.000		0.000		SiGi – SjGi	0.000		0.000	

4.5.4 Specific leaf area (SLA) (cm^2 g^{-1})

Specific leaf area can be used to estimate the reproductive strategy of a particular plant based upon light and moisture (humidity) levels, among other factors. Specific leaf area is one of the most widely accepted key leaf characteristics used during the study of leaf traits. Drought and water stress have varying effects on specific leaf area. In a variety of species, drought decreases specific leaf area. SLA is the one-sided area of a fresh leaf, divided by its oven-dry mass. SLA is frequently used in growth analysis because it is often positively related to potential RGR across species.

SLA per plant was significantly influenced by different high density plant spacings and genotypes (Table 4.17). At square stage maximum SLA was recorded with 75 x 10 cm spacing in genotype Deltapine 9121 (128 cm^2 g^{-1}). At flower formation stage also maximum specific leaf area was recorded at 75 x 10 cm spacing in the genotype Deltapine 9121 (127 cm^2 g^{-1}). At boll initiation stage specific leaf area showed the same trend as in square and flower formation. At 75 x 10 cm spacing in the genotype Deltapine 9121 maximum rate was recorded (128 cm^2 g^{-1}). The mean seasonal SLAs for the segments from the bottom to the top of the canopy were 26.2, 25.6, 20.9, 19.4, and 18.1 m^2 kg^{-1}. Except for the upper most segment, SLA increased from 43 to 90 days after emergence (DAE) and declined from 100 DAE. The decline coincided with boll maturation but also with canopy defoliation. It was possible to account for 93% of the variation in SLA for all segments by plotting SLA against light flux density within the cotton canopy (Reddy *et al.* 1989).

Table 4.17: Specific leaf area (cm^2 g^{-1}) at different growth stages of cotton genotypes under different plant spacings.

Square stage					Flower stage					Boll initiation stage				
Spacings	Genotypes			Mean	Spacings	Genotypes			Mean	Spacings	Genotypes			Mean
	G_1	G_2	G_3			G_1	G_2	G_3			G_1	G_2	G_3	
S_1	85	82	128	98	S_1	90	98	127	105	S_1	87	80	126	98
S_2	91	114	118	108	S_2	91	115	115	107	S_2	94	113	116	108
S_3	91	106	99	99	S_3	89	107	97	98	S_3	90	106	98	98
Mean	89	101	115		Mean	90	107	113		Mean	90	100	113	

Comparison	Std. Error	C.D.	Comparison	Std. Error	C.D.	Comparison	Std. Error	C.D.
Si – Sj	0.27	1.08	Si – Sj	0.19	0.77	Si – Sj	0.21	0.82
Gi – Gj	0.53	1.64	Gi – Gj	0.46	1.43	Gi – Gj	0.54	1.67
SiGi – SiGj	0.92	2.85	SiGi – SiGj	0.80	2.47	SiGi – SiGj	0.93	2.89
SiGi – SjGi	0.80	2.56	SiGi – SjGi	0.68	2.16	SiGi – SjGi	0.79	2.49

4.5.5 Specific leaf weight (SLW) (g cm^{-2})

The specific leaf weight (SLW, $g.cm^{-2}$) and its reciprocal, the specific leaf area (SLA, cm^2 g^{-1}), are key variables involved with or related to physiological processes occurring in the functioning of canopies. So leaves with lower SLA and/or higher SLW are thicker, while leaves with higher SLA and lower SLW are thinner. Leaf properties such as density, thickness, and chemical composition influence whole plant survival and metabolism.

SLW per plant was significantly influenced by different high density plant spacings and genotypes (Table 4.18). At square stage maximum specific leaf weight was recorded with 75 x 10 cm spacing in genotypes ADB-542 and Narasimha (0.012 g cm^{-2}). At flower formation stage maximum specific leaf weight was recorded at 75 x 10 cm, 60 x 10 cm and 45 x 10 cm spacing was similar in the genotype ADB-542 9121 (0.011 g cm^{-2}). At boll initiation stage maximum specific leaf weight was recorded at 75 x 10 cm spacing in the genotype Narasimha (0.012 g cm^{-2}). But for high yielding ability genotypes reported minimum specific leaf weight. Deltapine 9121 recorded minimum specific leaf weight throughout the crop growth period and it was recorded at 75 x 10 cm spacing. SLW recorded in Deltapine 9121 at square (0.008 g cm^{-2}), flower (0.008 g cm^{-2}) and boll initiation stage (0.008 g cm^{-2}) respectively. Singh *et al.* (2008) reported a negative correlation of specific leaf weight (SLW) with plant spacings. SLW was recorded maximum under normal (67.5 x 60 cm) row spacing (0.409 g dm^{-2}) than wider (100 x 60 cm) row spacing (0.363 g dm^{-2}). Ratnakumari *et al.*, (2012) reported higher yield of cotton due to specific leaf weight under rainfed condition. SLW at 60 DAS varied between 5.227-6.787 mg cm^{-2}. Maximum SLW at 60 DAS was recorded in cluster IV cotton variety and minimum in cluster VI. SLW at 120 DAS varied between 5.380-6.320 mg cm^{-2}. Maximum SLW at 120 DAS was recorded in cluster IV and minimum in cluster III (Haritha *et al.* 2014).

Table 4.18: Specific leaf weight (g cm^{-2}) at different growth stages of cotton genotypes under different plant spacings.

Square stage					Flower stage					Boll initiation stage				
Spacings	Genotypes			Mean	Spacings	Genotypes			Mean	Spacings	Genotypes			Mean
	G_1	G_2	G_3			G_1	G_2	G_3			G_1	G_2	G_3	
S_1	0.012	0.012	0.008	0.011	S_1	0.011	0.010	0.008	0.010	S_1	0.011	0.012	0.008	0.011
S_2	0.011	0.009	0.008	0.009	S_2	0.011	0.009	0.009	0.009	S_2	0.011	0.009	0.009	0.009
S_3	0.011	0.009	0.010	0.010	S_3	0.011	0.009	0.010	0.010	S_3	0.011	0.009	0.010	0.010
Mean	0.011	0.010	0.009		Mean	0.011	0.009	0.009		Mean	0.011	0.010	0.009	
Comparison	Std. Error		C.D.		Comparison	Std. Error		C.D.		Comparison	Std. Error		C.D.	
Si – Sj	0.000		0.000		Si – Sj	0.000		0.000		Si – Sj	0.000		0.000	
Gi – Gj	0.000		0.000		Gi – Gj	0.000		0.000		Gi – Gj	0.000		0.000	
SiGi – SiGj	0.000		0.000		SiGi – SiGj	0.000		0.000		SiGi – SiGj	0.000		0.000	
SiGi – SjGi	0.000		0.000		SiGi – SjGi	0.000		0.000		SiGi – SjGi	0.000		0.000	

4.6 Yield parameters

4.6.1 Number of bolls plant^{-1}

Number of bolls per plant was considered the first important contributor to seed cotton yield, followed by boll weight (Rauf *et al.* 2004). Alse and Jadhav (2011) reported green bolls per plant were significantly more in Dhroov *Bt* than Dhroov non *Bt*, Kashinath *Bt* and Nathbaba non *Bt.* Apparently better retention of early formed fruiting parts in Dhroov *Bt* has led to more efficient translocation of photosynthates into the reproductive sink component and consequently, the overall growth attainment got reduced in it as compared to other cultivar.

Number of bolls per plant was significantly influenced by different high density plant spacings and genotypes (Table in 4.19). Maximum number of bolls per plant (7.9) was recorded at wider row spacing of 75 x 10 cm spacing (1,33,333 plants ha^{-1}) in genotype Deltapine 9121 followed by ADB-542 (6.9) at same row spacing of 75 x 10 cm (1,33,333 plants ha^{-1}) and minimum number of bolls per plant (3.8) was recorded at closer spacing of 45 x 10 cm (2,22,222 plants ha^{-1}). The lowest plant density of 9,259 plants ha^{-1} recorded the maximum number of bolls per plant (32.87) compared to high plant density of 13,888 plants ha^{-1}, which recorded 30.78 bolls per plant. Direct seeding recorded a boll setting percentage of 30.29 as against 33.43 per cent under planting through poly bag seedlings (Rajakumar and Gurumurthy, 2008). *Bt* cotton genotypes recorded maximum total number of bolls per plant compared to non- *Bt* hybrid (Sudha *et al.* 2011).

4.6.2 Boll weight (g)

The *Bt* cotton hybrid produced significantly higher seed cotton yield in comparison to their respective non-*Bt* hybrids and local check. This increase in seed cotton yield might be due to more number of bolls per plant, boll weight per plant as compaired to local check (Nehra *et al*. 2004). The boll weight is major yield components in *G.hirsutum* cotton under rainfed condition (Singh *et al*. 1983). Khadi *et al.* (2008) reported that increase in lint yield because of increasing boll weight and boll number, which clearly indicated that *Bt* gene offers protection against boll worm damage and which in turn contributes to the development of a number of healthy bolls.

Boll weight was significantly influenced by different high density plant spacings and genotypes (Table in 4.20, fig 4.9). Maximum boll weight (2.90 g) was recorded at

wider row spacing of 75 x 10 cm spacing in genotype Deltapine 9121 followed by 2.57 g in the row spacing of 60 x 10 cm in the same genotype Deltapine 9121 and minimum boll weight (1.48 g) was recorded in Narasimha at closer spacing of 45 x 10 cm. Jadhav *et al.* (2015) reported boll weight was significantly influenced by plant geometries. Maximum boll weight (3.48 g) was recorded in wider spacing of 150 x 36 cm, followed by (3.28 g) in 120 x 45 cm and the minimum boll weight (3.10 g) recorded in 180 x 30 cm. The multiple regression and path analysis studies revealed that picked bolls and boll weight was more beneficial in increasing the seed cotton yield of MECH-184 Bt (Tayade *et al.* 2011).

4.6.3 Seed cotton yield (kg ha^{-1})

The yield components of cotton in its simplest form consist of two main components: viz., number of bolls per unit area and the weight of the bolls. The components of yield can be further considered as number of seeds/acre multiplied by the weight of fiber per seed. High seed cotton yield of upland cotton (*G.hirsutum L.*) genotypes was related to higher fruiting coefficient, medium leaf area, optimum amount of dry matter, low to medium photosynthetic rate and high to medium boll number and boll weight (Bharadwaj *et al*. 1971).

Higher yield per ha was supported by higher yield per plant. Yield ranged between 179.03 g per plant (JK-CH 99 *Bt*) to 114.81 g per plant (DCH-32) (Joshi *et al*., 2011). Seed cotton yield (g) per plant (or) seed cotton yield (kg) per plot (or) seed cotton yield kg ha^{-1} was significantly influenced by different high density plant spacings and genotypes (Table 4.21). Maximum seed cotton yield was recorded at wider row spacing of 75 x 10 cm in genotype Deltapine 9121 (23.17 g plant^{-1}, 5.2 kg plot^{-1} and 2888 kg ha^{-1}) and minimum seed cotton yield was recorded at closer row spacing of 45 x 10 cm in genotype Narasimha (5.63 g plant^{-1}, 2.09 kg plot^{-1} and 1160 kg ha^{-1}). Aziz *et al.* (2011) reported maximum seed cotton yield of 2.93 ton ha^{-1} for all the genotypes when the spacing was 75 × 45 cm. Minimum cotton yield (0.96 ton ha^{-1}) was obtained in genotype with 90 × 45 cm spacing. Singh *et al.* (2012) reported a positive correlation of seed cotton yield with plant geometries. Maximum seed cotton yield (2387 kg ha^{-1}) was recorded at wider spacing of 67.5 x 90 cm and minimum seed cotton yield (2218 kg ha^{-1}) with closer spacing of 67.5 x 75 cm. Venugopalan *et al.* (2014) reported 25-30% high yield over the recommended spacing on shallow to medium deep soils under rainfed condition at high densities viz., 1.5 to 2.5 lakh plants ha^{-1} at 45 or 60 cm spacing depending upon the soil type.

Table 4.19: Number of bolls per plant in cotton genotypes under different plant spacings.

Spacings	Genotypes			Mean
	G_1	G_2	G_3	
S_1	6.9	5.7	7.9	6.86
S_2	5.4	4.8	6.0	5.4
S_3	4.2	3.8	4.6	4.2
Mean	5.5	4.7	6.1	

Comparison	Std. Error	C.D.
Si – Sj	0.03	0.15
Gi – Gj	0.01	0.04
SiGi – SiGj	0.02	0.06
SiGi – SjGi	0.04	0.16

Table 4.20: Boll weights (g) of cotton genotypes under different plant spacings.

Spacings	Genotypes			Mean
	G_1	G_2	G_3	
S_1	2.40	2.24	2.90	2.51
S_2	2.10	1.95	2.57	2.20
S_3	1.68	1.48	2.14	1.76
Mean	2.06	1.89	2.53	

Comparison	Std. Error	C.D.
Si – Sj	0.007	0.030
Gi – Gj	0.004	0.015
SiGi – SiGj	0.008	0.026
SiGi – SjGi	0.010	0.036

Fig. 4.9: Boll weights (g) of cotton genotypes under different plant spacings.

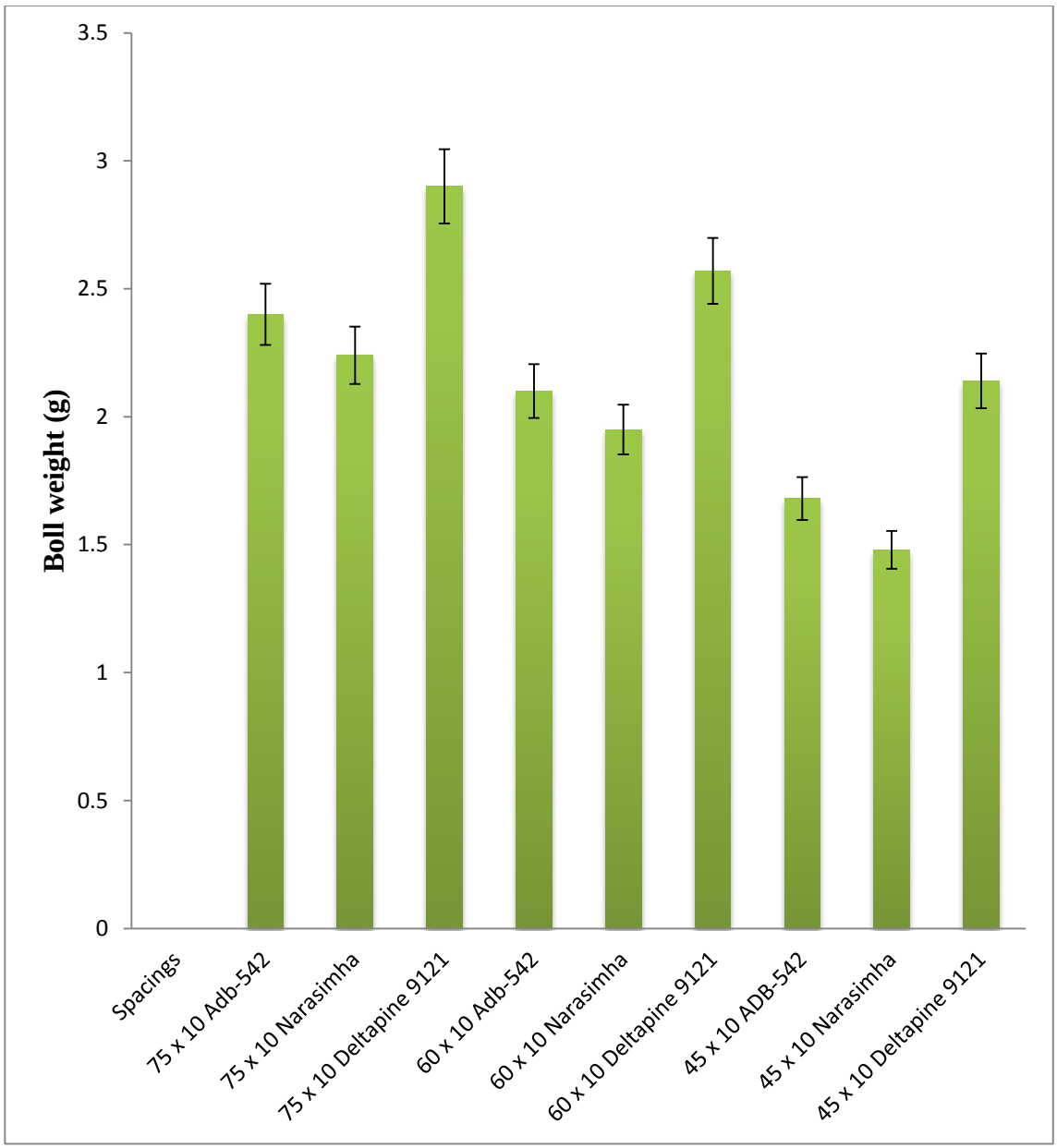


Table 4.21: Seed cotton yield (kg ha^{-1}) of cotton genotypes under different plant spacings.

Seed cotton yield (g) plant^{-1}				
Spacings	Genotypes			Mean
	G_1	G_2	G_3	
S_1	16.63	12.78	23.17	17.53
S_2	11.35	9.37	15.44	12.06
S_3	7.06	5.63	9.85	7.52
Mean	11.68	9.26	16.15	

Comparison	Std. Error	C.D.
Si – Sj	0.25	0.98
Gi – Gj	0.11	0.34
SiGi – SiGj	0.19	0.60
SiGi – SjGi	0.29	1.10

Seed cotton yield (kg) plot^{-1}				
Spacings	Genotypes			Mean
	G_1	G_2	G_3	
S_1	3.72	2.96	5.2	3.96
S_2	3.10	2.61	4.31	3.34
S_3	2.58	2.09	3.6	2.76
Mean	3.13	2.55	4.37	

Comparison	Std. Error	C.D.
Si – Sj	0.02	0.08
Gi – Gj	0.01	0.05
SiGi – SiGj	0.03	0.10
SiGi – SjGi	0.03	0.11

Seed cotton yield (kg ha^{-1})				
Spacings	Genotypes			Mean
	G_1	G_2	G_3	
S_1	2060	1644	2888	2197
S_2	1722	1450	2394	1855
S_3	1438	1160	2000	1533
Mean	1740	1418	2427	

Comparison	Std. Error	C.D.
Si – Sj	16.2	45.2
Gi – Gj	14.7	32.2
SiGi – SiGj	25.6	55.8
SiGi – SjGi	26.5	63.7

4.6.4 Lint yield (kg ha^{-1})

Lint yield was significantly related to open boll number at harvest. In a short-season environment, the retention of early squares and their development into open bolls was an important factor in lint yield production. Cotton in the fine-textured soils tends to produce larger lint yields compared with the cotton in the coarse-textured soils. Early-season meteorological conditions, which influenced square shedding and boll development, may have affected lint yields interactively with soil texture and irrigation.

Lint yield was significantly influenced by different high density plant spacings and genotypes (Table in 4.22). Maximum lint yield (826 kg ha^{-1}) was recorded at wider row spacing of 75 x 10 cm spacing in genotype Deltapine 9121. By decreasing row spacing lint yield was also decreased. Minimum lint yield (332 kg ha^{-1}) was recorded in Narasimha at closer spacing of 45 x 10 cm. Singh *et al.* (2012) reported a positive correlation of lint yield with plant geometries. Maximum lint yield (823.3 kg ha^{-1}) was recorded at wider spacing of 67.5 x 90 cm and minimum lint yield (761.1 kg ha^{-1}) with closer spacing of 67.5 x 75 cm. Negative correlation of lint yield with plant geometries was recorded. Maximum lint yield (777.8 kg ha^{-1}) was recorded at closer spacing of 67.5 x 60 cm and minimum lint yield (684.6 kg ha^{-1}) with wider spacing of 67.5 x 75 cm (Singh *et al.* 2015). Lint yield was negatively correlated with plant spacings but the NPK levels were positively correlated. Maximum lint yield (345 kg ha^{-1}) was recorded in closer pacing of 60 x 60 cm, but in wider spacing of 90 x 60 cm lint yield was minimum (301 kg ha^{-1}).

4.6.4 Seed index (g)

Lint yield showed a significant effect of spacings and genotypes on the seed index. Seed index varied from 7.14-7.50 g between the spacings and among the genotypes varied between 7.34-7.39 g. Maximum seed index (7.50 g) was recorded at closer spacing of 90 x 60 cm followed by 7.47 g was in 120 x 45 cm and minimum seed index (7.14 g) in wider spacing of 180 x 30 cm. While, in genotypes Ajit 155 *Bt* recorded maximum seed index (7.39 g) followed by Bunny *Bt* (7.36 g) and RCH 2 *Bt* was recorded minimum (7.34 g) (Pendharkar *et al.* 2010). Singh *et al.* (2014) reported lint yield of hybrid *Bt* cotton to be significantly affected by inter cropping systems under different plant spacings. Maximum seed index (8.30 g) was recorded in sole *Bt* cotton at 67.5 x 75 cm spacing and minimum seed index (7.88 g) was recorded in *Bt* cotton + fodder bajra (1:2) intercropping system at 135 x 37.5 cm spacing.

Seed index was significantly influenced by different high density plant spacings and genotypes (Table in 4.23). Maximum seed index (10.7 g) was recorded at wider row spacing of 75 x 10 cm spacing in genotype Deltapine 9121. By decreasing row spacing seed index was also decreased. Minimum seed index (7.6 g) was recorded in Narasimha at closer spacing of 45 x 10 cm. Seed index varied insignificantly among the different genotypes of cotton. Genotype CB-9 produced the maximum seed index (10.10 g) and minimum number of seed index (8.00 g) was recorded in BC-0406 genotype (Aziz *et al.* 2011). Bharathi *et al.* (2014) reported a significant effect of spacings and genotypes on the seed index. Seed index varied from 10.35-10.76 g between the spacings and among the genotypes varied between 10.46-10.62 g. Maximum seed index (10.76 g) was recorded at wider spacing of 120 x 60 cm and minimum seed index (10.46 g) in closer spacing of 90 x 45 cm. While, in genotypes NCS 145 *Bt* recorded maximum seed index (10.62 g) and NCS 145 non *Bt* recorded minimum (10.46 g).

Table 4.22: Lint yield (kg ha^{-1}) of cotton genotypes under different plant spacings.

Spacings	Genotypes			Mean
	G_1	G_2	G_3	
S_1	589	470	826	628
S_2	492	415	685	531
S_3	411	332	572	438
Mean	498	406	694	

Comparison	Std. Error	C.D.
Si – Sj	3.29	12.92
Gi – Gj	2.99	9.216
SiGi – SiGj	5.18	15.96
SiGi – SjGi	5.36	18.22

Table 4.23: Seed index (g) of cotton genotypes under different plant spacings.

Spacings	Genotypes			Mean
	G_1	G_2	G_3	
S_1	9.3	8.8	10.7	9.6
S_2	9.0	8.2	10.4	9.2
S_3	8.1	7.6	9.1	8.3
Mean	8.8	8.2	10.1	

Comparison	Std. Error	C.D.
Si – Sj	0.012	0.050
Gi – Gj	0.014	0.045
SiGi – SiGj	0.025	0.079
SiGi – SjGi	0.024	0.081

CHAPTER-V

SUMMARY AND CONCLUSSION

CHAPTER V

SUMMARY AND CONCLUSIONS

The present investigation on “Identification of cotton growth stages and growth pattern studies in cotton genotypes” was under taken with three objectives viz., (i) to determine the duration for growth phases in cotton, (ii) to find out the requirement for photo induction of flowering to maturity and (iii) to find out the growth phases, yield attributes and yield. The research work was carried out at college farm, College of Agriculture, Professor Jayashankar Telangana State Agricultural University, Rajendranagar, Hyderabad during *kharif* season of 2015-16. The experiment laid out in split plot design, with three replications, three different plant spacings and three genotypes (two varieties and one hybrid). The results obtained are summarized here under :-

In respect of phenological observations earliness is desirable character. Earliness was recorded for stages viz., squaring, flowering, boll initiation and peak boll burst. For square initiation, spacings x genotypes interaction was found to be non significant. For this stage to appear among three different spacings, 42.1 to 43.1 days was required. Early squaring was recorded in 75 x 10 cm spacing. Genotypes initiated squaring in 41.1 to 43.4 days. Deltapine 9121 showed early squaring (41.1 days). For flower initiation spacings x genotypes interaction was also found to be non significant. Among three different spacings number of days required for flowering was 66.8 to 69.1. Early flowering was recorded in 75 x 10 cm spacing. Genotypes recorded flowering in 66.6 to 69.3 days. Deltapine 9121 showed early flowering (66.8 days). For boll initiation, spacings x genotypes interaction was also found to be non significant. For bolls to initiate among three different spacings, number of days required were 93.4 to 95.5. Early boll initiation was recorded in 75 x 10 cm spacing. Genotypes initiated bolls in 92.3 to 96.4 days. Deltapine 9121 showed early boll initiation. For boll burst, spacings x genotypes interaction recorded minimum days (114.0 days) in Deltapine 9121 at 75 x 10 cm spacing.

Growing degree-days are important to study the relationship between growth and temperature. It is desirable to have minimum GDD for attaining any growth stage. For attaining any stage, required GDD with respect of spacings x genotypes interaction was found to be non significant. For squaring, flowering and bolls initiation to appear among three different spacings number of GDD required was 740 to 756 for squaring,

1148 to 1185 for flowering and 1588 to 1622 for bolls initiation. Among all the tested spacings in 75 x 10 cm spacing required minimum GDD for attaining three growth stages. GDD required for genotypes for attaining squaring, flowering and bolls initiation was 722 to 762, 1144 to 1188 and 1570 to 1636 respectively. Among all the tested genotypes Deltapine 9121 required minimum GDD to attain the three growth stages.

Morphological parameters were recorded at square, flower and boll initiation stages. Spacings x genotypes interaction was significant. Deltapine 9121 at three growth stages recorded maximum plant height (32.6, 56.3 and 78.1 cm) in 75 x 10 cm spacing and Narasimha recorded minimum plant height (27.8, 38.0 and 48.3 cm) in 45 x 10 cm at boll initiation stage. Deltapine 9121 was found tall where as Narasimha remained dwarf.

Deltapine 9121 showed significantly maximum leaf area (1764, 2796 and 3489 cm^2) in 75 x 10 cm spacing while, Narasimha showed minimum leaf area (454, 641 and 773 cm^2) at boll initiation stage.

The number of monopodia, sympodia was counted at three growth stages. Deltapine 9121 showed significantly maximum number of monopodia at 75 x 10 cm spacing (2.0, 1.6 and 1.3). Deltapine 9121 showed significantly maximum number of sympodia at 75 x 10 cm spacing (13, 13.6 and 17.3). Narasimha at 45 x 10 cm spacing recorded minimum sympodia (10.3, 11.3 and 11.6)

Deltapine 9121 at 75 x 10 cm spacing recorded maximum dry matter production (17.2, 35.6 and 90.1 g). Thus these cotton hybrid under wider row spacing of 75 cm seem to more efficient as compared to other cotton genotypes under 60 and 45 cm row space.

Physiological parameters were recorded at square, flower and boll initiation stages. Spacings x genotypes interaction was significant. Deltapine 9121 at 75 x 10 cm spacing recorded maximum chlorophyll-a (1.02, 1.19 and 1.11 mg g^{-1}), chlorophyll-b (1.57, 1.96 and 1.77 mg g^{-1}), total chlorophyll (2.71, 3.29 and 3.11 mg g^{-1}) and carotenoids (0.41, 0.73 and 0.68 mg g^{-1}). Narasimha at 45 x 10 cm spacing recorded minimum chlorophyll-a (0.44, 0.55 and 0.43 mg g^{-1}), chlorophyll-b (0.35, 0.61 and 0.46 mg g^{-1}), total chlorophyll (0.93, 1.36 and 0.91 mg g^{-1}) and carotenoids (0.14, 0.30 and 0.20 mg g^{-1}).

SCMR values in Deltapine 9121 at 75 x 10 cm spacing were maximum (28.0, 29.4 and 39.2) and Narasimha at 45 x 10 cm spacing recorded minimum (18.4, 19.3 and 29.1).

Deltapine 9121 at 75 x 10 cm spacing recorded maximum photosynthetic rate (11.8, 19.7 and 23.6 μ mol CO_2 m^{-2} s^{-1}) and Narasimha at 45 x 10 cm spacing recorded minimum (6.8, 10.7 and 13.2 μ mol CO_2 m^{-2} s^{-1}).

Chlorophyll stability index (%) in Deltapine 9121 at 75 x 10 cm spacing recorded maximum (31, 47 and 49 %) and Narasimha at 45 x 10 cm spacing recorded minimum (18.3, 20.6 and 25.2 %).

Proline accumulation was maximum in Deltapine 9121 at 75 x 10 cm spacing (476, 693 and 933 μg g^{-1} fresh weight) at boll initiation stage. Narasimha recorded minimum at 45 x 10 cm spacing (163, 186 and 281 μg g^{-1} fresh weight).

From the study of plant growth parameters, the crop growth rate was minimum at initial stages. CGR was higher from 40-60 DAS to 60-90 DAS and then decreased 90-120 DAS among all the treatments. In general the CGR was maximum in Deltapine 9121 at 75 x 10 cm spacing. At peak period i.e. 60-90 DAS the CGR was significantly maximum in Deltapine 9121 at 75 x 10 cm spacing (1.81 g day^{-1}). In case of RGR was maximum at initial stages. Narasimha at 60 x 10 cm spacing showed maximum RGR i.e. 0.037 g g^{-1} day^{-1} at 40-60 DAS and also Narasimha at 45 x 10 cm spacing showed minimum RGR at this stage (0.033 g g^{-1} day^{-1}). In case of NAR it was maximum at initial stage and then on later it declined.). At 40-60 DAS maximum NAR (0.001 g cm^{-2} d^{-1}) was recorded in 75 x 10 cm spacing in genotype Narasimha (0.001 g cm^{-2} d^{-1}), 60 x 10 cm spacing all the tested genotypes and in 45 x 10 cm spacing all the tested genotypes recorded the similar rate of assimilates. SLA was minimum at initial stage and increased in later subsequent growth stages. Maximum SLA was recorded in Deltapine 9121 at 75 x 10 cm spacing (126 cm^2 g^{-1}) and minimum in Narasimha at 75 x 10 cm spacing (80 cm^2 g^{-1}) at 90 DAS. SLW was maximum in Narasimha at 75 x 10 cm spacing (0.012 g cm^{-2}) and minimum in Deltapine 9121 at 75 x 10 cm spacing (0.008 g cm^{-2}) at 90 DAS.

Seed cotton yield and its attributing characters revealed that number of boll ranged in between 3.8-7.9. Deltapine 9121 at 75 x 10 cm spacing recorded maximum number of bolls (7.9) and consequently gave maximum seed cotton yield. Boll weight

ranged from 1.48 to 2.90 g in different treatments. Maximum boll weight recorded in Deltapine 9121 at 75 x 10 cm spacing i.e. 2.90 g. Seed cotton yield per plant varied from 5.63 to 23.17 g plant^{-1}. Maximum seed cotton yield was recorded by Deltapine 9121 at 75 x 10 cm spacing (23.17 g plant^{-1}).

Lint yield varied from 332 to 826 kg ha^{-1}. Maximum lint yield was found in Deltapine 9121 at 75 x 10 cm spacing and minimum lint yield was found in Narasimha at 45 x 10 cm spacing. Seed index varied from 7.6 to 10.7 g. Maximum seed index was found in Deltapine 9121 at 75 x 10 cm spacing (10.7 g) and minimum seed index was found in Narasimha at 45 x 10 cm spacing (7.6 g).

Deltapine 9121 at 75 x 10 cm spacing recorded maximum yield. It was attributed to the increase in the characters viz. plant height, leaf area, number of sympodia, dry matter production per plant, leaf pigments, SCMR, photosynthetic rate, chlorophyll stability index, proline accumulation, number of bolls per plant and boll weight.

Table 5.1: Summary table of response of genotypes and spacings on various plant characters.

S.No	Character	Spacing	Genotype	Interaction	Value	Value
1	Days to squaring	75 x 10	Deltapine	NS	41.1 G	42.1 S
2	Days to flowering	75 x 10	Deltapine	NS	66.6 G	66.8 S
3	Days to boll	75 x 10	Deltapine	NS	92.3 G	93.4 S
4	Days to boll burst	75 x 10	Deltapine	Significant		114
5	GDD for	75 x 10	Deltapine	NS	722	740
6	GDD for	75 x 10	Deltapine	NS	1144	1148
7	GDD for boll	75 x 10	Deltapine	NS	1570	1588
8	Plant height	75 x 10	Deltapine	Significant		78.1
9	Leaf area	75 x 10	Deltapine	Significant		3489
10	Monopodia	75 x 10	Deltapine	Significant		1.3
11	Sympodia	75 x 10	Deltapine	Significant		17.3
12	Dry matter	75 x 10	Deltapine	Significant		90.1

13	Total chlorophyll	75 x 10	Deltapine	Significant		3.11
14	SCMR	75 x 10	Deltapine	Significant		39.2
15	Photosynthetic	75 x 10	Deltapine	Significant		23.6
16	CSI	75 x 10	Deltapine	Significant		42
17	Proline	75 x 10	Deltapine	Significant		933
18	CGR	75 x 10	Deltapine	Significant		1.81
19	RGR	60 x 10	Narasimha	Significant		0.037
20	NAR	75 x 10	Deltapine	Significant		0.0008
21	SLA	75 x 10	Deltapine	Significant		126
22	SLW	75 x 10	Narasimha	Significant		0.012
23	Boll num	75 x 10	Deltapine	Significant		7.9
24	Boll weight	75 x 10	Deltapine	Significant		2.90
25	Seed cotton yield	75 x 10	Deltapine	Significant		23.17
26	Lint yield	75 x 10	Deltapine	Significant		826
27	Seed index	75 x 10	Deltapine	Significant		10.7

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The pattern of 'Literature cited' presented above is in accordance with the guidelines' for thesis presentation for Professor Jayashankar Telangana State Agricultural University, Hyderabad.

APPENDIX

APPENDIX- A

MONTHLY METEOROLOGICAL DATA RECORDED AT ARI, RAJENDRANAGAR 2015-2016

Standard Week	Temperature (°C)		Relative Humidity (%)		Rainfall (mm)	Rainy days	Sunshine hours	Wind Speed (km/hr)	Evaporation rate Total (mm/day)
	Max.	Min.	High	Low					
14-20 JULY	33.1	23.6	84	58	2.6	0.0	7.1	8.5	6.0
21-27	32.4	23.5	79	51	1.0	0.0	5.0	11.0	6.4
28-3 AUG	33.6	22.7	79	46	1.1	0.0	8.4	9.7	7.8
4-10	31.5	23.9	84	59	1.6	0.0	4.1	7.1	5.7
11-17	30.4	22.5	89	71	4.3	1.0	3.0	4.7	3.6
18-24	31.6	22.7	92	67	7.1	0.0	4.9	2.7	4.5
25-31AUG	30.3	22.1	85	65	4.1	0.0	4.9	3.2	5.4
1-7 SEP	32.8	23.1	84	55	2.5	0.0	7.4	2.5	5.7
8-14	30.4	22.0	95	81	6.9	0.0	3.3	0.9	3.1
15-21	28.9	22.4	92	72	14.4	1.0	2.4	1.3	3.0
22-28	31.9	22.1	89	54	0.0	0.0	7.2	0.2	4.3
29-5 OCT	31.2	21.9	95	63	5.2	0.0	5.4	0.2	3.5
6-12	32.7	20.1	90	40	0.0	0.0	7.8	0.2	4.3
13-19	33.1	19.4	91	41	0.0	0.0	8.2	0.2	4.2
20-26	32.8	18.1	91	40	0.0	0.0	9.3	1.8	5.1
27-2 NOV	31.4	19.9	89	50	2.6	0.0	7.5	1.6	3.9
3-9	31.6	18.1	93	62	0.0	0.0	8.0	1.3	4.1
10-16	30.9	16.0	86	64	0.0	0.0	7.4	2.8	4.4
17-23	28.4	18.8	81	54	0.1	0.0	5.0	1.9	3.6
24-30 NOV	30.6	17.1	89	44	0.0	0.0	8.8	0.6	4.0