CHAPTER II

REVIEW OF LITERATURE

Cotton, the most important commercial crop playing a key role in economic and social affairs of the world, continues to be acclaimed as 'king of fibres'. Cultivation of cotton is highly labour intensive, particularly for picking. In most of the developing countries, especially in India cost on labour hiring is swiftly escalating. The mechanization in cotton production will definitely play a key role by keeping the expenditure under control. High density planting system in cotton coupled with mechanization by boosting the production due to synchronized maturity, enabled mechanized picking. Thus, an attempt has been made through this study to check the influence of the mechanization in cotton with high density planting. In this backdrop, an attempt is made here to review the existing literature on cotton mechanization and its crop geometry under relevant headings. The present review has been confined to recent advances in high density planting system and mechanization in particular.

2.1. HIGH DENSITY PLANTING

The concept of high density cotton planting, more popularly known as Ultra Narrow Row (UNR) cotton was initiated by Briggs et al. (1967). The UNR system is popular in several countries like Brazil, China, Australia, Spain, Uzbekistan, Argentina and the USA. The availability of compact genotypes, acceptance of weed and pest management technologies including transgenics, development of stripper harvesting machines and widespread application of growth regulators have made this high density cotton production systems successful in these countries (Rossi et al., 2004).
The major advantage of the UNR cotton plants is, it produces less number of bolls/plant but retain a higher percentage of the total number of bolls in the first sympodial position and a lower percentage in the second position than conventionally planted cotton (Vories and Glover, 2006). The other advantages include better light interception; efficient leaf area development and early canopy closure and reduced competitiveness with weeds (Wright et al., 2011). In addition, plants under closer spacing produced significantly more seed cotton yield, crop productivity and profitability over wider plant spacing (Raut et al., 2005; Sisodia and Khamparia, 2007 and Shukla et al., 2013).

Thus, the high density planting system (HDPS) is now being conceived as an alternate production system having a potential for improving the productivity and profitability, increasing input use efficiency, reducing input costs and minimizing the risks associated with the current cotton production system in India.

2.1.1. Effect of crop geometry on cotton

A proper spacing between plants and rows is a key agronomic factor to optimize the crop profit (Zaxosa et al., 2012). Any manipulations in crop geometry and planting density should be viewed as a time tested agronomic technique to get higher yield and profit (Venugopal et al., 2013). Plant density directly influences the radiation interception, moisture availability, wind movement and humidity (Heitholt et al., 1992) that in turn affects the canopy height, branching pattern, fruiting behavior, crop maturity and yield. Adequate plant density facilitates the efficient use of applied fertilizers and irrigation (Abbas, 2000). So, establishment of an appropriate plant stand is of paramount importance to obtain high yields as lower plant density would result in wastage of resources (Brodrick et al., 2013).

2.1.1.1. Effect of crop geometry on growth parameters

2.1.1.1.1. Plant height

Jost and Cothren (2000) observed that cotton sowed with row spacing of 101 cm (9.9 plant/m²) recorded taller plants of 77.5 cm than other row spacings of 76, 19 cm and 38 cm in clay soil of Stoneville. Brar et al. (2002) reported that the plant height was significantly low at 67.5 cm x 45 cm spacing (117.9 cm) than 67.5 cm x 15 cm (127.8 cm)
and 67.5 cm x 30 cm (124.5 cm) in Ludhiana, Punjab. Deol and Brar (2003) observed that significantly higher plant height in spacings of 70 cm x 20 cm (131.5 cm) than 100 cm x 20 cm (129.3 cm) under clay loam soil of Ludhiana, Punjab. This higher plant height under narrow spacing was due to more competition among plants for natural resources.

Nichols et al. (2004) found that cotton height prior to harvest was approximately 11 cm less in the 25 and 38 cm row spacing than the 101 cm row spacing in one of the two years in very fine sandy loam soil, Stoneville. Pettigrew and Johnson (2005) reported that plant height was not influenced by various plant densities of 7, 9, 11, or 13 plants/ m². Ram and Giri (2006) revealed that higher plant density of 5555 plants/ha (60 cm x 30 cm spacing) produced significantly more plant height (83.11 cm) than lower plant densities (37037 and 27777 plants/ha) which recorded 80.40 and 77.61 cm of plant height in clay soil of Parbhani, Maharashtra under rainfed condition.

Sisodia and Khamparia (2007) registered closer spacing of 45 cm x 45 cm resulted in taller plants than wider spacings of 60 cm x 45 cm and 60 cm x 60 cm under rainfed condition in Madhya Pradesh. Bhalerao et al. (2008) observed that taller plants were recorded (114.3 cm) with spacing of 90 cm x 90 cm than 90 cm x 120 cm (114.0 cm), 90 cm x 45 cm (105.5 cm) and 90 cm x 60 cm (105.3 cm) under rainfed condition in clayey soil of Akola, Maharashtra. Aruna and Reddy (2009) reported no significant difference in plant height with plant geometry of 120 cm x 90 cm (88.2 cm), 90 cm x 90 cm (88.7 cm), 90 cm x 60 cm (88.7 cm) and 90 cm x 45 cm (88.6 cm) under vertisols of Nandyal, Andra Pradesh.

Bhalerao et al. (2010) opined that under rainfed condition, maximum plant height (78.1 cm) was observed with closer spacing (60 cm x 30 cm) than wider spacing (60 cm x 45 cm) which recorded 76.0 cm of plant height in deep black cotton soil of Akola, Maharashtra. Lower plant population (18,518 plants/ha) with 90 cm x 60 cm spacing recorded significantly higher plant height (115.1 cm) over higher plant densities (44,444 plants/ha) with 75 cm x 30 cm spacing and 55,555 plants/ha with 60 cm x 30 cm and 90 cm x 20 cm spacing under dryland condition of Raichur, Karnataka (Manjunatha et al., 2010).

Ali et al. (2011) found that crop sown with 45 cm plant spacing tended to produce shorter plants (92.6 cm) while, taller plants were recorded with 15 cm plant spacing.
(99.7 cm) under silt loam soil of Pakistan. Maximum plant height (134.5 cm) was recorded with spacing of 90 cm x 90 cm than 90 cm x 45 cm (126.8 cm) and 120 cm x 60 cm (133.5 cm) in vertisols under rainfed conditions of Andhra Pradesh (Bharathi et al., 2012). Population level of 1,23,500 plants/ha gave taller plants of 95 cm than 74,100 and 9,880 plants/ha (83 cm and 89.17 cm) population levels (Aslam et al., 2013). Ghule et al. (2013) indicated that maximum plant height (67.7 cm) was recorded with 180 cm x 30 cm spacing than the other spacings of 120 cm x 45 cm (65.2 cm) and 90 cm x 60 cm (64.9 cm) under rainfed vertisol of Parbhani.

Significantly higher plant height (117.0 cm) was recorded with wider spacing of 120 cm x 60 cm (13,888 plants/ha) than closer spacing of 90 cm x 45 cm (24,691 plants/ha) which recorded 108.0 cm under rainfed vertisols, Guntur (Bharathi et al., 2014). Brar et al. (2015) reported that under sandy loam soil, plant geometry of 67.5 cm x 60 cm registered higher plant height (138.9 cm) than the plant geometry of 67.5 cm x 75 cm (136.4 cm) under irrigated condition of Ludhiana with intra hirsutum cultivars.

Munir et al. (2015) observed that narrow row spacing of 60 cm recorded higher (114 cm) plant height than the row spacing of 75 and 90 cm in loam soil of Pakistan. Paslawar et al. (2015) observed that the plant height was significantly higher in two year experimentation (71.3 and 70.9 cm) with narrow planting of 45 cm x 10 cm than the spacing of 45 cm x 15 cm (64.0 and 68.7 cm), 45 cm x 20 cm (62.5 and 66.9 cm) and 60 cm x 50 cm (61.0 and 62.9 cm) under rainfed situation in black cotton soil of Akola, Maharashtra.

Singh et al. (2015) reported that higher plant height (139.8 cm) was recorded in plant geometry of 67.5 cm x 60 cm over that of 67.5 cm x 75 cm (136.2 cm) under semi arid condition of Punjab. Killi et al. (2016) reported that narrow row spacing of 35 cm x 20 cm recorded higher plant height (67.4 cm) than the conventional row spacing of 70 cm x 20 cm (63.8 cm) in alluvial clay loam soil of Turkey. The plant height was higher with 60 cm x 30 cm at first picking (131.7 and 141.2 cm) than 90 cm x 60 cm (120.3 and 132.8 cm) in two year experimentation under sandy loam soil of Rajendranagar, Hyderabad (Nagender et al., 2017).
2.1.1.1.2. Dry matter production

Jost and Cothren (2000) observed that the narrow row spacing 19 cm recorded more vegetative biomass/m² than the wider spacings of 38.1, 76.2 and 101.6 cm in clay soil of Stonville, USA. Basanagouda and Patil (2007) indicated that under rainfed condition, dry matter production/plant was higher (50.4 g) with closer spacing of 60 cm x 15 cm at harvest stage than 60 cm x 10 cm (49.0 g) and 60 cm x 20 cm (49.5g), whereas, under irrigated condition higher dry matter production/plant was recorded with spacing of 60 cm x 25 cm (58.7 g) than closer spacing of 60 cm x 20 cm (57.7 and 58.1g) in Dharwad, Karnataka. In clay loam soils of Warangal, Reddy and Gopinath (2008) reported maximum drymatter with closer plant geometry of 90 cm x 30 cm, which was on par with 90 cm x 60 cm (3365 kg/ha) and significantly superior over 90 cm x 90 cm (2839 kg/ha).

Bhalerao et al. (2008) illustrated that dry matter production/plant was higher (127.1 g) with wider spacing 90 cm x 120 cm than closer spacings 90 cm x 90 cm (121.1 g), 90 cm x 60 cm (89.9 g) and 90 cm x 45 cm (81.2 g) under rainfed condition of Akola, Maharashtra. Bhalerao et al. (2010) observed that minimum dry matter production of 99.8 g/plant with closer spacing (60 cm x 30 cm) than 114.0 g/plant with wider spacing (60 cm x 45 cm) in medium deep black soils of Akola, Maharashtra. Manjunatha et al. (2010) revealed that lower plant population (18,518 plants/ha) with 90 cm x 60 cm spacing recorded significantly higher dry matter production (436.8 g/plant) over higher plant densities (44,444 plants/ha) with 75 cm x 30 cm spacing and 55,555 plants/ha with 60 cm x 30 and 90 cm x 20 cm spacings.

Wider spacing recorded higher dry matter production of 188.2 g/plant than closer spacing with 163.0 g/plant in sandy loamy soil of Haryana under irrigated condition (Kumar et al., 2011). Dong et al. (2012) found that the biological yield at high plant density (7.5 plants/m²) was 19.5 per cent greater than that at low plant density (3.0 plants/m²) in saline sandy loam soil of China. Shukla et al. (2013) registered higher dry matter production/ plant (84.4 g) with wider spacing of 90 cm x 60 cm than closer spacing of 60 cm x 60 cm which recorded 74.07 g of dry matter production/plant under rainfed condition of Akola, Maharashtra.
Plant geometry of 150 cm x 36 cm recorded significantly higher dry matter production (286.5 and 282.9 g/plant) than spacings 90 cm x 60 cm, 120 cm x 45 cm and 180 cm x 30 cm during two years of experimentation under irrigated condition of Parbhani (Jadhav et al., 2015). Paslawar et al. (2015) stated that higher dry matter production/plant (68.2 g) was recorded with wider spacing of 60 cm x 15 cm than narrow spacing of 45 cm x 10 cm (35.8 g), 45 cm x 15cm (42.9 g) and 45 cm x 20 cm (53.7 g) under rainfed vertisol of Akola, Maharashtra. Significantly more dry matter accumulation/plant of 298 g/plant was observed in 90 cm x 60 cm (18518 plants/ha) than 60 cm x 30 cm (55555 plants/ha) and 45 cm x 15 cm (148148 plants/ha) in sandy clay loam soil of Rajendranagar, Hyderabad (Nagender et al., 2017).

2.1.1.1.3. Number of monopodial branches/plant

Higher number of monopodial branches/plant (3.4/plant) was recorded with wider intra row spacing of 60 cm as compared to 45 cm (2.9/plant) and 30 cm (3.0/plant) plant spacing with an inter row spacing of 90 cm in clay loam soil under irrigated condition of Bathinda, Punjab, India (Buttar and Singh, 2007). High population coupled with closer spacing of 90 cm x 45 cm recorded more number of monopodial branches/plant (1.83/plant) than the low population with wider spacing of 90 cm x 60 cm (1.00/plant), 90 cm x 90 cm (0.70/plant) and 90 cm x 120 cm (1.00 /plant) under rainfed condition of Akola, Maharashtra (Bhalerao et al., 2008).

More number of monopodial branches (2.0/plant) was recorded with 90 cm row spacing, which was comparable with 75 cm row spacing, whereas, significantly less number of monopodial branches/plant (1.7) was recorded with 60 cm row spacing (Ahmad et al., 2010). Bhalerao et al. (2010) outlined that there was no significant difference between spacings of 60 cm x 30 cm and 60 cm x 45 cm with the number of monopodial branches/plant.

Stephenson et al. (2011) stated that the number of monopodial branches/plant increased (3, 2.1, 1.9, 1.6 and 1.4/plant) with decreasing plant density (7, 9, 11, 13 and 15 plants/m²) in silt loam soil under rainfed condition of Marianna. Dahiphale et al. (2012) observed that plant geometry of 120 cm x 45 cm recorded more number of monopodial branches/plant (1.4 at 60 DAS and 2.4 at 90 DAS) than closer spacing of 90 cm x 60 cm
(1.2 at 60 DAS and 1.9 at 90 DAS) and 180 cm x 30 cm (1.2 at 60 DAS and 2.0 at 90 DAS) plant geometries in clay soil, Parbhani.

Ganjir et al. (2013) revealed that higher monopodial branches/plant was recorded under lower plant densities wherein, higher number of monopodial branches/plant (2.1) was recorded in 60 cm x 30 cm (55,555 plants/ha) spacing and lesser number of monopodia/plant (1.4) was recorded in 60 cm x 10 cm (1,66,666 plants/ha) spacing. Bharathi et al. (2014) noted that closer spacing (90 cm x 45 cm) recorded less number of monopodial branches (1.1/plant) than wider spacing of 120 cm x 60 cm (1.4/plant) under rainfed vertisol of Gunter. Brar et al. (2015) reported that under sandy loam soil, wider spacing of 67.5 cm x 75 cm recorded more number of monopodial branches/plant (2.3) than closer spacing of 67.5 cm x 60 cm (2.0/plant) in Ludhiana.

Jadhav et al. (2015) recorded higher number of monopodial branches/plant (2.7 and 2.9) with 150 cm x 36 cm plant geometry as compared to plant geometries 90 cm x 60 cm (2.4 and 2.6 cm), 120 cm x 45 cm (2.5 and 2.7/plant) and 180 cm x 30 cm (2.5 x 2.4/plant) during two years of experimentation under irrigated condition of Parbhani. Singh et al. (2015) registered more number of monopodial branches/plant (1.6) in sandy loamy soil with wider spacing of 67.5 cm x 70 cm than closer spacing 67.5 cm x 60 cm (1.2/plant) in Punjab. Meena et al. (2017) stated that the higher monopodial branches (1.51/plant) was observed at sowing of 90 cm x 90 cm wider plant spacing over sowing of 90 cm x 60 cm (1.33/plant) and 90 cm x 45 cm (1.24/plant) closer plant spacing in sandy clay loam soil of Banswara, Rajasthan.

2.1.1.2. Effect of crop geometry on physiological parameters

2.1.1.2.1. Leaf area index and leaf area duration

Basanagouda and Patil (2007) enunciated that under rainfed condition, higher leaf area (18.7 dm²/plant) was recorded with spacing of 60 cm x 15 cm at harvest stage than 60 cm x 10 cm (16.9 dm²/plant) and 60 cm x 20 cm (17.2 dm²/plant) in Dharwad, Karnataka. Kumar (2009) observed that spacing of 67.5 cm x 60 cm produced maximum LAI (3.31) over 100 cm x 45 cm (3.02) and 100 cm x 60 cm (2.23) under loamy sand soil of Haryana. Significantly higher LAI (5.4) and leaf area duration (207.3) was recorded with plant population of 55,555 plants/ha with 60 cm x 30 cm spacing than spacing of
75 cm x 30 cm, 90 cm x 20 cm and 90 cm x 30 cm with cotton Bawny BG-II under rainfed condition in black soil of Raichur (Manjunatha et al., 2010).

Singh et al. (2011) observed that wider spacing of 100 cm x 60 cm significantly reduced the leaf area index by eight per cent than closer spacing of 67.5 cm x 60 cm in sandy loam soil of Modipuram, Meerut. Chukka (2012) found that wider plant geometry (180 cm x 30 cm) registered higher leaf area index of 1.07 than other plant geometries of 90 cm x 60 cm (1.03) and 120 cm x 45 cm (1.02) at 150 DAS under vertisol of Parbhani (Ghule et al., 2013). Shukla et al. (2013) illustrated that plants under closer spacing of 60 cm x 60 cm produced significantly higher LAI (1.50) due to less of horizontal space available for individual plant which was 31.3 per cent higher over wider spacing 90 cm x 60 cm which recorded 1.1 under rainfed condition of Akola, Maharashtra.

Closer plant spacing of 22.5 cm favored higher LAI (3.38) and LAD (299) as compared to wider plant spacings of 30 cm and 37.5 cm which recorded 3.07 and 2.76 of LAI and 266 and 237 of LAD, respectively in loamy soil of Pakistan (Munir, 2014). The highest LAI (4.2) was registered with dense plant population of 2.22 lakhs/ha than the plant population of 1.48 and 1.11 lakhs/ha under rainfed condition of Akola, Maharashtra (Paslawar et al., 2015). Nagender et al. (2017) observed that higher LAI (5.06) with the spacing of 45 cm x 15 cm (148148 plants/ha) and significantly superior to 60 cm x 30 cm (55555 plants/ha) and 90 cm x 60 cm (18518 plants/ha) in sandy loam soil of Rajendranagar, Hyderabad.

2.1.1.2.2. Physiological growth attributes

Higher values of physiological parameters like crop growth rate, relative growth rate, net assimilation rate and absolute growth rate indicate better growth and development of plant. Significantly higher net assimilation rate (0.044 g/dm²/day) and crop growth rate (20.6 g/m²/day) were recorded with plant population of 55,555 plants/ha with closer spacing of 60 cm x 30 cm than 75 cm x 30 cm, 90 cm x 20 cm and 90 cm x 30 cm under black soil of Raichur (Manjunatha et al., 2010).

Chukka (2012) observed that closer spacing of 90 cm x 30 cm with higher planting density of 37037 plants/ha recorded higher CGR (10.6 and 10.2 g/m²/day during 30-60 and 60-90 DAS, respectively) than 90 cm x 45 cm (24691 plants/ha) and 90 cm x
60 cm (18518 plants/ha) and the relative growth rate was significantly lower (0.017 g/g/day) with high density plant (90 cm x 45 cm) compared with that of low plant densities (90 cm x 30 and 90 cm x 60 cm) from 90-120 DAS in clay loam soil of Bapatla, Andhra Pradesh.

Shukla et al. (2013) stated that increased crop growth rate (0.399 and 1.355 g/day/plant) and relative growth rate (0.014 and 0.025 g/g/day/plant) were recorded with wider spacing of 90 cm x 60 cm than the closer spacing of 60 cm x 60 cm (CGR: 0.353 and 1.208 g/day/plant and RGR: 0.009 and 0.019 g/g/day/plant) at 120 and 150 DAS under rainfed condition of Akola, Maharashtra. The compact genotype of cotton Anjali, under closer spacing of 30 cm x 30 cm registered higher crop growth rate (8.78 g/m²/day) than the other spacings of 45 cm x 30 cm, 60 cm x 30 cm and 90 cm x 30 cm in Coimbatore, of Tamil Nadu, during winter irrigated season (Arunvenkatesh, 2013).

Munir (2014) reported that no significant difference in NAR between the plant spacing’s of 22.5, 30.0 and 37.5 cm and the higher mean CGR (7.07 g/m²/day) was recorded in close plant spacing (22.5 cm) compared to other plant spacings of 30.0 cm (6.61 g/m²/day) and 37.5 cm (5.74 g/m²/day) under loamy soil of Pakistan.

2.1.1.3. Effect of crop geometry on biochemical parameters

2.1.1.3.1. Chlorophyll index

Jahedi et al. (2013) reported that higher chlorophyll index (48.60) was recorded with closer row spacing of 30 cm, intermittent chlorophyll index (48.10) with medium row spacing of 50 cm and lesser chlorophyll index (47.40) was recorded under wider row spacing of 70 cm with cultivars Varamin, Khordad and Sepid under sandy loam soil of Gonabad.

Madhavi (2016) observed that plant density did not show any variation in chlorophyll index at 60 and 90 DAS but at 120 DAS significantly higher chlorophyll index (38.24) was recorded with 55,555 plants/ha (60 cm x 30 cm) than 111111 plants/ha (60 cm x 15 cm) and 148148 plants/ha (45 cm x 15 cm) recorded chlorophyll index of 35.03 and 35.77 in sandy loam soil of Rajendranagar, Hyderabad.

2.1.1.3.2. Light interception percentage
Close row spacing (19 to 25 cm) and high plant population in ultra rows lead to more rapid canopy closure than in wide rows (Robinson, 1993), which lead to increased light interception (Kreig, 1996). Jost and Cothren (2000) observed that canopy closure occurs more rapidly in the ultra-narrow row spacing (19 and 38.1 cm) than in the conventional row spacing (76.3 and 101.6 cm) in clay soil of Stoneville. Roche et al. (2003) found that the UNR crop reached maximum light interception earlier than the conventionally spaced crop.

Light penetration through a UNR cotton crop (25 cm row with 3,08,882 plants/ha) was reduced by over 70 per cent compared to wider row systems of 100 cm row with plant density of 10,000 plants/ha (Molin et al., 2004). Wilson (2006) revealed that greater light interception was observed in 38 cm rows relative to 97 cm rows. Reddy et al. (2009) opined that the cotton grown in 38 cm rows can close canopy early. Similarly, Singh et al. (2011) reported that narrow row spacing of 38 cm had higher canopy closure compared to wide row spacing, with 21, 12, 14, 10, 4 per cent higher canopy closure at 43, 58, 72, 84 and 98 days after sowing (DAS), respectively. Similarly, light interception at 43, 58, 72, 84 and 98 DAP was 17, 19, 15, 8 and per cent higher in 38 cm compared to 97 cm row spacings, respectively.

Arunvenkatesh (2013) reported that cotton with closer spacing of 30 x 30 cm recorded significantly higher light interception (84.4 per cent) at harvest stage than the spacing of 45 cm x 30 cm, 60 cm x 30 cm and 90 cm x 30 cm in winter irrigated cotton. The UNR treatment reached 80 per cent light interception 35 days earlier than the conventional spaced cotton in a semi-arid environment of north-west New South Wales, Australia (Brodrick et al., 2013).

2.1.1.4. Effect of crop geometry on earliness parameters

Saleem et al. (2009) observed that closer row spacing of 60 cm took lesser days (34.4, 43.7, 86.7 and 42.9 days) for appearance of first square, first flower, first boll open and boll maturation period than the row spacing of 75 and 90 cm of three cotton varieties NIAB-111, CIM-496 and FH-901 under sandy clay loam soil of Pakistan. Closer spacing (100 cm x 45 cm) recorded minimum days to 50 per cent flowering (73 days) and 50 per cent boll opening (119 days) than 100 cm x 60 cm recorded 85 days to 50 per cent
flowering and 144 days to 50 per cent boll opening in sandy loam soil of Hisar, Haryana (Kumar, 2009).

Chukka (2012) found that days to 50 per cent flowering was earlier (52.7 days) with the spacing of 90 cm x 30 cm (37037 plants/ha) than 90 cm x 45 cm (24691 plants/ha) and 90 cm x 60 cm (15818 plants/ha) both recorded 53.3 days in clay loam soil of Bapatla, Andhra Pradesh. Arunvenkatesh (2013) stated that closer spacing of 30 cm x 30 cm took lesser number of days (78.9 days) to attain 50 per cent flowering than 45 cm x 30 cm, 60 cm x 30 cm and 90 cm x 30 cm (80.5, 81.3 and 81.6 days) under clay loam soil at Coimbatore.

Akbar et al. (2015) reported that cotton cultivar MNH-886 with narrow row spacing (10 cm) started earlier (29.7 days) to square and flower initiation (53.2 days) than wider row spacing 20 and 30 cm (32.0 and 33.7 days for square initiation; 57.9 and 59.2 days for flower initiation) in Pakistan. Square and flower initiation started earlier by decreasing row width. Narrow rows (60 cm) started square initiation and flower initiation significantly earlier (29.0 and 49.1 days) than 75 cm (29.3 and 49.3 days) and 90 cm (29.6 and 49.5 days) row spacings in loamy soil, Pakistan (Munir et al., 2015).

2.1.1.5. Effect of crop geometry on yield attributes

2.1.1.5.1. Number of sympodial branches/plant

Higher number of sympodial branches/plant was registered with wider geometry (67.5 cm x 90 cm) which was 7.5 per cent higher over the narrow geometry (67.5 cm x 75 cm) (Narkhede et al., 2000). Nichols et al. (2004) reported that no significant difference in number of sympodial branches/plant between the row spacing’s of 25, 38 and 101 cm in very fine sandy loam soil at Stoneville. Bhalerao et al. (2008) illustrated that wider spacing 90 cm x 90 cm with population 12345 plants/ha recorded more number of symbodial branches/plant (24.4) than 90 cm x 120 cm with population 9,260 plants/ha (24.0), 90 cm x 60 cm with population 18,518 plants/ha (21.3) and 90 cm x 45 cm with population 24,691 plants/ha (20.4) under rainfed condition of Akola, Maharashtra. Manjunatha et al. (2010) observed that wider spacing (90 cm x 30 cm) recorded significantly more number of sympodial branches/plant (21.9) than the closer
spacings of 90 cm x 20 cm (19.1), 60 cm x 30 cm (19.8) and 75 cm x 30 cm (19.5) under medium black soil in Raichur, Karanataka.

Wider row spacing of 100 cm x 60 cm resulted in significant increased in sympodial branches/plant over recommended spacing of 67.5 cm x 60 cm in sandy loam soil, Haryana (Kumar et al., 2011). Alitabar et al. (2012) noticed higher number of sympodial branches (8.4/plant) with conventional row spacing (80 cm x 20 cm) than ultra-narrow row spacing (40 cm x 20 cm) which recorded 8.0 sympodial branches/plant in clay loam soil of Iran. Jahedi et al. (2013) observed that wider row spacing of 70 cm recorded higher number of sympodial branches (10.9/plant) than closer spacing of 30 and 50 cm which recorded 9.5 and 9.6 sympodial branches/plant under sandy loam soil of Gonabad. Bharathi et al. (2014) stated that closer spacing (90 cm x 45 cm) recorded lower sympodial branches of 18.7/plant than wider spacing (120 cm x 60 cm) which recorded 19.2 under rainfed vertisol in Guntur, Andra Pradesh.

Jadhav et al. (2015) observed that the number of sympodial branches/plant was effectively improved (30.9 and 37.5) by 150 cm x 36 cm plant geometry and it was significantly superior over the other plant geometries of 90 cm x 60 cm (27.8 and 34.3), 120 cm x 45 cm (28.1 and 34.9) and 180 cm x 30 cm (25.9 and 30.7) in the two years of experimentation under irrigated condition of Parbhani. Less number of sympodial branches/plant (8.2, 8.5 and 9.3) was observed under dense planting of 45 cm x 10 cm, 45 cm x 15 cm and 45 cm x 20 cm, whereas more number of sympodial branches/plant (11.2) was found under wider spacing (60 cm x 15 cm) under rainfed condition of Akola, Maharasra (Paslawar et al., 2015).

Gohil et al. (2016) observed that the maximum number of sympodial branches (22.0/plant) was obtained with the spacing of 120 cm x 60 cm than 120 cm x 45 cm (21.1/plant) and 120 cm x 30 cm (20.6/plant) under clayey soil of Surat. Similarly the higher number of sympodial branches/plant (19.6) was registered with wider spacing of 90 cm x 90 cm over than closer spacings of 90 cm x 60 cm (17.8/plant) and 90 cm x 45 cm (16.7/plant) in sandy clay loam soil of Banswara, Rajasthan (Meena et al., 2017). Nagender et al. (2017) registered higher number of sympodial branches (55/plant) with wider spacing of 90 cm x 60 cm (18518 plants/ha) than 60 cm x 30 cm (55555 plants/ha)
and 45 cm x 15 cm (148148 plants/ha) which recorded the lower number of sympodial branches (39 and 21/plant) in sandy loam soil of Rajendranagar, Hyderabad.

2.1.1.5.2. Number of bolls/plant

Jost and Cothren (2000) found that cotton plants grown in 19 cm row spacing had significantly less number of bolls/plant than all other row spacings (38.1, 76.2 and 101.6 cm) in clay soil, Stoneville. Enhanced number of bolls/plant under wider geometry (67.5 cm x 90 cm) recorded 7.5 per cent over that of narrow geometry (67.5 cm x 75 cm) in vertisols under rainfed condition (Narkhede et al., 2000). Kaur and Brar (2005) also recorded significantly higher number of bolls/plant with wider spacing (90 cm x 60 cm) as compared to narrow plant geometries (67.5 cm x 45 cm and 67.5 cm x 60 cm) under sandy loam soil of Ludhiana, Punjab under irrigated condition.

Significantly higher number of bolls/m² (119) was recorded with 38 cm rows, compared with 97 cm rows (107) in North Carolina with similar plant populations (Wilson, 2006). Narayana et al. (2007) reported significantly higher number of bolls/plant with wider plant geometry (120 cm x 60 cm) than closer plant geometry (90 cm x 60 cm) under vertisols of Guntur. Significantly higher number of bolls/plant (37.9) was observed with wider spacing of 90 cm x 120 cm as compared to other spacings of 90 cm x 90 cm (28.0), 90 cm x 60 cm (23.5) and 90 cm x 45 cm (18.7) under rainfed condition of Akola, Maharashtra (Bhalerao et al., 2008).

Aruna and Reddy (2009) observed that more number of bolls/plant (49.8) was recorded with 90 cm x 90 cm spacing than other spacings of 90 cm x 60 cm (45.5), 90 cm x 45 (46.0) and 120 cm x 60 cm (44.7) under vertisols of Nandyal. Higher number of bolls/plant (14.2) was recorded with wider spacing of 60 cm x 45 cm than closer spacing of 60 cm x 30 cm (11.1) under rainfed condition of Akola, Maharashtra (Bhalerao et al., 2010). Significantly higher number of good opened bolls/plant (18.1) and total number of harvested bolls (27.6) were registered with lower plant population (90 cm x 60 cm) compared with higher population (60 cm x 30 cm) under vertisol of Raichur, Karnataka (Manjunatha et al., 2010).

Singh et al. (2011) found that number of bolls/plant was higher (26.9) with wider spacing of 100 cm x 60 cm than closer spacing of 67.5 cm x 60 cm (24.7/plant) in sandy
loam soils. Nehra and Yadav (2012) revealed that number of bolls/plant was decreased with increase in plant population per unit area in sandy loam soils of Sriganganagar, Rajasthan. Jahedi et al. (2013) observed that row spacing of 70 cm produced more number of bolls/plant (24.5) than row spacing of 30 cm (17.1) and 50 cm (20.0) in sandy loam soil of Gonabad.

Bharathi et al. (2014) reported that due to higher interplant competition, contribution of yield components as number of bolls/plant was lower (29.3) at closer spacing (90 cm x 45 cm) compared to wider spacing (120 cm x 60 cm) which recorded 35.3 number of bolls/plant under rainfed vertisol of Guntur. Plant geometry of 150 cm x 36 cm recorded higher bolls/plant (64.1 and 66.7) compared with other plant geometries (90 cm x 60 cm, 120 cm x 45 cm and 180 cm x 30 cm) during two year experiments under irrigated condition of Parbhani (Jadhav et al., 2015).

Paslawar et al. (2015) observed higher number of bolls/plant (10.0) was recorded with wider planting (60 cm x 15 cm) than dense planting of 45 cm x 10 cm, 45 cm x 15 cm and 45 cm x 20 cm (6.2, 7.2 and 8.1 bolls/plant)under rainfed condition of Akola in Maharatra. Singh (2015) reported that significantly higher number of bolls/plant (44.6) was recorded with plant geometry of 67.5 cm x 75 cm over that spacing of 67.5 cm x 60 cm (40.9) under sandy loamy soil of Punjab.

Killi et al. (2016) reported that there was no significant difference in the number of bolls/plant with conventional row spacing (70 cm x 20 cm) and narrow row spacing (35 cm x 20 cm) recorded 3.8 and 3.7 bolls/plant under alluvial clay loam of Turkey. Gohil et al. (2016) observed the maximum numbers of bolls/plant (36.2) was recorded with 120 cm x 60 cm plant geometry as compared to 120 cm x 45 cm (33.7 bolls/plant) and 120 cm x 30 cm (36.2 bolls/plant) due to less competition exerted for light, moisture and nutrients under clayey soil of Surat.

Significantly higher number of picked bolls/plant (15.6) was recorded with wider plant spacing of 45 cm x 30 cm than 45 cm x 15 cm and 45 cm x 22.5 cm under clay textured soil of Parbhani (Kumar et al., 2017). Meena et al. (2017) observed that higher number of bolls/plant (25.2) was obtained with wider spacing of 90 cm x 90 cm than
90 cm x 60 cm (22.2) and 90 cm x 45 cm (21.2) in sandy clay loam soil of Banswara, Rajasthan.

2.1.1.5.3. Boll weight

Clawson et al. (2006) found that individual boll weight was decreased by reduction in row spacing. Basanagouda and Patil (2007) reported that maximum boll weight (3.5 g) was recorded with the spacing of 60 cm x 15 cm than 60 cm x 10 cm (3.4 g) and 60 cm x 20 cm (3.5 g) under rainfed condition of Dharwad, Karnataka. Bhalerao et al. (2008) observed that increased boll weight (4.4 g) was recorded with closer spacing of 90 cm x 45 cm coupled with high population (24,691 plants/ha) than low population 18,518 plants/ha (4.3 g), 12,345 plants/ha (4.1 g) and 9260 plants/ha (4.1 g) under rainfed condition of Akola, Maharashtra.

No significant difference was observed in boll weight between different spacing which recorded 90 cm x 45 cm (4.1 g), 90 cm x 60 cm (4.2 g), 90 m x 90 cm (4.2 g) and 120 cm x 60 cm (4.1 g) under vertisols of Nandyal (Aruna and Reddy, 2009). Ahmad et al. (2010) reported that higher boll weight (3.2 g) was recorded in 90 cm spaced cotton, followed by 75 cm spaced rows, whereas, lower boll weight (2.9 g) was noted in 60 cm spaced cotton. Brodrick et al. (2010) found that boll size was 16.1 per cent smaller for ultra narrow rows (25 cm) compared with conventional row spacing (100 cm) in alkaline soil of New South Wales, Australia.

Ali et al. (2011) observed that crop sown with 45 cm plant spacing significantly produced higher boll weight (2.6 g) and lower boll weight was obtained with plant spacing of 15 cm (2.3 g) and 30 cm (2.4 g) in silt loam soil of Pakistan. Dong et al. (2012) illustrated that low plant density increased boll weight by 5.8 and 4.5 per cent relative to the medium and high plant densities in saline sandy loam soil of yellow river valley of China. Higher average boll weight/plant (5.6 g) was recorded in 80 cm x 20 cm row spacing than 40 cm x 20 cm (5.2 g) in clay loam soil of Iran (Alitabar et al., 2012).

Jahedi et al. (2013) reported that cotton planted in wide rows (71,500 plants/ha in the 70 cm row spacing) had a higher percentage (23 per cent) of boll weight than cotton grown in narrow rows (1, 67,000 plants/ha in the 30 cm, 1, 00,000 plants/ha in the 50 cm) which recorded 4.6 and 5.02 g of boll weight under sandy loam soil in Gonabad. Closer
spacing of 90 cm x 45 cm recorded lower boll weight of 4.6 g than wider spacing of 120 cm x 60 cm which recorded 4.8 g of boll weight under rainfed vertisol in Guntur (Bharathi et al., 2014).

Jadhav et al. (2015) reported that plant geometry of 150 cm x 36 cm recorded higher bolls weight (3.5 and 3.7 g) compared with other plant geometries of 90 cm x 60 cm, 120 cm x 45 cm and 180 cm x 30 cm during the two year experimentation under irrigated condition of Parbhani. Wider spacing of 60 cm x 15 cm recorded higher boll weight (3.3 g) than the narrow spacing of 45 cm x 10 cm, 45 cm x 15 cm and 45 cm x 20 cm which recorded 3.0, 3.1 and 3.2 g of boll weight under rainfed condition of Akola, Maharastra (Paslawar et al., 2015).

Gohil et al. (2016) observed that wider spacing of 90 cm x 90 cm registered higher boll weight (3.5 g) than 90 cm x 60 cm (3.8 g) and 90 cm x 45 cm (3.7 g) in clayey soil of Surat. Significantly higher boll weight of 4.0 g was observed with wider spacing of 120 cm x 90 cm than 120 cm x 60 cm and 120 cm x 45 cm which recorded 3.7 and 3.6 g of boll weight in sandy clay loam soil of Banswara, Rajasthan (Meena et al. 2017).

2.1.1.6. Effect of crop geometry on seed cotton yield

Narkhede et al. (2000) revealed that plant geometry of 67.5 cm x 60 cm recorded significantly higher seed cotton yield (2259 kg/ha) by 15.3 per cent than 67.5 cm x 75 cm (1958 kg/ha) on vertisol under rainfed condition. Rout and Satapathy (2001) reported significantly higher seed cotton yield of 19.6 q/ha with 90 cm x 60 cm spacing followed by 105 cm x 60 cm spacing (17.4 q/ha) in sandy loam soil under rainfed condition of Umerkota, Orissa. In a year with limited early season rainfall, UNR cotton (8 inch) yielded over 50 per cent more than the wide row (36 inch) system in marginal soils of Alabama (Delaney et al., 2002). Katkar et al. (2003) indicated that plant spacing of 50 cm recorded higher seed cotton yield by 16 and 30 per cent higher than 75 and 100 cm plant spacing, respectively, with an inter row spacing of 132 cm.

Nehra and Kumawat (2003) reported that closer spacing of 75 cm x 15 cm gave significantly higher seed cotton yield (1411 kg/ha) than 75 cm x 22 cm (1240 kg/ha) and 75 cm x 30 cm (1264 kg/ha) on sandy loam soil under irrigated condition of Sriganganagar,
Richur. Lokhande et al. (2004) noted that higher seed cotton yield (1615 kg/ha) was recorded with closer spacing of 60 cm x 30 cm which was significantly (31 per cent) superior over wider spacing of 90 cm x 90 cm. Sankaranarayanan et al. (2004) concluded that closer spacing of 90 cm x 30 cm registered significantly superior cotton yield of 1519 kg/ha as compared to other spacing of 90 cm x 60 and 120 cm x 30 cm to an extent of 9 to 12 per cent.

Sisodia and Khamparia (2007) reported that closer plant spacing of 45 cm x 45 cm recorded 12.2 and 28.5 per cent higher yield per hectare over 60 cm x 45 cm (1234 kg/ha) and 60 cm x 60 cm (1078 kg/ha) respectively under rainfed condition of Madhya Pradesh. Basanagouda and Patil (2007) observed under rainfed condition, significantly higher seed cotton yield of 784.6 kg/ha was recorded with spacing of 60 cm x 15 cm than spacing of 60 cm x 10 cm (692 kg/ha) and 60 cm x 20 cm (709 kg/ha) and under irrigated condition the highest seed cotton yield (1669 kg/ha) was recorded with spacing of 60 cm x 25 cm than 60 cm x 20 cm (1521 kg/ha) and 60 cm x 30 cm (1619 kg/ha) in Dharwad of Karnataka.

Reddy and Gopinath (2008) stated that higher seed cotton yield (3614 kg/ha) was recorded with closer plant geometry of 90 cm x 30 cm which was comparable with 90 cm x 60 cm (3365 kg/ha) and significantly superior over 90 cm x 90 cm (2839 kg/ha) under rainfed vertisols of Warangal, Andhra Pradesh. Aruna and Reddy (2009) illustrated that planting cotton at 90 cm x 45 cm and 90 cm x 60 cm spacing recorded higher kapas yield of 2056 kg/ha and 1842 kg/ha than wider spacing of 90 cm x 90 cm (1494 kg/ha) and 120 cm x 60 cm (1453 kg/ha) under black cotton soil of Nandyal, Andra Pradesh.

Bhalerao et al. (2010) narrated that seed cotton yield was significantly increased with closer spacing of 60 cm x 30 cm (1671 kg/ha) than wider spacing of 60 cm x 45 cm (1524 kg/ha) in deep black soil of Akola, Maharashtra. Manjunatha et al. (2010) observed that significantly higher seed cotton yield (21q/ha) was registered with 60 cm x 30 cm and it was 35 per cent higher over 90 cm x 60 cm and 11 per cent over 75 cm x 30 cm but it was comparable with 90 cm x 20 cm (20 q/ha) in medium black soil of Raichur, Karnataka under rainfed condition.

Ali et al. (2011) revealed that significantly higher seed cotton yield (2454 kg/ha) was obtained with narrow spacing of 15 cm followed by 30 cm than 45 cm row spacing in silt loam soil of Pakistan. Venugopalan et al. (2011) concluded that the seed cotton
yield was significantly higher under closer spacing of 45 cm x 13.5 cm and 30 cm x 20 cm (1,66,000 plants/ha) under rainfed vertisols of Nagpur. Shekar et al. (2011) revealed that seed cotton yield increased with closer spacing of 90 cm x 30 cm (1668 kg/ha) than wider spacing of 90 cm x 45 cm and 90 cm x 60 cm (1423 kg/ha and 1247 kg/ha) in sandy clay loam soil under rainfed condition of Hyderabad. Plant geometry of 90 cm x 60 cm recorded significantly higher seed cotton yield (1527 kg/ha) than 180 cm x 30 cm (1212 kg/ha) and 120 cm x 45 cm (1172 kg/ha) geometries in clay soil of Parbhani (Dahiphale et al., 2012).

Nehra and Yadav (2012) reported that narrow spacing of 67.5 cm x 30 cm gave significantly higher seed cotton yield (2241 kg/ha) over wider spacings (67.5 cm x 45 cm and 67.5 cm x 60 cm) in sandy loam soils of Rajasthan. Shukla et al. (2013) opined that plants under closer spacing of 60 cm x 60 cm produced more seed cotton yield (910 kg/ha) which was 15.2 per cent over wider spacing of 90 cm x 60 cm which recorded 772 kg/ha of seed cotton yield under rainfed condition of Akola, Maharashtra. Bharathi et al. (2014) found that the seed cotton yield (2924 kg/ha) was increased by 21.7 per cent under closer spacing (90 cm x 45 cm) as compared to wider spacing of 120 cm x 60 cm (2402 kg/ha) under rainfed vertisol of Guntur.

A closer geometry of 100 cm x 40 cm gave higher seed cotton yield (3695 kg/ha) as compared to 100 cm x 50 cm (3290 kg/ha) and 100 cm x 60 cm (3185 kg/ha) and resulted in 16 per cent higher yield over 100 cm x 60 cm (Jat et al., 2014). Brar et al. (2015) noted that higher plant density at closer spacing of 67.5 cm x 60 cm recorded significantly higher seed cotton yield (2195 kg/ha) than lower plant density at wider spacing of 67.5 cm x 75 cm (2062 kg/ha) under sandy loam soil of Ludhiana. Jadhav et al. (2015) observed that the plant spacing of 150 cm x 36 cm produced the highest seed cotton yield (36 q/ha) which was significantly superior over plant spacings of 90 cm x 60 cm, 120 cm x 45 cm, 180 cm x 30 cm under irrigated condition of Parbhani.

Paslawar et al. (2015) illustrated that the seed cotton yield was significantly higher with narrow spacing of 45 cm x 10 cm (3218 and 3008 kg/ha) than wider spacing of 60 cm x 15 cm (2916 and 2128 kg/ha) in two year experimentation under rainfed condition of Akola, Maharashtra. Singh (2015) registered plant geometry of 67.5 cm x 60 cm recorded significantly better lint (777 kg/ha) and seed yield (1480.8 kg/ha) than
67.5 cm x 75 cm under loamy soil of Punjab. Divya et al. (2016) outlined that extra long stable (BG II) Bt cotton spaced with 120 cm x 45 cm produced significantly higher seed cotton yield (4226 kg/ha) over wider spacing of 150 cm x 60 cm (2842 kg/ha), 120 cm x 90 cm (2356 kg/ha) and control (2062 kg/ha) under sandy loam soil, Tamil Nadu.

Kumar et al. (2017) revealed that significantly higher seed cotton yield/plant (25.7 g) was under wider plant spacing of 45 cm x 30 cm due to better development of individual plant under wider plant spacing than the closer spacing of 45 cm x15 cm and 45 cm x 22.5 cm, but when considering unit area basis, cotton under 45 cm x 15 cm plant spacing produced considerably higher seed cotton yield (2063 kg/ha) under clay textured soil of Pharbahani. Meena et al. (2017) opined that the maximum seed cotton yield was recorded (2301 kg/ha) at sowing of 90 x 45 cm closer plant geometry over sowing of 90 x 60 cm (1934 kg/ha) and 90 x 90 cm (1759 kg/ha) wider plant geometry in sandy clay loam soil of Banswara, Rajasthan.

2.1.1.7. Effect of crop geometry on fibre quality

Deol (2001) reported that there was no effect of plant spacings (67.5 cm x 30 cm, 67.5 cm x 45 cm, 100 cm x 30 cm and 100 cm x 45 cm) on quality parameters like ginning outturn, 2.5 per cent span length, lint index, fibre fineness and maturity coefficient. Nichols et al. (2003) reported that wider row spacing with 76 cm recorded higher percentage of ginning outturn (37.1 per cent) than row spacing of 38 cm (32.6 per cent) and 25 cm (32.9 per cent) under sandy loam soil in Stoneville. Srinivasalu et al. (2006) stated that spacing levels did not affect fibre quality like 2.5 per cent span length and fibre strength.

Aruna and Reddy (2009) observed that fibre quality was not significantly influenced by plant population. Fibre quality parameters viz., 2.5 percent span length (27.3, 27.5, 27.6 and 27.8 mm), fibre strength (22.2, 22.4, 22.1 and 22.4 g/tex), uniformity ratio (43.9, 44.3, 43.8, 44.3 percent) and micronaire (4.1, 4.1, 4.2 and 4.2 10^-6g/inch) were obtained with plant spacing of 120 cm x 60 cm, 90 cm x 90 cm, 90 cm x 60 cm and 90 cm x45 cm under deep black soil of Nandyal, Andhra Pradesh. Ali et al. (2011) stated that wider plant spacing of 15, 30 and 45 cm recorded increased seed index of 8.6, 8.7 and 8.8 g under silt loam soil of Pakistan.
The quality parameters like ginning outturn, lint index and earliness index were not influenced significantly by plant geometry of 90 cm x 60 cm (34.7 per cent, 4.4 and 0.4), 120 cm x 45 cm (35.7 per cent, 4.7 and 0.4) and 180 cm x 30 cm (35.7 per cent, 4.4 and 0.4) under vertisol of Parbhani (Ghule et al., 2013). Higher ginning outturn (38.9 per cent) seed index (8.0 g) and 9.9 per cent higher lint index (5.2 g) were recorded under wider crop spacing of 90 cm x 60 cm than closer spacing of 60 cm x 60 cm (37.8 per cent, 7.8 g and 4.7 g) under rainfed condition of Akola in Maharasra (Shukla et al., 2013).

Bharathi et al. (2014) reported that no significant variations were observed regarding 2.5 per cent span length (31.2 and 31.1 mm), fibre strength (24.0 and 23.7 g/tex), micronaire (4.5 and 4.5 \(10^{6}\) g/inch), uniformity ratio (48.6 and 48.4), fibre elongation (5.7 and 5.7 per cent), seed index (10.8 and 10.5 g), lint index (5.6 and 5.5 g) and ginning outturn (34.4 and 34.6 per cent) with wider spacing of 120 cm x 60 cm and closer spacing of 90 cm x 45 cm under rainfed vertisol of Guntur. Brar et al. (2015) reported that ginning outturn was not significantly influenced by plant spacing of 67.5 cm x 45 cm (37.7 per cent) and 67.5 cm x 60 cm (37.8 per cent) under irrigated condition of Ludhiana.

JadHAV et al. (2015) revealed that plant spacing of 150 cm x 36 cm recorded significantly higher ginning outturn (35.2 and 35.9 per cent) as compared to other plant spacing of 90 cm x 60 cm, 120 cm x 45 cm, 180 cm x 30 cm in two year experimentation under irrigated condition, Parbhani. Singh (2015) found that there was no significant variation with fibre quality. Plant spacing of 67.5 cm x 60 cm and 67.5 cm x 75 cm recorded 34.4 and 34.9 per cent of ginning outturn, 27.3 and 26.8 mm of 2.5 per cent span length and 8.4 and 8.2 g of seed index under loamy sand soil of Punjab.

KILLI et al. (2016) reported that plant spacing did not influence ginning outturn. However, ginning outturn ranged between 39.9 per cent to 40.2 per cent in 70 cm (conventional) and 35 cm (narrow) row spacing, respectively, under alluvial clay loam of Turkey. The quality parameters in terms of ginning outturn, fibre uniformity ratio and bundle strength were not significantly influenced remarkably due to different plant geometry of 120 cm x 30 cm, 120 cm x 45 cm and 120 cm x 60 cm under clayey soil of Surat (Gohil et al., 2016).
2.1.1.8. Effect of crop geometry on root parameters

Arunvenkatesh (2013) reported that cotton with closer spacing of 30 cm x 30 cm produced higher root length (23.9 cm), low root volume (16.5) and low root dry weight (7.5 g) than wider spacings (45 cm x 30 cm, 60 cm x 30 cm and 90 cm x 30 cm) under clay loam soil of western zone of Tamil Nadu.

Baskar and Jaganathan (2014) stated that root length of cotton was higher (36.1 cm) with closer spacing (120 cm x 60 cm), whereas root spread and root dry weight were less (66.4 cm and 16.4 g) under wider spacings (120 cm x 90 cm, 150 cm x 60 cm and 150 cm x 90 cm) in sandy clay loam soil of Coimbatore.

2.1.1.9. Effect of crop geometry on nutrient uptake and post harvest soil nutrients

Donald (2005) reported that uptake of N was higher with narrow row spacing than wider spacing. Anand (2006) also observed an increased trend in nutrient uptake with increasing plant density of cotton. According to Bhalerao et al. (2010) higher plant population with 90 cm x 45 cm spacing recorded significantly higher total N, P and K uptake than 90 cm x 60 cm and 90 cm x 90 cm spacing. Significantly higher nutrient uptake (105.50, 23.42 and 118.75 kg/ha of N, P and K, respectively) was noticed with 60 cm x 30 cm than 75 cm x 30 cm, 90 cm x 20 cm and 90 cm x 60 cm under medium black soil of Raichur (Manjunatha et al., 2010).

Brodrick et al. (2012) revealed higher nitrogen uptake (263 kg/ha) under narrow spacing 25 cm with population of 36 plants/m² than conventional spacing of 100 cm with population of 12 plants/m²(254 kg/ ha) in a semi-arid environment of north-west New South Wales, Australia. Dahiphale et al. (2012) stated that the nutrient uptake was higher (56.2, 19.7 and 81.1 kg/ha of NPK) with wider spacing of 180 cm x 30 cm than closer spacing of 120 cm x 45 cm (52.87:16.22:76.81 kg/ha of NPK) and 90 cm x 60 cm (49.69:13.78:71.34 kg/ha of NPK) under clay soil of Parbhani due to closer intra row spacing which had greater nutrient uptake than wider intra row spacing.

Significant increase in nutrient uptake (110.5:9.75:127.2 kg of NPK) of cotton was observed with plant density of 1,48,148 plants/ha (45 cm x 15 cm) than 111111 plants/ha (60 cm x 15 cm) and 55555 plants/ha (60 cm x 30 cm) in sandy loam soil of
Rajendranagar, Hyderabad (Madhavi, 2016). Singh et al. (2016) observed that nutrient uptake was higher (177.6, 45.7 and 109.4 kg/ha of N, P and K, respectively) with closer spacing of 120 cm x 45 cm than 150 cm x 45 cm and 180 cm x 45 cm in loamy sand soil of Sardarkrushinagar, Gujarat.

2.1.1.10. Effect of crop geometry on weed and pest incidence

Crop suppression of weeds is generally maximized in closer row spacing and patterns that result in early canopy closure and maximum light interception by the cotton crop (Molin et al., 2004). The effect of crop canopy cover on weed germination could increase our understanding of potential weed growth suppression using alternative agronomic practices such as planting densities, row spacing and time of planting (Nyamusamba et al., 2007).

Webster (2007) found that relative competitiveness of the cotton canopy in ultra narrow row planting suppressed weed establishment and growth. Reddy et al. (2009) observed that cotton grown in 38 cm rows and 25 cm paired rows closed canopy 1 to 4 week earlier compared to cotton in 102 cm rows. Gwathmey et al. (2011) reported that weed suppression was directly related to plant population density and weeds were influenced more by row spacing and configuration than by seeds/m row, as weeds grew larger and more densely in wider rows and skipped rows.

Arunvenkatesh (2013) stated that weed infestation was less (28/m² of weed density and 94 g/m² weed dry weight) in closer narrow spacing of 30 cm x 30 cm than wider spacing of 45 cm x 30 cm, 60 cm x 30 cm and 90 cm x 30 cm and also the leaf hopper damage rating was less (1.40) under closer spacing of 30 cm x 30 cm than wider spacing of 45 cm x 30 cm, 60 cm x 30 cm and 90 cm x 30 cm (1.55, 1.51 and 1.56) under clay loam soil of Tamil Nadu. Patel et al. (2015) reported that lower spacing (120 cm x 45 cm) of plants showed significantly higher (5.30/leaf) leafhopper, (3.97/leaf) whitefly and (2.84/leaf) thrips population and the lowest (1.53, 2.42 and 0.88/leaf of leaf hopper, whitefly and thrips, respectively) pest population was recorded on Bt cotton cultivated at a wider plant spacing (150 cm x 45 cm) at Anand, Gujarat.

2.1.1.11. Effect of crop geometry on economics
Vishwanath (2007) reported that 90 cm x 30 cm spacing recorded significantly higher net return (₹ 38,603/ha) than 90 cm x 45 cm spacing (₹ 36,661/ha) and 90 cm x 60 cm (₹ 32,503/ha). Srinivasalu et al. (2006) noticed increased net return with 120 cm x 60 cm spacing (₹ 19,557/ha) when compared to 120 cm x 90 cm spacing (₹ 13,873/ha). Reddy and Gopinath (2008) indicated that plant geometry of 90 cm x 30 cm recorded higher gross return (₹ 68,678/ha) as well as net return (₹ 46,266/ha) over 90 cm x 60 cm and 90 cm x 90 cm plant geometries. However, benefit cost ratio was low (2.1) under closer spacing because of higher cost of cultivation for more seed requirement.

With decrease in plant density from 98,765 plants/ha (45 cm x 45 cm) to 74,074 (60 cm x 45 cm) and further to 55,555 plants/ha (60 cm x 60 cm), the net income reduced and the benefit cost ratio also showed same trend and the values in order were 1:3.35; 1:3.07 and 1:2.81, respectively (Sisodia et al., 2008). Shwetha (2008) found that the plant population of 37,036 plants/ha at 90 cm x 30 cm spacing fetched significantly higher net return (₹ 44,889/ha) over plant population of 18,518 plants/ha at 90 cm x 60 cm spacing (₹ 41,663/ha). Higher return with 90 cm x 30 cm spacing was mainly because of higher seed cotton yield/ha.

Manjunatha et al. (2010) reported that narrow spacing of 60 cm x 30 cm registered significantly higher net return (₹ 30,826/ha) when compared to 75 cm x 30 cm (₹ 26,317/ha), 90 cm x 60 cm (₹ 19,806/ha) and 90 cm x 20 cm (₹ 28,269/ha) in black cotton soil of Raichur, Karnataka. Bharathi et al. (2012) revealed that higher benefit cost ratio of 2.98 was recorded at closer spacing of 90 cm x 45 cm and there was a decline in BCR with increase in spacing. Ghule et al. (2013) stated that plant geometry of 90 cm x 60 cm recorded higher gross monetary return (₹ 45,780/ha), net monetary return (₹ 29,190/ha), cost of cultivation (₹ 16,570/ha) and B:C ratio (2.76) than plant geometry of 120 cm x 45 cm and 180 cm x 30 cm under vertisol of Parbhani. Closer spacing of 90 cm x 45 cm recorded high net return and B:C ratio (₹ 65,506/ha and 2.90) than wider spacing of 120 cm x 60 cm (₹ 48,381/ha and 2.42) under rainfed condition of Guntur (Bharathi et al., 2014).

The gross monetary return (₹ 1,52,180, 1,53,330 and 1,52,760/ha), net monetary return (₹ 1,03,740, 1,04,390 and 1,04,060/ha) and benefit cost ratio (3.13, 3.12 and 3.12)
were significantly higher in plant spacing of 150 cm x 36 cm compared to other plant spacings of 90 cm x 60 cm, 120 cm x 45 and 180 cm x 30 cm in two year experiment under irrigated condition at Parbhani (Jadhav et al., 2015). Paslawar et al. (2015) reported that higher plant population of 2.22 lakh plants/ha recorded higher gross monetary return (₹ 1,24,320/ha), net monetary return (₹ 85,076/ha), cost of cultivation (₹ 39,244/ha) and B:C ratio (3.17) than the lower plant population of 1.48 lakh plants/ha and 1.11 lakh plants/ha which recorded ₹ 1,16,120 and 91,800/ha of gross monetary return, ₹ 78,116 and 58,450/ha of net monetary returns, ₹ 38,004 and 33500/ha of cost of cultivation and 3.06 and 2.75 of B: C ratio.

Singh (2015) reported that significantly better gross return (₹ 81,314/ha), net return (₹ 52,023/ha) and B: C ratio (1.76) were observed under narrow (67.5 cm x 60 cm) as compared to wider geometry (67.5 cm x 75 cm) under loamy sand soil, Punjab. Divya et al. (2016) found that significantly higher gross return (₹ 2,83,142/ha), net return (₹ 2,27,392/ha) and B: C ratio (5.07) were obtained with the spacing of 120 cm x 45 cm when compared to control and 120 cm x 90 cm, 150 cm x 45 cm and 120 cm x 60 cm under irrigated condition of Perambalur, Tamil Nadu.

Kumar et al. (2017) observed that maximum gross monetary return (₹ 87,586/ha) net monetary return (₹ 50,031/ha) and B: C ratio (2.33) were recorded with closer spacing of 45 cm x 15 cm as compared to wider spacing (45 cm x 22.5 cm, 45 cm x 30 cm and 60 cm x 10 cm) due to higher number of picked bolls per unit area under clay soil of Pharbhani. The maximum net return (₹ 57553/ha) and B: C (2.50) was observed at sowing of 90 cm x 45 cm closer plant geometries over sowing of 90 cm x 60 cm (₹ 45690/ha and 2.01) and 90 cm x 90 cm (₹ 40565/ha and 1.93) wider plant spacing in sandy clay loam soil of Banswara, Rajasthan (Meena et al., 2017).

From the above review on high density planting system, it may be inferred that, increasing plant density increased the height of the plant, dry matter production and leaf area index, produced less number of bolls/plant than conventionally planted cotton but considering unit area basis produced higher number of bolls/plant and cotton yield due to availability of more nutrients and ample space. High density plating also ensured better
utilization sunlight, nutrients and other resources and facilitate the synchronize maturity. It also recorded higher net return, gross return and B: C ratio than wider spacing.

2.2. MECHANIZATION IN COTTON

The cost of cotton production is excessively high due to engagement of enormous labours, reducing the profit margin available to the producer. When mechanization is substituted for hired farm labourer, cost savings may be apparent to the employer. Again, there is a sense of pride in owing and using machinery to them. Mechanization is the package of technologies which ensures timely field operations, increases productivity, and reduces crop losses by improving the quality of produce. Farm machines have not only increased the mechanical advantage, but also helped to reduce drudgery while performing different agricultural operations. The contributions of agricultural mechanization in various stage of crop production can be viewed as saving in seeds (15-20 per cent), saving in fertilizers (15-20 per cent), saving in time (20-30 per cent), reduction in labour (20-30 percent), increase in cropping intensity (5-20 per cent) and higher productivity (10-15 per cent) (Iqbal et al., 2015). Mechanization is thus a labour augmenting technology increasing the output per worker rather than output per unit of land.

2.2.1. Effect of mechanized sowing in cotton

The labour requirement for planting cotton is high (15 per cent) which is next to harvesting operation (44 per cent). Usually, cotton is sown manually or behind the ‘desi’ plough which consumes more seed. Now-a-days farmers started to use seeds of high yielding varieties/hybrids, which are very costly therefore it cannot be sown traditionally owing to high seed rate and labour charge. So there is a need for machine sowing to save the cost and time (Vaiyapuri, 2004).

Pothecary (1968) stated that increasing awareness about the importance of sowing time necessitates the gradual replacement of human labour by machinery, not only for such arduous tasks as land preparation, but also where labour bottle necks occur in operations, such as planting and weeding. Effective and efficient use of farm machinery leads to increase in the exactness of operations like maintenance of optimum space between plants thereby population due to correct depth of sowing and fertilization etc.
The selection of suitable sowing equipment can play an imperative role in crop establishment by maintaining the sowing depth appropriately (Tanveer et al., 2003).

For sowing of row crops like cotton, maize, sunflower, groundnut and others, multi-crop planters are commonly used which maintains designed plant to plant distance (Farooq et al., 1992). Use of such planters may also require more than recommended seed rate. In order to overcome this problem, pneumatic planters, inclined/vertical seed plate planters are used in Punjab on a very limited scale (Singh et al., 2005).

Kathirvel et al. (2001) evaluated and reported that the till planter machine for cotton has forward speed of operation optimized as 1.4 m/s. The average draft and fuel consumption of the unit was 2300 N and 3.82 x 10⁻³ m³/hr, respectively. The field capacity of the unit was 0.81 ha/hr with field efficiency of 71.4 per cent. It registered less deviation (0.93 per cent) from recommended spacing, planted the recommended number of seeds and resulted in more uniform depth of seed placement. The cost of the till-planter was ₹ 22,500. The till-planter resulted in 23.7, 90.1 and 18.3 per cent saving in cost, time, and energy, respectively, when compared to the conventional method in Tamil Nadu.

El-Awad (2003) evaluated the mechanical sowing of various field crops viz., cotton, sorghum and sunflower in comparison with manual sowing and found that the seed rate of cotton, sorghum and sunflower were reduced by about 4, 33 and 17 per cent, respectively, and seeding by machines is cheaper than the manual sowing in reduction of operation cost. In further research, El-Awad (2005) detailed that the use of planter saved about 8.0 kg/ha of cotton seeds, which is about 40 per cent lower than that used with manual sowing method.

Kathirvel et al., (2005) reported that sowing of cotton with ridger seeder, pneumatic planter and cultivator seeder resulted in 44.0, 42.9 and 41.6 percent saving in cost, and 96.4, 96.3 and 96.2 percent in time by the ridger seeder, pneumatic planter and cultivator seeder, respectively, when compared to manual sowing in Tamil Nadu. Singh et al. (2005) added that sowing of cotton with ridger seeder, pneumatic planter and cultivator seeder need minimum seed rate of 8.7, 4.0, 4.94 kg/ha than manual sowing (14.6 kg/ha) in Uttar Pradesh.
El-Awad (2006) highlighted that comparison of mechanical sowing of chemically delinted seeds with manual sowing operation indicated that the time required for manual sowing was 19 times more than the requirement of mechanical sowing. Mechanical sowing resulted in saving of about 40 per cent of the seed rate and in significantly narrower spacing of about 24 cm with approximately similar plant population to the recommended one, with 1-2 seeds/hill. On the other hand, manual sowing operation resulted in spacing between plants of about 46 cm with 5-6 plants/hole. However, mechanical sowing resulted in insignificantly greater yields of cotton.

Research trails with tractor mounted inclined plate planter conducted at 5 centres namely JNKVV Jabalpur, AAI Allahabad, MPKV Rahuri, OUAT Bhubaneshwar and RAU Pusa centres in total 35 ha, revealed that the depth of sowing varied from 30 to 50 mm at the forward speed of 3.4 km/hr, the field capacity and field efficiency were 0.8 ha/hr and 75 per cent, respectively. The cost of operation was ₹ 274/ha, whereas the cost of manual planting was ₹ 480/ha (ICAR, 2007).

Planting of cotton variety LH 1556 was done with both the machines viz., pneumatic planter as well as inclined plate planter at the Departmental Research Farm in an area of 0.24 ha each in PAU, Ludhiana. Result revealed that the field capacity and field efficiency of the pneumatic planter and inclined plate planter were 0.49 ha/hr and 77 per cent, 0.35 ha/hr and 76.08 per cent, respectively. The average number of missing hills was lower for pneumatic planter (0.33) than inclined plate planter (1.33). Percentage of singles was higher for pneumatic planter (94.20 per cent) as compared to inclined plate planter (85.54 per cent) and percentage of doubles was higher in case of inclined plate planter (9.64). The yield for the inclined plate planter was 1167 kg/ha and for the pneumatic planter it was 1262 kg/ha (TMC, 2007).

Kamaraj and Kathirvel (2008) developed tractor operated belt type cotton planter which recorded minimum draft of 950 N and minimum fuel consumption of 3.8 l/hr. The belt type cotton planter proved its superiority by registering 73.3 per cent of two plants per hill, 6.7 percent of missing hills and maintained the recommended plant population and desired plant spacing. Sowing operation energy requirement were more (220.03 MJ) in mechanized method where as cost of operation was less ( ₹ 535/ha) over
the conventional method (175.72 MJ/ha and ₹812.5/ha). The use of belt type cotton planter for planting cotton resulted in 68.6 and 98.5 per cent saving in cost and time, respectively, when compared to the manual planting in Akola, Maharashtra.

Multicrop planter of tractor operated 6-row inclined plate planter for planting of bold and small seeds was evaluated in PAU, Ludhiana. Result of the research revealed that the field capacity of the equipment is 0.42 ha/hr with an effective width of coverage of 1.85 m. The approximate cost of the equipment is ₹40,000/-. The cost of operation with inclined plate planter was ₹2300/ha as compared to ₹3500/ha by conventional method (ICAR, 2010).

Chandel et al. (2010) reported that cotton sown with inclined plate planter registered lower (3.4 l/ha) fuel consumption, 85.9 per cent of single and 7.0 per cent of double seeds per hill with higher yield (1675 kg/ha), 46.2 percent saving in cost and 97.1 per cent saving in time than manual sowing. Khobragade et al. (2010) evaluated that the cotton sowing with tractor drawn cotton pneumatic planter, inclined plate type planter, vertical roller type planter and animal drawn CICR cotton planter consumed more energy (43.8, 100, 134 and 5.5 hp-hr/ha) than the manual sowing (25 hp-hr/ha) but saved ₹1737 of the cost of cultivation by recording a cost of ₹563/ha than the manual sowing (₹2300/ha) in Chandrapur.

Dixit et al. (2011) compared the performance of tractor operated inclined plate planter and pneumatic planters for planting cotton variety LH-1556. The plant to plant spacing obtained with pneumatic planter was 44 cm (recommended 45 cm), the number of missing hills/10 m was 0.33 and percentage of doubles was 4.35 whereas for inclined plate planter, plant spacing was just 36 cm only, the average number of missing hills/10 m was 1.33 and percentage of doubles was 9.64. The capacity of pneumatic planter was 0.49 ha/hr and that of inclined plate planter 0.35 ha/hr. Thus pneumatic planter strongly holds an advantage over inclined plate planter.

Raghavendra et al. (2013) developed a ridge planter for cotton, the forward speed of operation was optimized as 1.25 m/s, considering seed rate and seed spacing. The average draft and fuel consumption of the planter was 2300 N and 3.83 l/hr, respectively. The field capacity of the planter was 0.89 ha/hr with field efficiency of
73.6 per cent. The cost of operation of ridge planter for sowing cotton was ₹433/ha compared to ₹1013/ha for conventional method.

Sharma et al. (2013) compared the inclined cell plate type of Bt cotton planter with existing inclined plate type cotton planter and evaluated it. The effective field capacity of both machines was 0.73 and 0.71 ha/hr at average operating speeds of 4.1 and 3.8 km/hr, respectively. Time lost in turning of both planters was 35 and 37 sec/turn and the field efficiency was 59.3 and 58.8 per cent, respectively. The germination of seed was recorded after 21 days of planting and it was 16-19 plants in case of improved Bt Cotton planter and 12-16 in existing planter. The distribution of plants in row and crop response at farmer’s field indicated that mean plant spacing was 71.8 cm and quality of feeding index was 75.6 per cent in case of improved Bt Cotton planter whereas, the mean spacing of 77.6 cm and quality feeding index 68.8 per cent was recorded in existing cotton planter. The missing index and multiple index recorded in improved Bt cotton planter were 15.5 per cent and 8.9 per cent, respectively, whereas it was 22.9 per cent and 8.33 per cent in existing cotton planter.

Dineshkumar and Jaimin (2014) reported that in manually operated cotton planter in Godha, the speed was 1.62 km/hr, actual operating time of 4.5 minute was required to cover an area of 0.01 ha with actual field capacity of 0.132 ha/hr and field efficiency was 79.5 per cent. The percentage damage in cotton seed was 1.236 per cent more by planter compared to manual sowing. The average time requirement was 7.6 hr/ha while in manual sowing it was around 11.1 hr/ha. The average seed rate in manual cotton planter was 3.031 kg/ha. But the cost of sowing cotton manually was approximately ₹ 209/ha; whereas the cost by this machine was ₹ 168/ha.

Hoque and Karim (2015) conducted a field test with inclined plate planter in Gazipur and Barisal and reported that the field capacity and field efficiency of inclined plate planter were 0.17 ha/hr and 75 per cent, respectively. Coefficient of seed distribution uniformity and coefficient of planting depth uniformity were 97 and 94 per cent, respectively. Time and cost saving to complete land preparation and planting of maize by inclined plate planter were 90 and 86 percent, respectively than manual sowing.
The above review on mechanized cotton sowing resolved that manual sowing is highly a labour intensive practice engulfing vast time and money from farmer’s pocket. So, mechanization could be viewed as the only one valuable substitute to hurdle over this hitch. Mechanization is found to be a superior way to cut down input charges (labour and seed) by using minimum energy to ensure expected placing of seeds at appropriate depth in comparison with the conventional method of sowing.

2.2.2. Effect of Mechanized weeding in cotton

Weed control is one of the most expensive and labour intensive operation in crop production. In India, ₹ 4200 million is being lost annually due to weeds (Natarajan, 1987). On an average one third of the cost of cultivation ₹ 954/ha, is being incurred on weeding, out of the cost of cultivation of ₹ 3000/ha for agricultural crops (Tajuddin et al., 1991)

Indian farmers majorly follow mechanical weeding though chemical weeding is slowly gaining momentum in recent years, in spite of its higher cost. The labourious operation of weeding is performed with the use of hand hoe in upright bending posture, inducing back pain for labourers. Weeding by using hand hoe demands 300-1200 man-hr/ha during entire crop duration (2-4 weeding), where dearth of labours arises at peak seasons, thus, proves that age old traditional methods are costly and time consuming. So to overcome this problem effective weeding technique is a main necessity in farming (Tajuddin et al., 1991)

Mechanical weeding has an advantage over chemical weeding because herbicide application is generally expensive, hazardous and selective. Besides, mechanical weeding keeps the soil surface loose by production of soil mulch which results in better aeration and moisture conversation (Duraisamy and Tajuddin, 1999). Pannu et al. (2002) evaluated a self-propelled, diesel engine (3.8 hp) operated power weeder and found it suitable for weeding wider row crops like maize, cotton, sugarcane, etc., The machine was operated at an average forward speed of 1.64 km/hr. The depth of operation ranged from 4 to 7cm and hold efficiency was 88 per cent. The average fuel consumption was 1.05 l/hr. The field capacity ranged from 0.6 to 1.0 ha/day. The cost of weeding was ₹ 978/ha.
Tajuddin (2006) designed, developed and tested a weeding machine powered by a 2.2 kW, petrol start kerosene run engine in cotton. The rated engine speed of 3300 rpm at load was reduced to 660 rev/min of ground wheels by belt - pulley and sprocket-chain mechanisms in three steps. A sweep type weeding blade was designed for structural strength. Cost of operation by the power weeder was computed to be ₹ 580/ha. The machine was found useful for weeding in between standing rows of cash crops like cotton, tapioca and grapes. The weeder had the field capacity of 0.1 ha/hr. The weeder could cover an area of one ha in a day of 8 hr. The cost of weeding by this machine comes to only one-third of the weeding cost by manual labourers in Tamil Nadu.

Kathirvel et al. (2007) revealed that the savings in cost of the weeding operation with bullock drawn junior hoe, self-propelled power weeder and tractor drawn weeding cum earthing-up implement was 78.7, 79.8 and 68.7 per cent, respectively, when compared to manual weeding. The savings in time of operation with bullock drawn junior hoe, self-propelled power weeder and tractor drawn weeding cum earthing-up implement when compared to manual weeding was 96.5, 96.6 and 98.9 per cent, respectively.

A tractor operated three row rotary weeder along with two commercially available self propelled machine were used for weeding purposes viz., RPW-1 with a 4.8 hp diesel engine and RPW-2 with a 6.5 hp petrol engine, were evaluated for weeding in cotton. Weeding efficiency was about 94-95 per cent for both self propelled weeder as compared to 90 per cent for tractor operated rotary weeder. But the field capacity was less for the former. Injury to plant was 1-3 percent. Saving in cost and labour was 30-40 percent and about 90 percent as compared to manual weeding in Tamil Nadu (TMC, 2008).

Dixit and Sayed (2008) evaluated the field performance of power weeder for rain-fed crop in Kashmir valley. The time input for the power weeder was about 157 hr/ha less than manual weeding. The power weeder achieved the lowest weeding time (10 hr/ha), maximum coverage area (0.1 ha/hr) over the traditional practice.

Kathirvel et al. (2009) studied the economics of three weeder and concluded that the saving in cost with TNAU-Varun, Oleo and Balram power weeder was 21.5, 16.2 and 23.1 per cent, respectively, when compared with manual weeding. The saving in time
with the TNAU-Varun, Oleo and Balram power weedeers was 59.8, 58.6, and 59.8 per cent, respectively.

Veerangouda et al. (2010) evaluated the field performance of different weedeers namely hand hoe, peg type dry land weeder, animal drawn blade hoe and power weeder in cotton, Raichur, with the actual field capacity of 0.005, 0.009, 0.092 and 0.07 ha/hr, respectively. The maximum value of cost of operation (₹ 1666/ha) was observed with hand hoe while the animal drawn blade hoe recorded minimum value (₹ 399/ha). The savings in cost of weeding was 22.2, 76.1 and 42.3 per cent higher with peg type dry land weeder, animal drawn blade hoe and power weeder than manual weeding by hand hoe.

Mor (2014) reported that the walk behind engine operated power weeder in cotton with average field capacity and field efficiency was 0.16 ha/hr and 65 per cent and recorded minimum fuel consumption (1.25 l/ha). The labour requirement was minimum with power weeder than manual weeding which required 160 man-hr/ha and saved 68.70 and 80 per cent cost on time and labour by recording 6.25 hr/ha and ₹ 6870/ha with B: C ratio of 4.4 on comparison with manual weeding. The reason for higher B:C ratio in walk behind engine operated power weeder was because of low cost of operation.

Kumar et al. (2014) evaluated the performance of a self-propelled walk behind power weeder and compared with manual weeding at farmer’s field in Kharif, 2010. The field capacity of the power weeder was 0.12 ha/hr with the field efficiency of 93 per cent. The weeding efficiency of the power weeder was 65 per cent as compared to 96 per cent by manual weeding. The plant damage was 60 per cent less in power weeding than manual weeding. The fuel consumption was 0.65 l/hr or 5.42 l/ha. There were 95 per cent time and 82 per cent cost saving in weeding with power weeder as compared to manual weeding.

Haribabu et al. (2015) reported that the field capacity of the weedeers were 114 and 208 man/ha for power weeder and wheel hoe, respectively, in cotton at Guntur. The weeding efficiency of the power weeder was 81 per cent and that of wheel hoe was 75 per cent. In both the weedeers, there was not much plant damage observed during operation in the field.
The field capacity of self propelled weeder was 0.07- 0.09 ha/hr and of tractor operated weeder was 0.25 - 0.33 ha/hr respectively. Injury to plant was less than 1 per cent in self propelled weeders but in tractor operated weeders, it was 1-4 per cent. Re-emergence of weeds was less in case of self propelled weeders as compared to sweep weeder. Saving in labour requirement was about 64 to 67 per cent in cotton (GOI, 2016).

From the above review, it can be concluded that manual weeding is labour and time consuming and labourers are unavailable at peak time. Moreover, labour efficiency is greatly affected due to more fatigue in bending posture to do hoeing. So, from the reviews it could be concluded that in order to reduce labour cost and save time, mechanical weeding would be the best option as it showcased higher weed control efficiency with limited plant damage.

2.2.3. Effect of drip irrigation and fertigation in cotton

Cotton under drip irrigation provides a number of different benefits to farmers over the conventional flood irrigation. It reduces the cost of cultivation, especially in labour-intensive operations like weeding, irrigation, etc., because drip irrigation does not allow weed to come up in the non crop space by restricting water beyond the root zone of the crop and also not warrants much ploughing (Dhawan, 2002). Jayabal et al. (2000) reported that fertigation with water soluble fertilizer in cotton saved 25 per cent of fertilizers and recorded a yield increase of 28 per cent over soil application of fertilizer.

Janat and Somi (2001) revealed that fertigation of cotton under the given circumstances improved water use efficiency, nitrogen use efficiency, seed cotton yield, dry matter production, earliness and in some cases lint properties. Furthermore, 35-55 percent of irrigation water was saved, more than 50 per cent of seed cotton yield was increased and water use efficiency was increased by almost 90 per cent under drip fertigation than the surface irrigated cotton.

Narayanamoorthy (2008) stated that drip irrigation reduced the cost of irrigation by about 50 per cent and helped to reduce the cost on weeding, intercultural and preparatory works. This also saved the consumption of electricity by about 140 kWh per acre compared with flood irrigation. The productivity of drip-irrigated cotton was about
114 per cent higher than the corresponding flood irrigation. The profit of the cotton crop cultivated using drip irrigation was higher by about ₹20,601/acre than flood irrigation.

Jalajakshi and Jagadish (2009) stated that the total cost of cultivation per acre of cotton under the drip irrigation technology was ₹10,579/ha, while that under flood irrigation method was higher as ₹12456/ha. Thus, there was a saving of ₹1,875/ha, constituting 15 per cent, although a higher cost was incurred on picking in the case of drip irrigation technology on account of higher yield to the tune of half a tonne. The net profit and B:C ratio earned per acre of cotton in the case of drip irrigation technology was ₹18,541/ha and 2.75, respectively, whereas that under the conventional flood irrigation method was only of ₹5,544/ha and 1.44. Pawar et al. (2014) evaluated that drip irrigation in cotton resulted in 24.7 per cent increase in yield with 56.9 per cent water saving, whereas drip with fertigation resulted in 31.7 to 64 per cent increase in seed cotton yield with equal amount of water saving as compared to conventional method.

Cotton cultivated under drip irrigation system drastically reduces the cost of cultivation in operation like irrigation (40 per cent), weeding and other intercultural operations (35 per cent), field preparatory works (26 per cent) and also 28 per cent less quantity of seeds is required as compared to flood irrigation system. The number of irrigations used for drip irrigated were (48) substantially higher than that of flood irrigated crop (6), however, the hours used for each turn of irrigation was about 1.65 hours/ha under drip irrigation as against the use of 19.75 hours/ha under flood irrigation, thus farmer were able to save 2.95 hp hour of water per hectare. This was about 33 per cent saving over flood irrigation. Drip irrigation substantially reduces the working hours of pump set by reducing the water consumption. The productivity of cotton under drip irrigation (23.35 q/ha) was about 27 per cent higher over flood irrigation (18.37 q/ha) in Haryana (Pawar et al., 2015).

Drip irrigation in many diverse agro-ecological situations registered higher yield (15 to 30 per cent) besides saving water (30 to 45 per cent) and improving lint quality in comparison to conventional furrow, overhead sprinkler and centre pivot sprinkler irrigation methods. Under Adana, Turkey agro-climatic conditions subsurface drip irrigated cotton raised on 11 ha registered seed cotton yield of 5.5 to 5.8 tonnes/ha (33 per
cent increase over furrow irrigated cotton) besides saving 30 per cent water, 20 per cent energy, 15 per cent labour and 5 per cent plant protection chemicals (NETAFIM, 2017).

From the above reviews it can be concluded that adoption of drip irrigation and fertigation for cotton proved to be technically feasible and economically viable and beneficial in many ways to farmers.

2.2.4. Effect of mechanical picking in Cotton

The area under cotton crop in India was 115.5 lakh hectares with a production of 400 lakh bales with a yield of 2,200 Kg of seed cotton per hectare during the year 2013-14. Despite huge production of cotton in India, cotton picking is still practiced manually. Cotton picking is a tedious and highly labourious work (Goyal, 1979). Cotton crop requires 250 man/ha for hand picking and an adult person can pick about 10-15 kg of seed cotton per day (Ahmed et al., 1987). Cotton picking machinery available in developed countries is technically sophisticated, but at the same time it is costly and suited only for large land holdings. Mechanical cotton pickers are not yet successful in India, because it prevents staggered picking of cotton varieties. Moreover, defoliation is also necessary prior to mechanical picking but defoliants are hardly available in Indian markets. With the recent development in technology, battery powered portable handheld cotton picking machines became available in huge number, which the farmers can use with ease.

Muthamilvelan et al. (2007) reported that the cost of cotton picker machine was ₹ 5000 and the cost of picking was ₹ 4.6/kg of cotton in Meghalaya. In this area, entire cotton is handpicked by human labour involving about 1565 man-hr/ha. The saving in cost, time and energy compared to manual method of cotton picking was 9.0, 75.0 and 68.2 per cent, respectively. The breakeven point was 394.46 kg per annum and the payback period was 0.81 year.

The portable cotton picker has specific mechanical arrangement so that cotton from each boll can be picked. It is a hand operated machine and has a pair of chain with small sharp edged teeth and sprockets and is operated by a light weight 12 V battery. Cotton gets entangled with the chain and is collected and guided into the collection bag.
It has two rollers inside having blades on their outer periphery. Design of machine makes it easy to operate and affordable for field operators (Dixit et al., 2008).

Manes et al. (2012) reported that the battery powered portable cotton picker has a pair of chain with small sharp edged teeth and sprockets and is operated by a light weight 12 V battery. Cotton gets entangled with the chain and is collected and guided into the collection bag. Output capacity of cotton picker varied from 17.0 - 22.6 kg/day for Bt and American cotton varieties. Picking efficiency was 68 - 91 per cent as recorded from experimental trial carried out in Ludhiana.

SIMA (2015) manufactured battery-powered portable handheld kapas picking machine for farmers. The machine is provided with cotton collection bag. With manual picking, a farm worker will be able to pick 13 kg to 15 kg of kapas a day and the farmer pays ₹230 to ₹250 as wages. This works out to over 35 per cent of kapas cost.

Kaur and Sharma (2015) examined on ergonomic assessment of conventional and mechanical methods of cotton picking. The conventional hand picking and mechanical (battery operated manual hand picker) methods of picking cotton were assessed to know the drudgery involved so that improvements can be made. The parameters for ergonomic assessment were working heart rate, energy expenditure, muscular fatigue, postural analysis and drudgery scores on five point scales. There was significant reduction in all the parameters including drudgery scores when activity was performed with battery operated manual hand picker besides increase in picking efficiency as compared to picking with hands.

Deshmukhand Mohanty (2016) reported that portable hand held light weight cotton picker was designed to suit Indian farmers of different farm categories as it can save time and can be cost effective. Current labour wages which constitute about 35 per cent of the total cost of cultivation can be reduced to about 10 per cent with the use of cotton picker over a period of time. Moreover, the problems like child labour and bleeding of fingers by burs can be prevented. This new development in agricultural sector can benefit millions of farmers across cotton producing nations in Asia.

Wadkar and Akkulwar (2016) reported that cotton picker works devoid of defoliant at high speed but it necessitates the need for adequate training and willingness to adopt. Adequately trained female and male picker can pick 80 and 41 per cent more
seed cotton and 44 per cent more cotton area was picked with portable cotton picker recorded under rainfed cotton in Wardha, Maharashtra, India.

Selvaraju et al. (2016) revealed that the preliminary harvesting studies were conducted with hand operated cotton picker machine (weighed about 2.5 kg with solar panel and also with battery) at Tamil Nadu, Karnataka and Rajasthan on Bt hybrids and varieties under both irrigated and rainfed conditions. The results revealed that the machine can harvest 20 kg of seed cotton per hour and 150-180 kg for six hours, while manually the maximum harvest per day would be 10 to 15 kg only. The harvesting machine can be used upto six hours at a stretch. Due to shortage of labour and also higher wages for harvesting of cotton kapas, there is a vast scope for picking machine for farmers.

By reviewing the portable battery operated cotton picker, it may be concluded that by considering the cost of picking, breakeven point, pay- back period, time saving and energy saving, picking through cotton picker is found to be highly promising.

2.2.5. Energy and economics in cotton mechanization

Karale et al. (2008) studied energy economics of small farming crop production operations in cotton crop at Gorwha village. The operational energy input in conventional cultivation method of cotton crop (696.8 MJ/ha) was higher than mechanized farming (507.7 MJ/ha). On the basis of the cost of energy, the cotton crop with the mechanized farming uses lesser energy for maximizing the net profit of the small farmers.

Kambalkar et al. (2010) observed that the energy requirements in mechanized method of cotton cultivation were quite higher than traditional method, but the cost of operation was observed to be higher in traditional method. Overall energy requirement in cotton crop in mechanized method was observed to be 4336 MJ/ha having cost ₹ 11439/ha, whereas energy requirement in traditional method was less i.e. 4284 MJ/ha having cost ₹ 14287/ha. This might be due to engagement of more man and animal hours in traditional farming operation, which required more wages with less energy production capacity.
Gajakos et al. (2015) reported that the cost of cultivation of mechanized practice was less (₹ 17,897/ha) than conventional practice (₹ 13,231/ha) under rainfed cotton cultivation at Akola, Maharashtra. The total input for cotton cultivation approximately by conventional practice was ₹ 30,022/ha and net profit obtained was ₹ 15,978/ha and by mechanize practice the total input was ₹ 25,356/ha and net profit obtained was ₹ 20,643/ha. So by using improved mechanization in cotton cultivation farmers can increase their income approximately by ₹ 4,665/ha.

Prashanthi (2015) evaluated the average total cost of cultivation per hectare of mechanized and non-mechanized cotton farms and stated that the same was ₹ 1,01,236 and ₹ 1,06,569/ha, respectively. The cost of production of each quintals of cotton on mechanized farms was estimated to be ₹ 2416/ha. The same on non-mechanized farms was ₹ 2765/ha. The gross return per hectare of cotton cultivation from mechanized farms were ₹ 1,14,300/ha, while the same in case of non-mechanized farms were ₹ 1,07,700/ha.

From the review on cotton mechanization, it can be concluded that energy requirement in conventional cultivation method of cotton was high compared to mechanized cultivation method. But, considering the cost of cultivation, mechanized cultivation recorded less cost than the conventional cultivation method, because in conventional method more labour and animal hours were engaged in farming operation, which required more wages with less energy production capacity. So, in order to get high cotton productivity with low investment, mechanization is the best option.

2.2.6. Benefits of cotton mechanization

Singh et al. (2016) observed that high density planting system supported by cotton mechanization provided 25 to 40 per cent yield increase compared to farmer practice. Yield increase is attributed to higher plant density compared to conventional practice. This yield increase provides a strong basis for adoption of cotton mechanization. Farmers who adopt mechanized method of cultivation spend additional costs of ₹ 5311/acre towards increased seed rate and use of agrochemicals. There is no incremental cost of picking through machine because as of today the cost of picking by machine is equal to average cost of picking by labour. In future, the labour cost is expected to increase at a fast pace compared to cost of picking by machine and more and
more farmers will see this as a benefit and shift towards mechanical picking. This additional cost can be easily covered with incremental revenue of ₹ 9702/acre on account of 25 to 40 per cent yield increase. Therefore, farmer tends to get benefited if he decides to adopt mechanized cotton cultivation.

From the foregoing review, it could be concluded that high density planting system in cotton gives higher yield than the conventional one due to lower production cost, higher productivity, higher water and nutrient use efficiency, early crop maturity with synchronous bursting and low incidence of pest and diseases. All these make them amenable for mechanization. Mechanization helps to reduce the cost, energy and time of cultivation than the conventional method. So adoption of mechanization along with high density planting system could help the farmer to increase profit with low cost of cultivation.