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RESEARCH

Planting Density Affected Dry Matter Production, Partitioning, and Yield in Machine Harvestable Chickpea Genotypes in the Irrigated Ecosystem

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Abstract
The important causes for lack of improvement in production and low chickpea yields are inappropriate crop management, variety-based un-optimized planting density, variety not suitable for machine harvest and losses during harvesting operations. In this study, we hypothesized that increased planting density can compensate for the yield reduction in tall chickpea genotypes by accomodating more plants per unit area than existing genotypes and improving the plant architecture to facilitate mechanical harvesting. We analyzed variations among five genotypes (ICCV-11601, ICCV-11602, ICCV-11603, ICCV-11604 and JG-11) for dry matter production, partitioning, and yields in response to planting densities (33.3–46.6 plants m^{-2}) at International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru, Telangana, India. In general, higher dry matter production and partitioning was observed in the tall/erect genotypes than semi-erect genotype. The higher dry matter was produced by genotype ICCV-11604. In the case of planting density, an increase in planting density from 33.3 to 46.6 plants m^{-2} decreased the dry matter production and its partitioning in different parts. The normal planting density of 33.3 plants m^{-2} observed higher dry matter per plant. The interaction of JG-11 × 40% higher density of 46.6 plants m^{-2} recorded maximum seed yield (3048 kg ha^{-1}). However, the tall genotype ICCV-11604 × 46.6 plants m^{-2} interaction recorded higher seed yield (2840 kg ha^{-1}) than JG-11 × normal density of 33.3 plants m^{-2} (2666 kg ha^{-1}). The increase in planting density could compensate for the yield reduction in tall chickpea genotypes and facilitate mechanical harvesting to reduce the drudgery on scarce labour and save time and cost.

Keywords Tall genotypes · Harvest index · Machine harvest · Biological yield · Chickpea

Introduction

Chickpea is cultivated globally on 14.56 million hectares, adding 14.78 million tonnes of grains annually to the world food basket, with average productivity of 1015 kg ha^{-1}. India's important pulse crop, sharing 27.26 and 38.05% of the total area and total production of pulses, respectively, with average productivity of 951 kg ha^{-1} (FAO 2019). The lack of improvement in chickpea production and low productivity in the country is the use of un-optimized planting density, cultivation of unsuitable varieties for machine harvesting, inappropriate crop management, the abundance of insect pests and diseases, and losses during harvesting operations (Hassan et al. 2003; Yadav et al. 2007; Patil et al. 2017). There is a yield gap and less area expansion in chickpea, resulting in lower production in India. It can be bridged by using an optimized seed rate or planting density of various genotypes to improve production and area in the country (Yadav et al. 2007; Singh et al. 2019).

The total dry matter production is a measure of plant photosynthetic efficiency (Iqbal et al. 2014). The partitioning in different plant parts is the best index of genotypes' performance (Mansur et al. 2009) and the response to growing conditions (planting densities, irrigation ecosystems, etc.). The productivity of crop depends not only on the total dry matter production but also on its useful partitioning to the seed;

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this is a key to yield stability (Kumar et al. 2010). Dry matter partitioning is the result of the flow of assimilates from source to sinks (Marcelis 1996). An improved partitioning of dry matter to the developing pods will lead to increased pods per plant and increased pod and seed yield, the two most essential yield components in chickpea. Planting density may influence the use of environmental resources by changing the relative importance of inter and intraplant competition for ecological resources such as soil, water, nutrients, and light. Planting density has more effect on growth, yield, and yield attributes of chickpea. Many researchers reported the effect of spacing and planting density on dry matter production, yield and other agronomic traits of chickpea (Mansur et al. 2009; Kashfiet al. 2010; Naim et al. 2017; Agajie 2018; Mekuanint et al. 2018). Results of an experiment by Shaikh and Mungse (1998) revealed that dry matter per plant decreased with an increase in planting density.

The performance of genotype is governed by many factors, which determine the yield potentiality individually or in combination. The dry matter production and partitioning of a particular genotype also depend on agronomic practices and morphology of a genotype (Mansur et al. 2009). Further, by way of the partitioning of dry matter in different parts, a genotype can yield better. Thus, identifying all such favourable yield and growth components and their integration in one genotype leads to better performance over other genotypes. The tall and erect genotypes amenable for machine harvest are long duration and relatively less yielder. The yield can be improved by manipulating planting density and providing supplemental irrigations. This observation was confirmed by Muehlbauer and Singh (1987). They reported that the erect chickpea lines have fewer branches and hence fewer reproductive nodes than bushy lines; increasing the number of plants per unit area has been proposed when sowing these lines to increase their yield per unit area. Also, irrigating chickpea at critical stages produced higher yields at several locations in India (Lende and Patil 2017). Reddy and Ahlawat (1998) reported that two irrigations at branching and pod initiation increased plant growth and yields of chickpea compared to no irrigation. Dry matter production under irrigated ecosystems reported increasing significantly by agronomic manipulations, including genotypes and planting density, while its distribution is also affected (Mansur et al. 2009, 2014). The machine harvestable genotypes with tall/erect growth habits perform differently under different planting densities. They may be useful as it could resist excessive vegetative growth and accommodate more plants per unit area. Increasing planting density can compensate for the yield reduction in tall/erect genotypes compared to existing genotypes and facilitate mechanical harvesting to reduce the drudgery on scarce labour and save time and cost. This information is meager for adapting machine harvestable chickpea genotypes (Patil et al. 2014). Therefore, we planned to study the effect of planting density on machine harvestable chickpea genotypes with an objective to know how tall/erect genotypes perform under higher planting densities for dry matter production and yields per plant and unit area and recommend the genotype-based planting density under irrigated ecosystem.

Materials and Methods

Experimental Site

The field experiments were conducted for two consecutive years (2011–2012 and 2012–2013) at the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru, Telangana, India, which located at the latitude of 17° 53′ N and longitude of 78° 27′ E and an altitude of 545 m above mean sea level. The site receives a relatively well distributed mean annual rainfall of 908.0 mm. The soil type of the field site was Vertisol. The textural class of soil of experimental sites during both the years was black clayey loam. The detail of the soil properties of the experimental sites are furnished in Table 1.

Experimental Design, Treatments and Crop Management

The experiment was laid out in a split-plot design with five genotypes and three planting densities and the treatment combination arranged in a randomized block design with three replications. The chickpea genotypes consisted of four tall and erect genotypes suitable for machine harvest viz.,

Table 1 Physical and chemical properties of soil in the experimental sites at ICRISAT, Patancheru, India

Parameters	Value obtained	
	1st year site	2nd year site
Physical properties		
Particle size analysis		
Coarse sand (%)	18.02	16.04
Fine sand (%)	19.50	15.83
Silt (%)	15.81	17.48
Clay (%)	46.67	50.65
Textural class	Clayey loam	Clayey loam
Chemical properties		
Available nitrogen (kg ha^{-1})	282.50	296.94
Available P_2O_5 (kg ha^{-1})	24.53	26.17
Available K_2O (kg ha^{-1})	319.01	328.26
Organic carbon (%)	0.54	0.55
Soil pH	8.00	8.10
Electrical conductivity (dS m^{-1})	0.18	0.15

ICCV-11601, ICCV-11602, ICCV-11603 and ICCV-11604 and one semi-erect genotype JG-11 (check), in main plots and three levels of planting densities viz., normal planting density (33.3 plants m^{-2}), 20% higher (39.9 plants m^{-2}) and 40% higher (46.6 plants m^{-2}) than normal planting density in subplots.

The land plowed and prepared the broad bed and furrows of 1.2 m breadth before sowing. The recommended doses of fertilizer (25:50:0 kg NPK ha^{-1}) were uniformly applied before the experiment's layout. Before sowing, the seeds were treated with fungicide Captan @ 4 g kg^{-1}. Planting was done on broad beds by hand dibbling the seeds up to 3 to 4 cm deep. Seeds are sown at different planting densities as per treatments viz., 33.3, 39.9, and 46.6 plants m^{-2} by adjusting the seed rate in 30 cm inter-row and 10.00 cm, 8.35 cm and 7.15 cm, respectively intra-row spacing. The sowing was done during the second fortnight of October of both year of experimentation. The crop was raised under an irrigation ecosystem and two irrigations applied at the vegetative and flowering stage at 30 mm of water. Need-based crop protection and agronomic practices were carried out as per package of the practice of raising the chickpea crop.

Plant Parameters Measured

Dry Matter Production and Partition

In each plot, five randomly selected plants from destructive sampling area at 30, 60, 75/90 days after sowing (DAS) and at harvest used for dry matter accumulation in leaves, stem, and reproductive parts (flowers, pods). The data recorded at 75 DAS for JG-11 and 90 DAS for other genotypes (ICCV-11601, ICCV-11602, ICCV-11603 and ICCV-11604). The genotype JG-11 matures early than tall genotypes, so data recorded at 75 DAS for JG-11 and rest genotypes at 90 DAS. The plant parts separated and oven-dried at 70 ± 5 °C to attain a constant weight and weighed separately to determine the dry matter accumulation (DMA) in leaves, stem, and reproductive parts. The average total dry matter production (TDMP) per plant was then calculated by the summation of dry matter accumulation in different plant parts at various growth stages.

Yield Attributes

Pod yield per plant was measured from five tagged plants per plot individually at harvest and the weight of pods of the individual plant was taken separately to compute pod weight per plant. Seed yield per plant was measured by taking weight threshed and cleaned seeds of five tagged plant pods and recorded average of five plants expressed as seed yield per plant in grams. One hundred seeds were manually counted from the sample drawn randomly from each net plot area and 100-seed weight recorded in grams by adopting the ISTA procedure (ISTA 1999).

Yields and Harvest Index

The biological yield was obtained from the net plot area. The harvested plants from each net plot were bundled, dried and weighed in kg by using a battery-operated weighing balance. The harvested plant buddles from each net plot were threshed, cleaned, dried in the shade and weighed in kgs and recorded as a seed yield. The seed weight from five plants used for taking observations was also added for computing the seed yield per ha. Based on the yield of a net plot, the seed and biological yield per hectare was computed and expressed in kilograms per hectare.

The recovery of seeds from total dry matter (biological yield) was considered harvest index (HI), which was expressed in percentage. The HI was calculated by using the following formula suggested by Donald (1962).

$$\text{Harvest Index } (\%) = \frac{\text{Economic yield } \left(\text{kg ha}^{-1}\right)}{\text{Biological yield } \left(\text{kg ha}^{-1}\right)} \times 100$$

Statistical Analysis

The data on different attributes collected subjected to Fisher's method of analysis of variance (ANOVA) following an appropriate procedure to split-plot design using the methods described by Gomez and Gomez (1984). Whenever the effects of the main-factor, sub-factor, and interactions were significant, the means compared using the least significant differences (LSD) test at $p \leq 0.05$ using MSTAT-C software. The treatment means were compared by using letters. The interactions data of mentioned parameters averaged across the year, calculating the coefficients of correlation. Then coefficients of correlation were worked out among the specified parameters using an excel worksheet.

Results

The mean data of 2 years presented and discussed in this paper as there were similar trends for most of the parameters. However, the parameters which have not a similar trend; those data presented and discussed individually.

Dry Matter Partitioning

The mean data of 2 years regarding dry matter partitioning in the leaves, stem, and reproductive parts at 30, 60, 75/90 DAS, and harvest depicted in Figs. 1, 2, 3 and 4. Data analysis clarified that dry matter partitioning in leaves, stem, and reproductive parts was significantly ($p \leq 0.05$) varied by genotypes, planting densities and interactions.

The mean data indicated that the dry matter accumulation (DMA) in leaves (g plant^{-1}) varied significantly among the genotypes at all the growth stages (Fig. 1a). Tall genotype ICCV-11601 recorded significantly higher DMA in leaves (2.45 and 5.75 g plant^{-1}) at 30 and 60 DAS, respectively, which was statistically at par with ICCV-11603 (2.13 and 5.62 g plant^{-1}, respectively). At 75/90 DAS, the genotypes ICCV-11603 recorded significantly higher values (6.10 g plant^{-1}), which was at par with ICCV-11604 (5.89 g plant^{-1}). However, at harvest, ICCV-11604 recorded significantly higher DMA in leaves (4.98 g plant^{-1}) than other tested genotypes except ICCV-11603 and ICCV-11601 (4.79 g and 4.63 g plant^{-1}, respectively). Effect of planting densities on DMA in leaves also found significant at all the growth stages, except at 30 DAS (Fig. 1b). The increased in the planting density decreased the DMA in leaves significantly

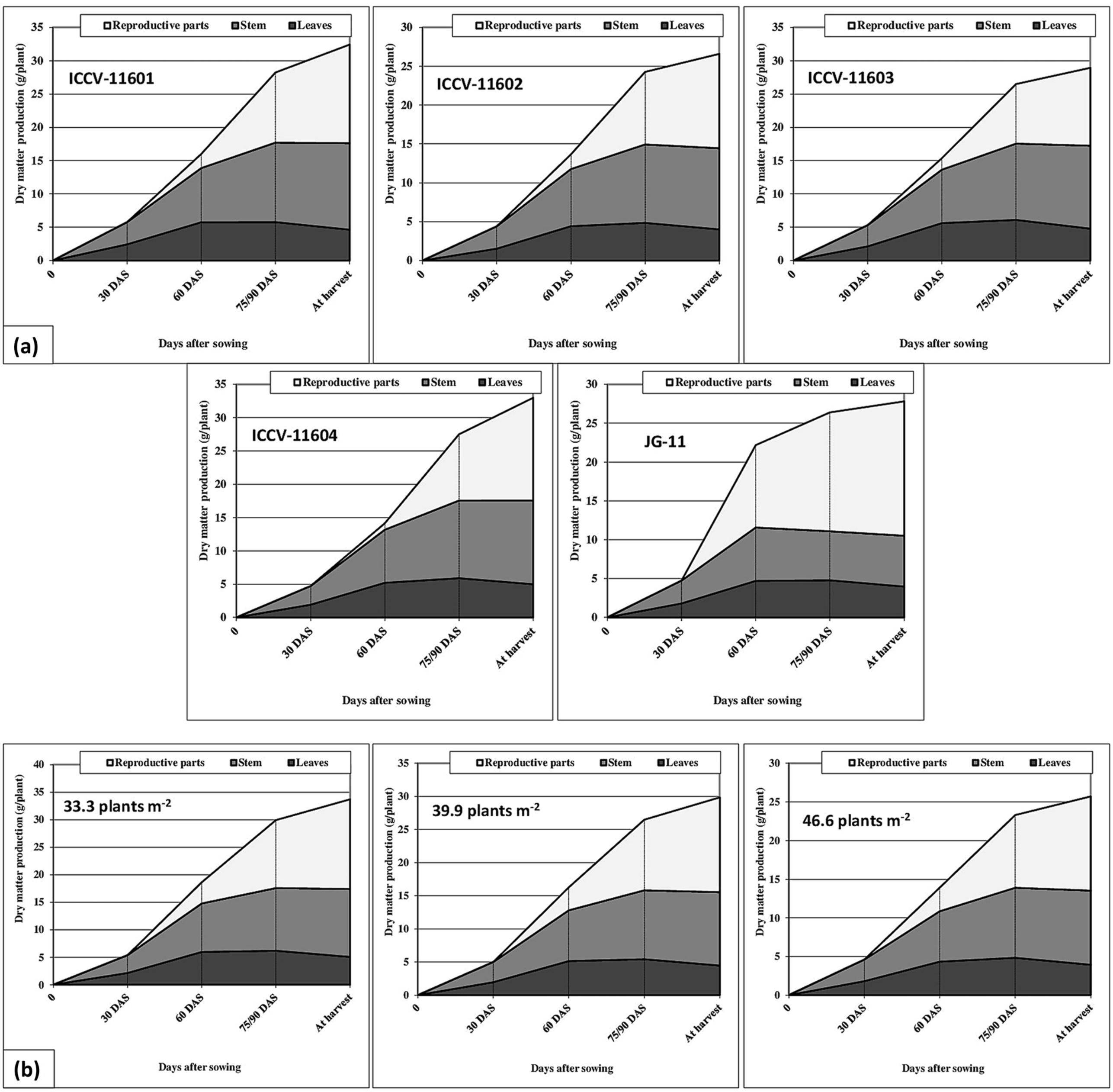

Fig.1 Dry matter accumulations in different parts of chickpea (mean of two years) as influenced by **a** genotypes and **b** planting densities

at 60, 75/90 DAS, and harvest. The DMA in leaves at the normal density of 33.3 plants m^{-2} was 5.95, 6.7, and 5.04 g $plant^{-1}$, respectively, at 60, 75/90 DAS, and harvest compared to higher planting densities of 39.9 plants m^{-2} and 46.6 plants m^{-2}. The interaction effect was significant at all the growth stages except at 30 days after sowing (Fig. 2). The interaction of genotype ICCV-11601 and planting density of 33.3 plants m^{-2} (6.56 g $plant^{-1}$) at 60 DAS, ICCV-11603 × 33.3 plants m^{-2} (6.64 g $plant^{-1}$) at 75/90 DAS and ICCV-11604 × 33.3 plants m^{-2} (5.60 g $plant^{-1}$) at harvest recorded significantly higher DMA in leaves than other treatment interactions. A similar trend of DMA in leaves was observed during both the years of experimentation.

The mean DMA in the stem (g $plant^{-1}$) was significantly influenced due to various genotypes at all the growth stages except at 30 DAS (Fig. 1a). The tall genotypes ICCV-11601 produced significantly higher DMA in the stem at 60, 75/90 DAS, and harvest (8.13, 11.93, and 12.99 g $plant^{-1}$, respectively). Planting chickpea at normal planting density (33.3 plants m^{-2}) recorded significantly higher DMA in the stem at 60 DAS (8.81 g $plant^{-1}$), 75/90 DAS (11.39 g $plant^{-1}$) and at harvest (12.34 g $plant^{-1}$) as compared to higher planting densities of 39.9 plants m^{-2} and 46.6 plants m^{-2} (Fig. 1b). It also differed significantly due to interaction effects at all the crop growth stages except at 30 DAS (Fig. 3). The interaction of genotype ICCV-11601 and 33.3 plants m^{-2} recorded significantly higher DMA in the stem at 60 DAS (9.26 g $plant^{-1}$), at 75/90 DAS (12.98 g $plant^{-1}$) and at harvest (14.25 g $plant^{-1}$). A similar trend was also observed during the individual years of experimentation.

The mean DMA in reproductive parts at 60, 75/90 DAS, and harvest varied significantly among the genotypes and planting densities (Fig. 1a). Significantly higher DMA in reproductive parts produced by the genotype JG-11 (10.60, 15.30, and 17.29 g $plant^{-1}$) than other tested genotypes at 60 DAS, 75/90 DAS and harvest, respectively. The DMA in reproductive parts decreased significantly with the increase in planting density (Fig. 1b). At harvest, planting at the normal density of 33.3 plants m^{-2} resulted in significantly higher DMA in the reproductive part (16.30 g $plant^{-1}$) than higher planting densities of 39.9 plants m^{-2} and 46.6 plants m^{-2} (14.31 g and 12.19 g $plant^{-1}$, respectively). A similar trend was followed at the initial stages (60 and 75/90 DAS) also. The interaction effect also significant for DMA in the reproductive parts at all the stages of crop growth (Fig. 4). At 60 DAS and 75/90 DAS, significantly higher DMA in reproductive parts was produced by interaction JG-11 × 33.3 plants m^{-2} (11.66 and 17.35 g $plant^{-1}$, respectively) followed by JG-11 × 39.9 plants m^{-2} (10.63 and 15.26 g $plant^{-1}$, respectively). Similarly, at harvest, the same interaction was recorded significantly higher DMA in reproductive parts (20.16 g $plant^{-1}$), but which was closely followed by ICCV-11604 × 33.3 plants m^{-2} (17.29 g $plant^{-1}$). A similar trend was observed during the individual years. Significantly higher DMA in reproductive parts at 60 DAS, 75/90 DAS and harvest was also recorded with interaction JG-11 × 33.3 plants m^{-2} during 1st year (11.51, 16.51 and 19.25 g $plant^{-1}$, respectively) and 2nd year (11.80, 18.19 and 21.08 g $plant^{-1}$, respectively).

Total Dry Matter Production (TDMP)

The mean TDMP of 2 years was varied significantly ($p \leq 0.05$) at 30, 60, and 75/90 DAS and harvest due to genotypes and planting densities (Table 2). Significantly higher TDMP was produced by ICCV-11601 (5.78 and 28.22 g $plant^{-1}$) compared to other tested genotypes at 30 and 75/90 DAS but was on par with ICCV-11603 (5.30 g $plant^{-1}$) at 30 DAS and ICCV-11604 (27.49 g $plant^{-1}$) at 75/90 DAS. The JG-11 produced significantly higher TDMP (22.17 g $plant^{-1}$) at 60 DAS and ICCV-11604 (32.98 g $plant^{-1}$) at harvest. The increase in planting density from 33.3 to 46.6 plants m^{-2} resulted in progressive and significant decreases in mean TDMP from 5.37 to 4.59 g $plant^{-1}$ at 30 DAS, 18.61–13.91 g $plant^{-1}$ at 60 DAS, 29.92–23.31 g $plant^{-1}$ at 75/90 DAS, and 33.67–25.71 g $plant^{-1}$ at harvest. However, 20% and 40% higher density than normal were statistically on par at 30 DAS. However, during the individual year, the TDMP was not siginificant at 30 DAS.

The interaction effect of genotypes × planting densities was significant at all growth stages except at 30 DAS (Table 3). Interaction effect of JG-11 × normal planting density of 33.3 plants m^{-2} (25.53 g $plant^{-1}$) at 60 DAS and ICCV-11601 × planting density of 33.3 plants m^{-2} (32.05 g $plant^{-1}$) at 75/90 DAS observed significantly higher TDMP compared to other interactions. The highest values were found at harvest in ICCV-11604 × planting density of 33.3 plants m^{-2} (36.78 g $plant^{-1}$) than all other treatment combinations. However, treatment ICCV-11601 × planting density of 33.3 plants m^{-2} (35.81 g $plant^{-1}$) was statistically at par with the best treatment. A similar trend for TDMP noticed during the individual year of experimentation.

Yield Attributes

The mean data of 2 years showed that yield attributes like pod and seed yield per plant varied significantly ($p \leq 0.05$) among the genotypes, planting density and interactions (Tables 4, 5). The data presented in Table 4 indicated that the significantly higher mean pod and seed yield per plant observed with the semi-erect genotypes JG-11 (13.89 and 11.73 g, respectively) followed by a tall genotype ICCV-11604 (13.27 and 11.02 g, respectively). Like TDMP, per plant pod and seed yield progressively decreased with the

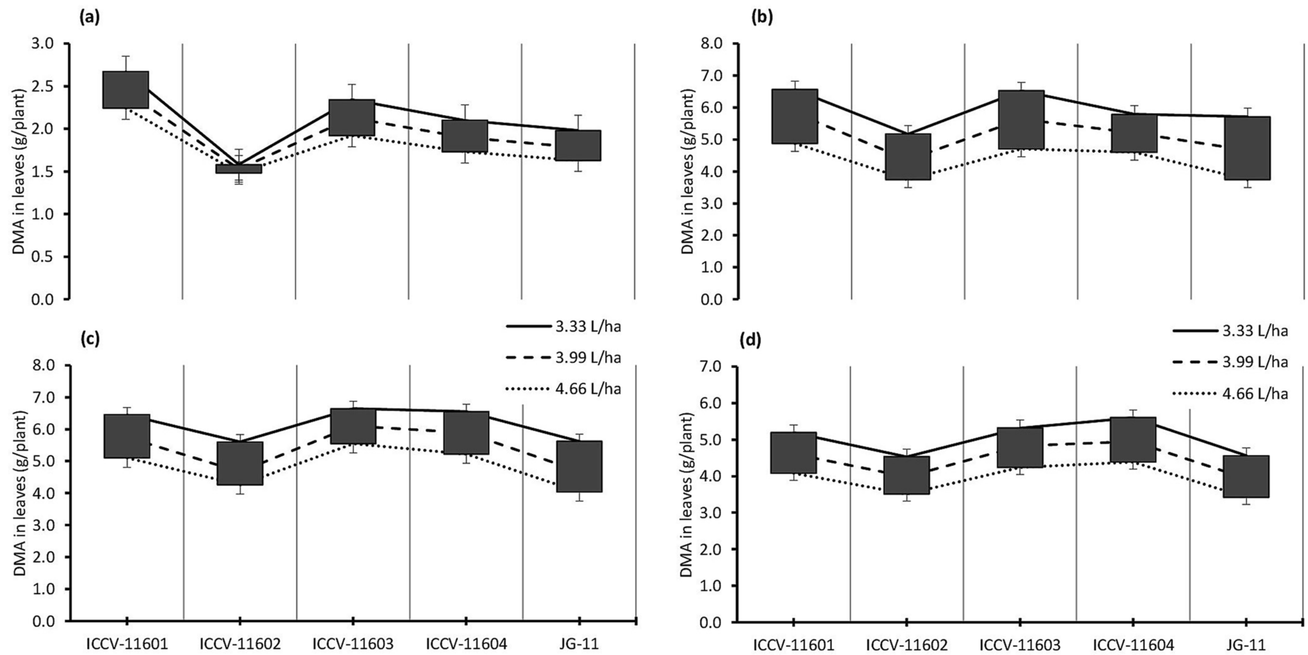

Fig. 2 Interaction effect of genotypes × planting densities on dry matter accumulation in the leaves of chickpea (mean of two years) at different growth stages; **a** 30 days after sowing, **b** 60 days after sowing, **c** 75/90 days after sowing and **d** harvest

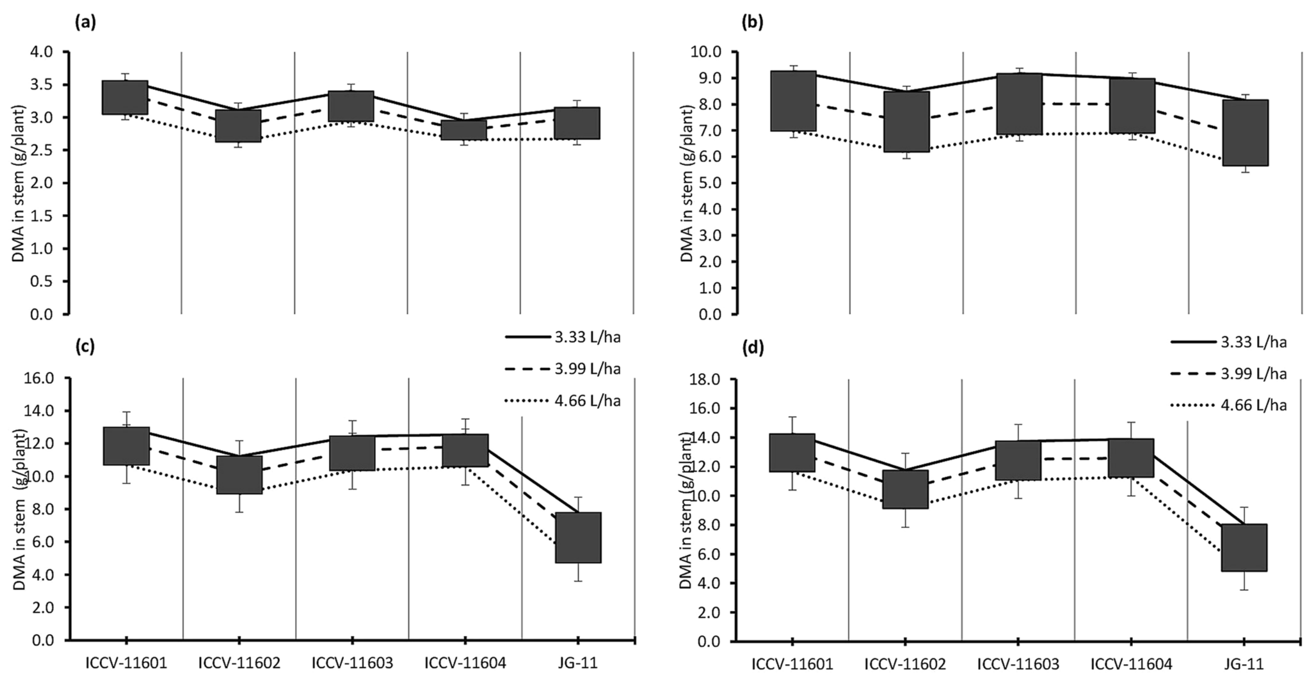

Fig. 3 Interaction effect of genotypes × planting densities on dry matter accumulation in the stem of chickpea (mean of two years) at different growth stages; **a** 30 days after sowing, **b** 60 days after sowing, **c** 75/90 days after sowing and **d** harvest

increase in the planting density. The planting density of 33.3 plants m^{-2} recorded significantly higher pod and seed yield per plant (13.50 and 11.33 g, respectively) compared to 20% higher planting density of 39.9 plants m^{-2} (12.97 and 10.81 g, respectively) and 40% higher planting density of 46.6 plants m^{-2} (12.41 and 10.26 g, respectively). The

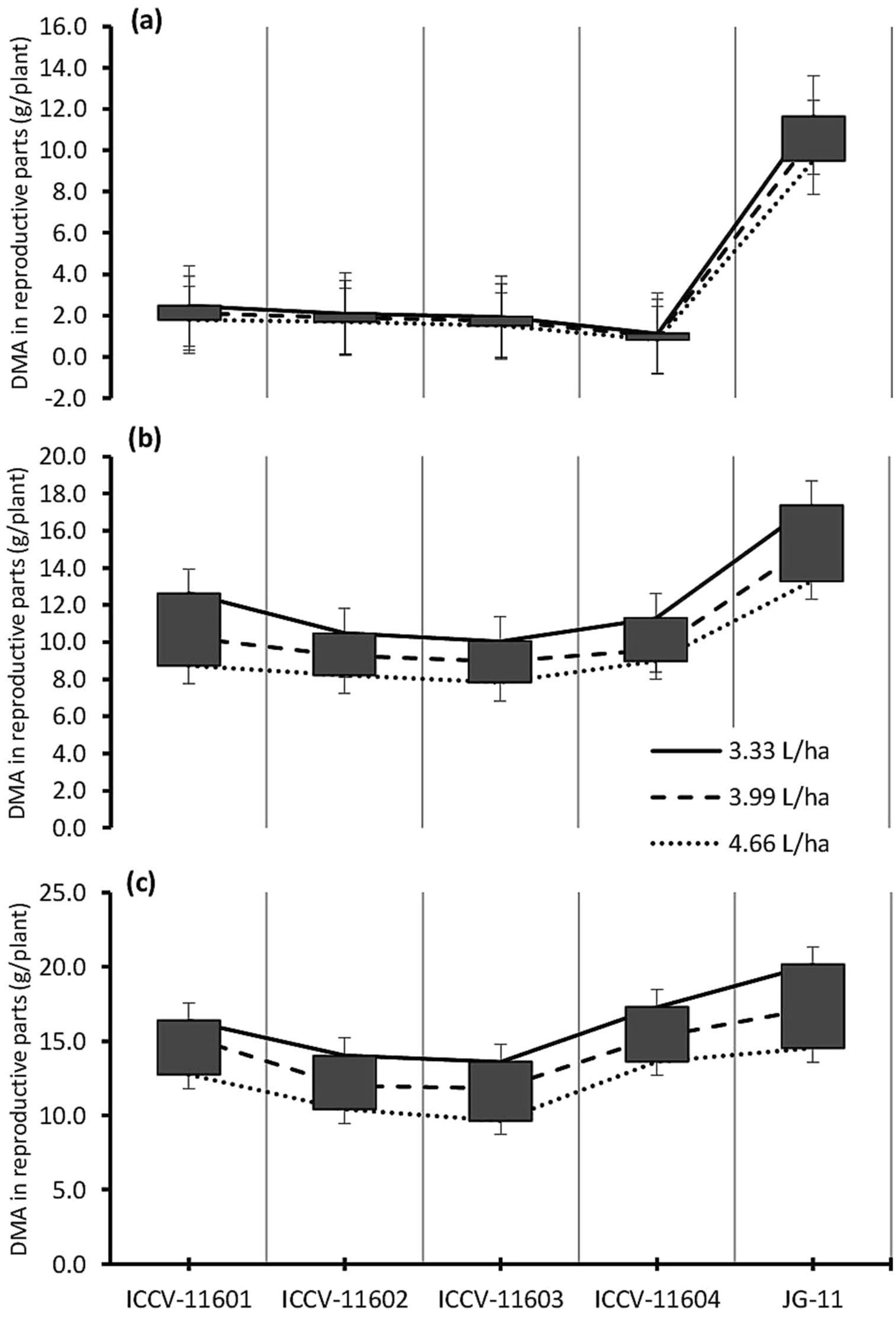

Fig. 4 Interaction effect of genotypes × planting densities on dry matter accumulation in the reproductive parts of chickpea (mean of two years) at different growth stages; **a** 60 days after sowing, **b** 75/90 days after sowing and **c** harvest

interaction effect was significant concerning pod and seed yield per plant (Table 5). The interaction of JG-11 × normal planting density registered significantly higher por yield (14.83 g) and seed yield per plant (12.67 g). Also, a significant difference in 100-seed weight was observed among the genotypes but not differed significantly among the planting densities and interactions. The genotype ICCV-11604 has bolder seeds and recorded a higher 100-seed weight (24.55 g), which was on par with ICCV-11601 (24.02 g) and JG-11 (23.89 g).

Yields and Harvest Index

The data on seed yield, biological yield, and harvest index varied significantly ($p \leq 0.05$) due to genotypes, planting density, and interaction (Tables 6, 7). The data presented in Table 6 indicated that the higher mean seed yield (2865 kg ha^{-1}) was recorded with semi-erect genotype JG-11, followed by a tall genotype ICCV-11604 (2511 kg ha^{-1}). Still, the higher mean biological yield (6441 kg ha^{-1}) was recorded with ICCV-11604 (6441 kg ha^{-1}) and was statistically at par with ICCV-11601 (6325 kg ha^{-1}). The lower mean seed and biological yield were recorded with ICCV-11603 (2385 kg ha^{-1}) and JG-11(6002 kg ha^{-1}), respectively. Unlike pod and seed weight per plant, the mean seed yield (2169–2754 kg ha^{-1}) and biological yield (5668–6748 kg ha^{-1}) increased with an increase in planting density from 33.3 to 46.6 plants m^{-2}. Interaction effect was significant with respect to seed and biological yield (Table 7). The interaction of JG-11 × 40% higher density of 46.6 plants m^{-2} observed significantly higher seed yield (3048 kg ha^{-1}) followed by 20% higher density of 39.9 plants m^{-2} (2882 kg ha^{-1}) and normal density of 33.3 plants m^{-2} (2666 kg ha^{-1}), whereas, ICCV-11604 × 40% higher density (2840 kg ha^{-1}) produced significantly higher seed yield than JG-11 × normal density. However, significantly maximum biological yield was recorded with ICCV-11604 × 40% higher density (6913 kg ha^{-1}). A similar trend of increment in seed and biological yield was observed during the individual year of experimentation.

The mean harvest index was significantly ($p \leq 0.05$) highest in JG-11 (47.00%), followed by ICCV-11062 (39.42%). The harvest index increased with a decrease in planting density from 46.6 plants m^{-2} (40.04%) to 33.3 plants m^{-2} (38.38%). Among interactions, it was significantly more (47.48%) in JG-11 × 20% higher density treatment combination. Similar trend of harvest index was noticed during the individual year of experimentation.

Relations Among Dry Matter Production, Accumulation and Yield Components

It was observed that mean data on per plant pod and seed yield showed a positive correlation with TDMP and DMA in stem and reproductive parts. In contrast, DMA in leaves has a negative correlation (Table 8). The TDMP showed a positive and significant correlation with DMA in leaves, stem, and reproductive parts. There was also a significant relationship between pod yield per plant and TDMP ($p \leq 0.05$; Fig. 5a) and seed yield per plant and TDMP ($p \leq 0.05$; Fig. 5b).

Discussion

Genotype Effect

The performance of genotypes is governed by many factors, which determine the yield potentiality individually or in combination. Optimum leaf area index (LAI) coupled with higher photosynthetic activity can lead to higher biomass production. Further, by way of the partitioning of dry matter, a genotype can yield better. The dry matter production and partitioning and yields of a particular genotype

Table 2 Total dry matter production (TDMP) of chickpea genotypes as influenced by planting densities under irrigated ecosystem

Treatment	TDMP (g plant^{-1})											
	30 DAS			60 DAS			75/90 DAS$^{\#}$			At harvest		
	1st year	2nd year	Mean	1st year	2nd year	Mean	1st year	2nd year	Mean	1st year	2nd year	Mean
Genotypes												
ICCV-11601	5.60^{a}	5.95^{a}	5.78^{a}	15.64^{b}	16.36^{b}	16.00^{b}	27.01^{a}	29.44^{a}	28.22^{a}	30.95^{a}	33.90^{a}	32.42^{a}
ICCV-11602	4.24^{a}	4.56^{a}	4.40^{b}	13.32^{c}	14.00^{c}	13.66^{d}	23.42^{c}	25.11^{c}	24.27^{c}	25.26^{c}	27.91^{c}	26.58^{d}
ICCV-11603	5.19^{a}	5.42^{a}	5.3^{ab}	15.00^{b}	15.71^{b}	15.35^{c}	25.70^{ab}	27.27^{b}	26.49^{b}	27.68^{b}	30.20^{b}	28.94^{b}
ICCV-11604	4.59^{a}	4.83^{a}	4.71^{b}	13.78^{c}	14.48^{c}	14.13^{d}	26.17^{ab}	28.80^{ab}	27.49^{a}	31.97^{a}	33.98^{a}	32.98^{a}
JG-11	4.68^{a}	4.79^{a}	4.74^{b}	21.61^{a}	22.73^{a}	22.17^{a}	25.04^{b}	27.71^{b}	26.38^{b}	26.55^{bc}	29.05^{bc}	27.80^{c}
S.Em ±	0.30	0.39	0.25	0.29	0.27	0.20	0.41	0.37	0.27	0.58	0.45	0.37
Planting densities												
Normal density	5.25^{a}	5.48^{a}	5.37^{a}	18.26^{a}	18.97^{a}	18.61^{a}	28.90^{a}	30.93^{a}	29.92^{a}	32.41^{a}	34.94^{a}	33.67^{a}
20% higher	4.87^{a}	5.13^{a}	5.00^{ab}	15.89^{b}	16.65^{b}	16.27^{b}	25.32^{b}	27.64^{b}	26.48^{b}	28.61^{b}	31.10^{b}	29.85^{b}
40% higher	4.47^{a}	4.71^{a}	4.59^{b}	13.46^{c}	14.35^{c}	13.91^{c}	22.18^{c}	24.43^{c}	23.31^{c}	24.43^{c}	26.99^{c}	25.71^{c}
S.Em ±	0.30	0.22	0.18	0.19	0.20	0.14	0.21	0.21	0.15	0.26	0.27	0.19
Interaction effect	ns	ns	ns	*	*	*	*	*	*	*	*	*

Means with the same letter(s) are not significantly different at 5% level of probability

*Significant at 5%; ns, not significant; DAS, Days after sowing; #75 DAS for JG-11 and 90 DAS for other varieties

Normal planting density—33.3 plants m^{-2}; 20% higher planting density than normal—39.9 plants m^{-2}; 40% higher planting density than normal—46.6 plants m^{-2}

Table 3 Interaction effect of genotypes × planting densities on total dry matter production (TDMP) of chickpea under irrigated ecosystem

Genotypes	Planting densities	TDMP (g plant^{-1})											
		30 DAS			60 DAS			75/90 DAS$^{\#}$			At harvest		
		1st year	2nd year	Mean	1st year	2nd year	Mean	1st year	2nd year	Mean	1st year	2nd year	Mean
ICCV-11601	Normal	6.05^{a}	6.42^{a}	6.23^{a}	17.95^{c}	18.62^{cd}	18.28^{c}	30.71^{a}	33.39^{a}	32.05^{a}	34.51^{a}	37.12^{a}	35.81^{a}
	20% higher	5.66^{a}	5.96^{a}	5.81^{a}	15.63^{d}	16.54^{e}	16.08^{e}	26.86^{c}	29.3^{cd}	28.08^{d}	31.52^{b}	34.44^{b}	32.98^{b}
	40% higher	5.10^{a}	5.49^{a}	5.29^{a}	13.35^{e}	13.93^{fg}	13.64^{f}	23.45^{de}	25.63^{ef}	24.54^{f}	26.83^{d}	30.13^{cd}	28.48^{d}
ICCV-11602	Normal	4.50^{a}	4.88^{a}	4.69^{a}	15.42^{d}	16.06^{e}	15.74^{e}	26.44^{c}	28.18^{d}	27.31^{d}	28.91^{c}	31.70^{c}	30.31^{c}
	20% higher	4.25^{a}	4.55^{a}	4.40^{a}	13.29^{e}	13.95^{fg}	13.62^{f}	23.30^{e}	24.85^{f}	24.07^{fg}	25.09^{e}	27.74^{de}	26.41^{e}
	40% higher	3.98^{a}	4.24^{a}	4.11^{a}	11.26^{f}	11.98^{g}	11.62^{h}	20.53^{f}	22.32^{g}	21.42^{h}	21.77^{f}	24.29^{f}	23.03^{g}
ICCV-11603	Normal	5.61^{a}	5.87^{a}	5.74^{a}	17.26^{c}	17.98^{d}	17.62^{d}	28.26^{b}	29.97^{c}	29.11^{c}	31.25^{b}	34.12^{b}	32.69^{b}
	20% higher	5.21^{a}	5.42^{a}	5.31^{a}	15.03^{d}	15.76^{ef}	15.40^{e}	25.88^{cd}	27.37^{de}	26.63^{e}	27.92^{cd}	30.37^{cd}	29.14^{cd}
	40% higher	4.76^{a}	4.96^{a}	4.86^{a}	12.70^{ef}	13.39^{fg}	13.05^{fg}	22.96^{e}	24.48^{fg}	23.72^{g}	23.86^{e}	26.10^{e}	24.98^{f}
ICCV-11604	Normal	4.89^{a}	5.19^{a}	5.04^{a}	15.52^{d}	16.27^{e}	15.90^{e}	29.42^{ab}	31.31^{bc}	30.37^{b}	35.82^{a}	37.75^{a}	36.78^{a}
	20% higher	4.59^{a}	4.81^{a}	4.70^{a}	13.83^{e}	14.52^{f}	14.18^{f}	25.85^{cd}	28.72^{cd}	27.29^{de}	31.95^{b}	33.75^{b}	32.85^{b}
	40% higher	4.30^{a}	4.50^{a}	4.40^{a}	11.99^{f}	12.65^{g}	12.32^{gh}	23.24^{e}	26.37^{e}	24.81^{f}	28.14^{cd}	30.45^{cd}	29.29^{c}
JG-11	Normal	5.21^{a}	5.05^{a}	5.13^{a}	25.17^{a}	25.90^{a}	25.53^{a}	29.69^{a}	31.81^{b}	30.75^{b}	31.57^{b}	33.99^{b}	32.78^{b}
	20% higher	4.64^{a}	4.93^{a}	4.78^{a}	21.66^{b}	22.47^{b}	22.07^{b}	24.70^{d}	27.97^{d}	26.34^{e}	26.55^{de}	29.20^{d}	27.87^{d}
	40% higher	4.21^{a}	4.39^{a}	4.30^{a}	18.00^{c}	19.81^{c}	18.91^{c}	20.73^{f}	23.35^{g}	22.04^{h}	21.54^{f}	23.97^{f}	22.76^{g}
S.Em ±		0.66	0.50	0.41	0.45	0.46	0.31	0.46	0.47	0.33	0.76	0.67	0.42

Means with the same letter(s) are not significantly different at 5% level of probability

DAS, Days after sowing; $^{\#}$75 DAS for JG-11 and 90 DAS for other varieties; Normal density—33.3 plants m^{-2}; 20% higher density than normal—39.9 plants m^{-2}; 40% higher density than normal—46.6 plants m^{-2}

also depend on agronomic practices and morphology of a genotype (Mansur et al. 2009). Thus, identifying all such favourable growth and yield attributes and their integration in one genotype leads to better performance over other. In the present study, the semi-erect genotype JG-11 recorded to the extent of 24, 18, 26, and 15% higher seed yield than tall genotypes viz., ICCV-11601, ICCV-11602, ICVV-11603, and ICCV-11604, respectively. Seed yield was governed by the number of growth and yield components that have a direct or indirect impact. Among the yield components, pod and seed yield per plant more closely related to seed yield, which was higher in semi-erect genotype JG-11 followed by tall genotype ICCV-11604. Other yield components in turn determine yields per plant in chickpea (Jadhav and Pawar 1999; Chaitanya and Chandrika 2006).

Table 4 Yield attributes of chickpea genotypes as influenced by planting densities under irrigated ecosystem

Treatment	Pod yield (g plant^{-1})			Seed yield (g plant^{-1})			100-seed weight (g)		
	1st year	2nd year	Mean	1st year	2nd year	Mean	1st year	2nd year	Mean
Genotypes									
ICCV-11601	12.27^{cd}	12.72^{d}	12.50^{d}	10.14^{c}	10.59^{c}	10.37^{d}	23.66^{ab}	24.38^{a}	24.02^{a}
ICCV-11602	12.52^{c}	12.98^{c}	12.75^{c}	10.38^{c}	10.86^{c}	10.62^{c}	17.58c	18.39^{c}	17.99^{c}
ICCV-11603	12.00^{d}	12.83^{cd}	12.41^{d}	9.85^{d}	10.68^{c}	10.27^{d}	22.47^{b}	23.07^{b}	22.77^{b}
ICCV-11604	12.90^{b}	13.63^{b}	13.27^{b}	10.66^{b}	11.39^{b}	11.02^{b}	24.12^{a}	24.99^{a}	24.55^{a}
JG-11	13.65^{a}	14.13^{a}	13.89^{a}	11.49^{a}	11.96^{a}	11.73^{a}	23.36^{ab}	24.42^{a}	23.89^{a}
S.Em ±	0.08	0.08	0.06	0.08	0.09	0.06	0.45	0.33	0.28
Planting densities									
Normal density	13.21^{a}	13.80^{a}	13.50^{a}	11.04^{a}	11.62^{a}	11.33^{a}	22.58^{a}	23.41^{a}	23.00^{a}
20% higher	12.68^{b}	13.27^{b}	12.97^{b}	10.51^{b}	11.12^{b}	10.81^{b}	22.25^{a}	23.04^{a}	22.64^{a}
40% higher	12.12^{c}	12.71^{c}	12.41^{c}	9.96^{c}	10.55^{c}	10.26^{c}	21.89^{a}	22.71^{a}	22.30^{a}
S.Em ±	0.06	0.06	0.04	0.06	0.07	0.04	0.40	0.41	0.29
Interaction effect	*	*	*	*	*	*	ns	ns	ns

Means with the same letter(s) are not significantly different at 5% level of probability

*Significant at 5%; ns, not significant; Normal planting density—33.3 plants m^{-2}; 20% higher planting density than normal—39.9 plants m^{-2}; 40% higher planting density than normal—46.6 plants m^{-2}

Table 5 Interaction effect of genotypes × planting densities on yield attributes of chickpea under irrigated ecosystem

Genotypes	Planting densities	Pod yield (g plant^{-1})			Seed yield (g plant^{-1})			100-seed weight (g)		
		1st year	2nd year	Mean	1st year	2nd year	Mean	1st year	2nd year	Mean
ICCV-11601	Normal	12.71^{cd}	13.18^{d}	12.94^{d}	10.57^{de}	11.03^{cd}	10.80^{de}	24.18^{a}	24.91^{a}	24.54^{a}
	20% higher	12.27^{de}	12.73^{e}	12.50^{e}	10.14^{e}	10.60^{de}	10.37^{f}	23.66^{a}	24.27^{a}	23.96^{a}
	40% higher	11.84^{ef}	12.25^{f}	12.05^{f}	9.72^{f}	10.13^{e}	9.93^{g}	23.14^{a}	23.97^{a}	23.56^{a}
ICCV-11602	Normal	12.96^{c}	13.39^{cd}	13.17^{cd}	10.80^{cd}	11.24^{cd}	11.02^{d}	17.91^{a}	18.67^{a}	18.29^{a}
	20% higher	12.54^{d}	12.99^{de}	12.76^{de}	10.40^{de}	10.91^{d}	10.65^{ef}	17.57^{a}	18.30^{a}	17.93^{a}
	40% higher	12.07^{e}	12.56^{ef}	12.32^{e}	9.94^{ef}	10.43^{e}	10.18^{fg}	17.28^{a}	18.21^{a}	17.75^{a}
ICCV-11603	Normal	12.46^{de}	13.3^{cd}	12.88^{d}	10.31^{de}	11.14^{cd}	10.73^{e}	23.02^{a}	23.35^{a}	23.19^{a}
	20% higher	12.03^{e}	12.85^{de}	12.44^{e}	9.87^{ef}	10.70^{de}	10.29^{f}	22.56^{a}	22.99^{a}	22.78^{a}
	40% higher	11.50^{f}	12.33^{f}	11.92^{f}	9.37^{f}	10.20^{e}	9.79^{g}	21.84^{a}	22.86^{a}	22.35^{a}
ICCV-11604	Normal	13.33^{bc}	14.05^{b}	13.69^{b}	11.08^{c}	11.79^{bc}	11.44^{c}	24.28^{a}	25.16^{a}	24.72^{a}
	20% higher	12.91^{cd}	13.64^{c}	13.27^{c}	10.66^{d}	11.40^{c}	11.03^{d}	24.02^{a}	25.01^{a}	24.52^{a}
	40% higher	12.47^{de}	13.21^{d}	12.84^{d}	10.23^{e}	10.97^{cd}	10.6^{ef}	24.05^{a}	24.80^{a}	24.43^{a}
JG-11	Normal	14.60^{a}	15.07^{a}	14.83^{a}	12.44^{a}	12.91^{a}	12.67^{a}	23.53^{a}	24.96^{a}	24.25^{a}
	20% higher	13.64^{b}	14.14^{b}	13.89^{b}	11.48^{b}	11.97^{b}	11.73^{b}	23.42^{a}	24.61^{a}	24.02^{a}
	40% higher	12.72^{cd}	13.17^{d}	12.95^{d}	10.56^{de}	11.01^{cd}	10.78d^{e}	23.12^{a}	23.69^{a}	23.41^{a}
S.Em ±		0.13	0.12	0.09	0.13	0.15	0.10	0.90	0.91	0.64

Means with the same letter(s) are not significantly different at 5% level of probability

Normal density—33.3 plants m^{-2}; 20% higher density than normal—39.9 plants m^{-2}; 40% higher density than normal—46.6 plants m^{-2}

Thus, owing to the integration of all the favourable yield components such as relatively more 100-seed weight and higher pod and seed yield per plant in tall genotype ICCV-11604, produced significantly higher seed yield compared to the rest of the tall genotypes. The improvement of biological yield in ICCV-11604 was to the tune of 7.31% higher than JG-11. This improvement in ICCV-11604 might be due to taller plants and more total dry matter production. The differences in yield and yield attributing characters among the genotypes might be due to the genetic constitution of different genotypes, which provided the inherent capacity to perform genotypes in different ways. The difference among the genotypes also observed by several researchers (Masood and Singh 1999; Lather 2000; Satish and Kadian 2006; Verma et al. 2009; Goyal et al. 2010; Prasad et al. 2012; Singh et al. 2019).

Differences in yield and yield components could also be traced back to differences in TDMP and its distribution into different parts. The JG-11 efficient in producing more TDMP than tall genotypes at the initial stages and tall genotype ICCV-11604 at later stages. Similar results of variation in TDMP in chickpea genotypes based on their agronomic traits reported by Jadhav and Pawar (1999) and Satish et al. (2006). However, TDMP alone does not wholly reflect the efficiency of genotypes. Still, its accumulation in different parts, mainly in the plant's reproductive parts, is significant (Bing et al. 2015). When partitioning of total dry matter in different parts examined, it was apparent that JG-11 accumulated a higher proportion of dry matter in pods throughout the reproductive phase than all other genotypes. That apart, tall genotypes ICCV-11601 and ICCV-11604 accumulated higher DMA in stem and leaves, particularly the later one indicating the more photosynthetic efficiency of the plants, i.e., the more the DMA in leaves. Because of these characteristics, ICCV-11604 produced a higher quantum of photosynthates at harvest due to DMA in reproductive parts, contributing to higher seed yield. The chickpea plants' architecture modified the solar light penetration inside the crop canopy, which influenced plants' growth and development in response to different genotypes (Cici et al. 2008). On the same line, the tall genotype ICCV-11604 with higher translocation efficiency coupled with better sink capacity outperformed other genotypes. Such differential behaviour in TDMP and its distribution among chickpea genotypes could also ascribe to genotypes' genetic characteristics (Chaitanya and Chadrika 2006; Goyal et al. 2010; Prasad et al. 2012).

Planting Density Effect

Planting density adjustment is an essential agronomic manipulation for attaining higher yields (Munirathnam et al. 2015). The higher yields for a particular crop and environment can be obtained at that planting density where competition between the plants will be minimum. Genotype-based optimum planting density helps to efficiently utilize growth resources like soil, nutrients, and solar radiation (Agajie 2018). The optimum planting density depends on the type of genotype use (tall, erect, semi-erect, etc.) and its plant architecture to accommodate more plants per unit area (Singh et al. 2019). The genotype with tall/erect growth habits may be useful as they could resist excessive vegetative growth and accommodate more plants per unit area (Dahiya and

Table 6 Seed yield, biological yield and harvest index of chickpea genotypes as influenced by planting densities under irrigated ecosystem

Treatment	Seed yield (kg ha^{-1})			Biological yield (kg ha^{-1})			Harvest index (%)		
	1st year	2nd year	Mean	1st year	2nd year	Mean	1st year	2nd year	Mean
Genotypes									
ICCV-11601	2184^{c}	2433^{c}	2309^{d}	6224^{a}	6425^{b}	6325^{a}	34.87^{c}	37.20^{c}	36.03^{c}
ICCV-11602	2299^{bc}	2536^{bc}	2418^{c}	5891^{b}	6230^{c}	6061^{bc}	38.62^{b}	40.23^{b}	39.42^{b}
ICCV-11603	2176^{c}	2385^{c}	2280^{d}	5928^{b}	6341^{bc}	6135^{b}	36.16^{bc}	36.87^{c}	36.51^{c}
ICCV-11604	2388^{b}	2633^{b}	2511^{b}	6271^{a}	6611^{a}	6441^{a}	37.59^{b}	39.02^{bc}	38.30^{b}
JG-11	2783^{a}	2948^{a}	2865^{a}	5788^{b}	6216^{c}	6002^{c}	46.85^{a}	47.16^{a}	47^{a}
S.Em ±	48	35	30	75	40	42	0.77	0.61	0.49
Planting densities									
Normal density	2065^{c}	2274^{c}	2169^{c}	5471^{c}	5865^{c}	5668^{c}	37.84^{b}	38.92^{b}	38.38^{b}
20% higher	2396^{b}	2617^{b}	2506^{b}	5997^{b}	6327^{b}	6162^{b}	39.28^{a}	40.60^{a}	39.94^{a}
40% higher	2638^{a}	2871^{a}	2754^{a}	6593^{a}	6902^{a}	6748^{a}	39.32^{a}	40.76^{a}	40.04^{a}
S.Em ±	26	23	18	51	34	31	0.42	0.26	0.25
Interaction effect	*	*	*	*	*	*	*	*	*

Means with the same letter(s) are not significantly different at 5% level of probability

*Significant at 5%; Normal planting density—33.3 plants m^{-2}; 20% higher planting density than normal—39.9 plants m^{-2}; 40% higher planting density than normal—46.6 plants m^{-2}

Table 7 Interaction effect of genotypes × planting densities on seed yield, biological yield and harvest index of chickpea under irrigated ecosystem

Genotypes	Planting densities	Seed yield (kg ha^{-1})			Biological yield (kg ha^{-1})			Harvest index (%)		
		1st year	2nd year	Mean	1st year	2nd year	Mean	1st year	2nd year	Mean
ICCV-11601	Normal	1864^{e}	2105^{f}	1985^{h}	5747^{cd}	5956de	5852de	32.63^{d}	35.43^{d}	34.03^{e}
	20% higher	2217^{d}	2466^{d}	2341^{ef}	6177^{bc}	6404^{c}	6291^{c}	35.7^{c}	37.62^{c}	36.66^{cd}
	40% higher	2472^{c}	2729^{c}	2601^{d}	6748^{a}	6915^{ab}	6832^{a}	36.27^{c}	38.54^{c}	37.41^{cd}
ICCV-11602	Normal	1967^{e}	2200^{ef}	2084^{gh}	5065^{e}	5515^{f}	5290^{f}	38.87^{b}	39.96^{bc}	39.42^{bc}
	20% higher	2331^{cd}	2567^{d}	2449^{e}	5858^{c}	6157^{d}	6008^{d}	39.15^{b}	41.01^{b}	40.08^{b}
	40% higher	2598^{bc}	2842^{bc}	2720^{c}	6751^{a}	7017^{ab}	6884^{a}	37.83^{bc}	39.73^{bc}	38.78^{bc}
ICCV-11603	Normal	1865^{e}	2064^{f}	1965^{h}	5447^{d}	5883^{e}	5665^{e}	34.32^{cd}	35.16^{d}	34.74d^{e}
	20% higher	2212^{d}	2417de	2314^{f}	5895^{c}	6332^{cd}	6114^{cd}	36.73^{bc}	37.05^{cd}	36.89^{cd}
	40% higher	2451^{c}	2673^{cd}	2562^{d}	6442^{ab}	6809^{b}	6626^{b}	37.42^{bc}	38.42^{c}	37.92^{c}
ICCV-11604	Normal	2027^{e}	2267^{e}	2147^{g}	5782^{cd}	6163^{d}	5972^{d}	35.71^{c}	36.87^{cd}	36.29^{d}
	20% higher	2423^{c}	2666^{cd}	2544de	6275^{b}	6601^{bc}	6438^{bc}	37.8^{bc}	39.42^{bc}	38.61^{bc}
	40% higher	2715^{b}	2966^{b}	2840^{b}	6755^{a}	7071^{a}	6913^{a}	39.25^{b}	40.76^{b}	40.00^{b}
JG-11	Normal	2599^{bc}	2733^{c}	2666^{cd}	5314de	5807^{e}	5561^{e}	47.69^{a}	47.19^{a}	47.44^{a}
	20% higher	2796^{ab}	2967^{b}	2882^{b}	5780^{cd}	6142^{d}	5961^{d}	47.02^{a}	47.93^{a}	47.48^{a}
	40% higher	2952^{a}	3143^{a}	3048^{a}	6269^{b}	6700^{b}	6485^{bc}	45.83^{a}	46.35^{a}	46.09^{a}
S.Em ±		59	52	39	115	75	69	0.94	0.59	0.56

Means with the same letter(s) are not significantly different at 5% level of probability

Normal density—33.3 plants m^{-2}; 20% higher density than normal—39.9 plants m^{-2}; 40% higher density than normal—46.6 plants m^{-2}

Table 8 Correlation among the total dry matter production and partitioning in different parts (at harvest) and yield attributes

	DMA in leaves (g plant^{-1})	DMA in stem (g plant^{-1})	DMA reproductive parts (g plant^{-1})	TDMP (g plant^{-1})	Pod yield (g plant^{-1})	Seed yield (g plant^{-1})	100-seed weight (g)
DMA in leaves (g plant^{-1})	–						
DMA in stem (g plant^{-1})	0.85	–					
DMA reproductive parts (g plant^{-1})	0.49	0.20	–				
TDMP (g plant^{-1})	0.89	0.78	0.76	–			
Pod yield (g plant^{-1})	0.34	−0.10	0.89	0.51	–		
Seed yield (g plant^{-1})	0.33	−0.12	0.89	0.50	0.98	–	
100-seed weight (g)	0.24	0.23	0.50	0.44	0.31	0.28	–

DMA, dry matter accumulation; TDMP, total dry matter production

Lather 1990). According to Muehlbauer and Singh (1987), tall/erect chickpea lines have fewer primary and secondary branches, and hence lower yields; increasing planting density has been proposed to increase yield per unit area. In the present study, the results demonstrated an increase in planting density decreased the yields per plant but increased the yields per unit area. At 40% higher planting density (46.6 plants m^{-2}) and 20% higher density (39.9 plants m^{-2}) produced significantly higher seed yield per hectare than normal planting density (33.3 plants m^{-2}). However, growth and yield attribute better in normal planting density, which was mainly due to better resource availability and reduced interplant competition in the community (Karwasra and Faroda 1979; Singh et al. 2019), who also observed higher growth and yield attributes with lesser planting density in wider row spacing as compared to high-density of planting. Though yield attributing characters like pod and seed yield per plant better in normal planting density, the maximum seed and biological yield produced at 40% higher planting density. These improvements not sufficient to compensate for the increased plant number per unit area obtained from 40% enhanced planting density. Mansur et al. (2009) at Dharwad, India, also reported that chickpea genotypes produced significantly higher seed and biological yield with a higher

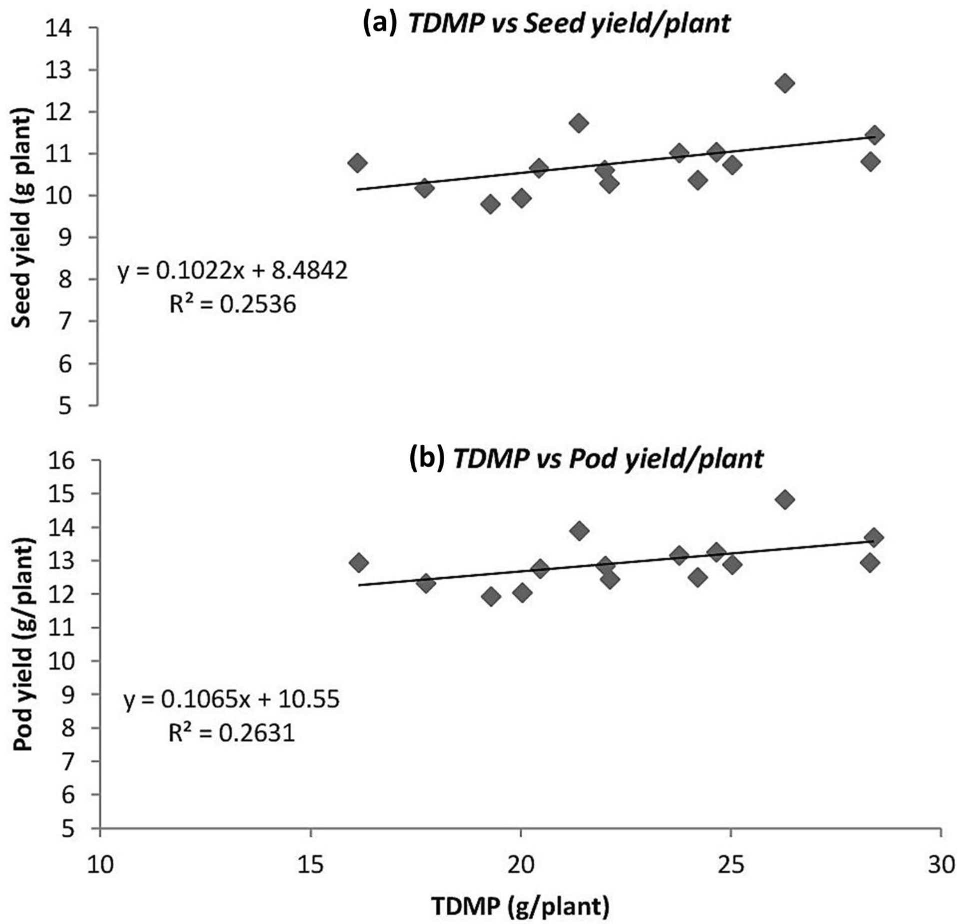

Fig. 5 Relationship between total dry matter production (TDMP) and yield attributes; **a** seed yield per plant, **b** pod yield per plant

planting density (44.0 plants m^{-2}). Some other previous studies showed that the yield per unit of chickpea increased with an increase in density from 33 to 54 plants m^{-2} (Ahmadian et al. 2005) and at a higher density of 45 plants m^{-2} (Yigitoglu 2006). Similar results were reported by Shaikh and Mungse (1998) and Kashfi et al. (2010). Increasing planting density by decreasing inter and intrarow spacing might have increased interspecific competition, which eventually reduced seed weight.

Moreover, decreasing planting density might have created more sunlight to penetrate the canopy that benefits more from the natural environment. Thus, this might have caused an increase in the number of branches and the increased photosynthesis level, resulting in more assimilates translocated and stored in seeds. The previous researchers reported that a hundred-seed weight was negatively related to planting density (Abate 2003; Agajie 2018). However, this experiment's result was not in line with other researchers who reported that individual seed weight was affected by planting density. A similar study made by Mansur et al. (2009) and Mekuanint et al. (2018) revealed no significant difference for this trait.

The TDMP and its accumulation in different plant parts were higher in normal planting density than 20% and 40% higher planting density. The highest TDMP at normal planting density may be attributed to significantly higher leaf area, the number of branches leading to higher DMA in leaves, stem, and reproductive parts. A similar result obtained by Mansur et al. (2009) reported that higher TDMP was observed at lower planting density than higher density in chickpea. The DMA in reproductive parts also depends on plants' photosynthetic ability at various growth stages, and that can be analyzed through DMA in leaves. These results are in agreement with Shaikh and Mungse (1998) and Naik et al. (2012).

Genotype × Planting Density Interaction Effect

The interaction effect of genotype × planting density significantly influenced TDMP and its distribution at different growth stages of chickpea. The interaction effects also significant concerning yield and yield components indicated that the genotypes differed in their phenotypic characters to their interaction with planting densities. The seed yield of chickpea was significantly higher in the interaction of JG-11 and 40% higher planting density compared to the rest of the interactions. These results are in agreement with Lather (2000). The increment in seed yield with an increase in planting density to 20% and 40% higher than normal was very less in the case of semi-erect genotype JG-11 but more in tall genotypes. On the same line, Munirathnam et al. (2015) observed that grain yield of machine harvestable chickpea genotype NBeG47 increased with increasing the planting density from 33 to 55 plants m^{-2}.

The progressive yield increase in the tall genotypes with planting densities can be attributed to pods' position. Pods are borne higher on the canopy permit yield increases in higher planting density and resulted in better light usage for photosynthesis—a similar observation made by Calcagno et al. (1988). Singh et al. (1980) found that the optimum planting density for chickpea was 25 plants m^{-2}, but that higher density may not be optimum for tall, erect genotypes that can bear pods high in the canopy. On the same line, Bythet al. (1979) reported that a tall type of chickpea genotype (NEC-138) produced 60% more yield at 50 plants m^{-2} than at 16.7 plants m^{-2}, while a local bushy variety showed little response. Singh et al. (2019) also reported a 9% increase in grain yield in tall chickpea variety HC 5 with closer spacing over normal plant spacing. The increased grain yield of variety HC 5 in closer spacing was mainly attributed to an increase in planting density (33%); however, all the plant attributes were reduced in high-density planting.

Significantly higher TDMP was observed in semi-erect genotype JG-11 at normal planting density at the initial crop growth stage. However, at harvest, significantly higher TDMP was found with tall genotype ICCV-11604 planted at normal density followed by ICCV-11601 with normal planting density. Tall genotypes had a relatively more vegetative growth period than semi-erect genotype JG-11, and it contributed to the pod dry matter in later stages, resulting in higher TDMP (Lather 2000). Therefore, the maximum biological yield was found with tall genotype ICCV-11604 at a 40% higher density. A significant increase in DMA in different parts is dependent on the contribution from growth parameters. Considerable improvement in the sink size (pods, grain weight, test weight, etc.) could be due to increased primary branches per plant, resulting in more reproductive parts. These parameters have contributed to better dry matter partitioning and distribution into different plant parts. The positive relationship of TDMP vs. pod yield per plant and TDMP vs. seed yield per plant was also reported by Mansur (2003).

Conclusion

The present study demonstrated that planting density significantly affected dry matter production and partitioning and yield of machine harvestable chickpea genotypes in irrigated ecosystems. The increased planting density compensates for the yield reduction in tall/erect chickpea genotypes and improves the plant architecture to facilitate mechanical harvesting but not for semi-erect genotype JG-11. The tall/erect genotype ICCV-11604 recorded higher dry matter production and partitioning than other tested genotypes but higher yield and yield attributes in semi-erect genotype JG-11, closely followed by ICCV-11604. However, in planting densities, the increased planting density from 33.3 to 46.6 plants m^{-2} decreased the dry matter production and partitioning and yield attributes per plant. Still, it increased the seed and biological yield per hectare. Therefore, we conclude that the tall/erect genotype ICCV-11604 planting at higher density of 46.6 plants m^{-2} in the irrigated ecosystem is a better option for adopting machine harvestable chickpea genotypes to reduce the drudgery on scarce labour and save time and cost. This study can help use machine harvestable chickpea genotypes with high-density planting to compensate for the relatively low yields in these genotypes and reduce the cost of chickpea cultivation. Further, we suggest the research on fertilizer and irrigation requirements for these machine harvestable genotypes to explore these genotypes' potential.

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