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Effect of plant density and plant growth regulators on yield and economics of cotton (*Gossypium hirsutum* L.)

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Abstract
A field experiment was conducted during *kharif*, 2022 at RARS, Lam. The experiment was laid out in Split-plot design with two main plots; M_1: Normal density (120 cm x 60 cm); M_2: High density (60 cm x 30 cm) and five sub-plots (Plant growth regulators and boron spray) *viz.*, S_1: Paclobutrazole @ 40 g *a.i.* ha^{-1}; S_2: NAA @ 20 ppm; S_3: Mepiquat chloride @ 100 ppm (each sprayed twice at 45 and 60 DAS); S_4: Boron @ 0.1% at 60 and 90 DAS and S_5: Control. Results revealed that high density planting (M_2) recorded maximum seed cotton yield (2131 kg ha^{-1}) and stalk yield (4678 kg ha^{-1}). Among the subplots, the boron nutrition (S_4) recorded maximum seed cotton yield (2002 kg ha^{-1}) and stalk yield (2461 kg ha^{-1}). The higher gross returns (1, 29, 559 Rs. ha^{-1} and 1, 21, 751 Rs. ha^{-1}), net returns (64, 254 Rs. ha^{-1} and 1, 21, 751 Rs. ha^{-1}), and benefit-cost ratio (1.98 and 2.17) were also recoded in high-density planting (M_2) and boron nutrition (S_4), respectively. The interaction of plant density and PGRs application was found non-significant. Hence, it can be concluded that high-density planting and boron nutrition are advantageous for cotton cultivation on black cotton soils of Guntur region.

Keywords: Plant density, plant growth regulators, boron nutrition, seed cotton yield, and economics

Introduction
Cotton is known as "White gold" due to its high commercial value. India is a leading cotton-growing country in the globe with 13.05 million hectares of area and 33.72 million bales production, respectively, supervened by the United States (3.01 M ha; 31.96 M bales) and China (3.03 M ha; 59.8 M bales). Andhra Pradesh with 6.95 lakh ha of cotton cultivation area stands in sixth position in area with production of 18.85 Lakh bales and fourth position in productivity with 461 kg lint ha^{-1} in India (ICAR-AICRP on Cotton Annual Report, 2022-23). The cotton productivity in the world during 2021-2022 was 1367 kg ha^{-1} and the productivity of cotton in India was 451 kg ha^{-1} (www.indiastat.com). There is a huge gap in productivity, which need to be boosted through systematic research work. High-density planting is an innovative approach for achieving high productivity in cotton; it requires careful planning, the right timing of sowing, close monitoring, and systematic research (Venugopalan *et al.*, 2013) [12]. Increased plant density leads plants to grow taller and experience higher vegetative growth, which increases competition among plants for resources and affects the balance between plant's vegetative and reproductive stages. For good square development, boll development, boll retention, and seed cotton yield, there were no sufficient photosynthates translocated. The source-sink relationship needs to be adjusted in order to resolve these issues. Plant growth regulators are capable of increasing yield by 100-200 per cent under laboratory conditions and 10-15 per cent in field conditions (Kirankumar *et al.*, 2001) [8]. Boron is one micronutrient having significant influence on yield attributes, yield, and economics of cotton. The study was therefore conducted to study the effect of plant density and plant growth regulators on yield and economics of cotton.

Materials and Methods
The experiment was conducted at Regional Agricultural Research Station, Lam, Andhra Pradesh in split plot design with two main plots (plant densities); M_1: Normal density (120 cm x 60 cm); M_2: High density (60 cm x 30 cm) and five sub-plots (Plant growth regulators and boron spray) *viz.*, S_1: Paclobutrazole @ 40 g *a.i.* ha^{-1}; S_2: NAA @ 20 ppm; S_3: Mepiquat chloride @ 100 ppm (each sprayed at 45 and 60 DAS); S_4: Boron @ 0.1% at 60 and 90 DAS and S_5: Control, which are replicated thrice.

The chemical properties of the experimental plot were determined by drawing representative soil samples randomly before the commencement of the experiment from a depth of 30 cm and composite samples were prepared and analysed for the chemical properties of the soil. The soil of the experimental plot was clay in texture with slight alkali in reaction (pH 7.9), low in organic carbon (0.31%) and available nitrogen (236 kg ha^{-1}), high in available phosphorus (36 kg ha^{-1}), and high in available potassium (684 kg ha^{-1}). The genotype used for the present study was popular Bt-hybrid (Platinum BG II). The nutrients (NPK) application was done as per the recommended dose (120-60-60 kg NPK ha^{-1}). The entire quantity of phosphorous was applied as basal and nitrogen and potassium were applied in three equal splits at 60 DAS and 90 DAS. Experiment was conducted purely under rainfed conditions. The data on seed cotton yield and stalk yield were recorded as per the standard procedures and statical analysis of data pertaining to seed cotton yield, stalk yield were carried out following the analysis of variance technique for split-plot design as given by Panse and Sukhatame (1978) [11].

Results and Discussion

Effect of plant density and plant growth regulators on seed cotton yield

The data on seed cotton yield was given in Table 1. Plant densities have a significant influence on seed cotton yield. High-density planting (M_2: 60 cm x 30 cm) recorded higher seed cotton yield of 2131 kg ha^{-1} which was 31.8% higher over 1454 kg ha^{-1} with normal-density planting (M_1: 120 cm X 60 cm). This might be due to an increase in the number of bolls and sympodial branches per unit area over normal density. Similar kind of results was noticed by Khan *et al.* (2020) [7].

Boron nutrition (S_4) treatment recorded significantly higher seed cotton yield over other plant growth regulators and yield increase was 22.2% higher over control (S_5). However, it was on a par with S_1 and S_3. It might be due to a direct influence of boron on flower development, pollen germination, fertilization, seed development, and fruit abscission (Brown *et al.*, 2002) [4]. An increase in seed cotton yield was linked to the direct role of boron in fertilization, pollen production, increase in pollen viability, pollen germination, and pollen tube growth reported by Agarwal *et al.* (1981) [1]. An increase in total number of bolls per unit area and the number of retained bolls per unit area has a direct influence on increased seed cotton yield per unit area. Similar findings were also observed with Ahmed *et al*. (2013) [2]. Lower plant densities though produced higher values of growth and yield attributes per plant, but yield per unit area was higher with high-plant densities. Changes in plant density might have modified the microclimate that might alter the incidence of pests and diseases as well which had been shown to enhance yield related physiological functions by increasing gross plant photosynthesis or by increasing the retention of bolls per unit area by enhanced partitioning of photosynthates to fruiting forms. The interaction effect of plant densities and plant growth regulators application and boron nutrition on seed cotton yield was found to be non-significant.

Plant densities showed a significant influence on stalk yield (Table 1). High-density planting (M_2: 60 cm X 30 cm) recorded higher stalk yield over normal-density planting (M_1: 120 cm X 60 cm). Although the accumulation of biomass per plant might have decreased due to dense canopy formation, which reduced light interception and increased resource competition, however, it was balanced by higher biomass production per unit area as a result of high-density planting. Similar kind of results were also obtained by Khan *et al.* (2020a) [7]. Control (S_5) recorded significantly higher stalk yield per hectare (4245 kg ha^{-1}). However, it was at par with S_4 and S_2. The lowest stalk yield per hectare was recorded with S_3 (Mepiquat chloride @ 100 ppm at 45 DAS and 60 DAS) that might be due to decreased plant height along with low drymatter. Similar results were reported by Bhorage (2016) [3]. Interaction effect of plant densities and plant growth regulators application and boron nutrition on stalk yield was found to be non-significant.

Effect of plant density and plant growth regulators on economics of cotton

Plant densities and PGRs application influenced the economics of cotton (Table 2). High-density planting (M_2: 60 cm X 30 cm) recorded higher gross returns (Rs. 1, 29, 559 ha^{-1}) and net returns (Rs. 64,254 ha^{-1}) than normal-density planting (M_1: 120 cm X 60 cm) which recorded gross returns of Rs. 88,398 ha^{-1} and net returns of Rs. 41,097 ha^{-1}. The narrow spacing recorded considerably the highest seed cotton yield, maximum gross monetary returns, net monetary returns, and B: C ratio compared to wider spacing due to more picked bolls per unit area (Kumar *et al.*, 2018) [9].

Foliar application of plant growth regulators and boron nutrition positively influenced the cotton production and economics. Boron nutrition (S_4) treatment recorded higher gross returns and net returns over S_3, S_2, and S_5. Gross returns were recorded in the order $S_4 > S_1 > S_3 > S_2 > S_5$ which was 22.2, 14.9, 13.6, 11.9% higher than control (S_5). Net returns also followed a similar pattern *i.e.*, 40.0, 27.7, 25.3, and 23.6% higher over control (S_5). It might be due to higher seed cotton yield (More *et al.*, 2022) [10].

High-density planting (M_2) recorded a higher B: C ratio (1.98) than normal-density planting (M_1-1.87). The narrow spacing was recorded considerably the highest seed cotton yield, maximum gross monetary returns, net monetary returns, and B:C ratio as compared to wider spacing due to a greater number of picked bolls per unit area (Kumar *et al.*, 2018) [9]. Among the sub plots, boron nutrition (S_4) treatment recorded numerically higher BC ratio over S_3, S_2 and S_5. B: C ratio was recorded in the order $S_4 > S_1 > S_3 > S_2 > S_5$ (2.16, 1.94, 1.92, 1.89 and 1.71, respectively), it might be due to higher seed cotton yield, gross monetary returns, and net monetary returns (More *et al.*, 2022) [10].

Interaction effect of plant densities and plant growth regulators application and boron nutrition on gross returns, net returns, and B: C was found to be non-significant.

Table 1: Seed cotton yield (kg ha^{-1}) and stalk yield (kg ha^{-1}) of cotton as influenced by different plant densities and growth regulators application

Treatments	Seed cotton yield (kg ha^{-1})	Stalk yield (kg ha^{-1})
Plant Densities (M)		
M_1 - 120 cm X 60 cm (13,888 pl. ha^{-1})	1454	2461
M_2 - 60 cm X 30 cm (55,555 pl. ha^{-1})	2131	4678
S.Em (+)	34.8	104.6
CD (P=0.05)	212	637
CV (%)	7.5	11.4
Plant Growth Regulators(S)		
S_1- PB@ 40 g *a.i.* ha^{-1} at 45 & 60 DAS	1831	3305
S_2- NAA @ 20 ppm at 45 & 60 DAS	1769	3733
S_3- MC @ 20 ppm at 45 & 60 DAS	1803	2717
S_4- Boron @ 0.1% at 60 & 90 DAS	2002	3844
S_5- Control	1557	4245
S.Em (+)	85.6	173.1
CD (P=0.05)	257	519
CV (%)	11.7	12.2
Interaction (M x S) & (S x M)		
CD (P=0.05)	NS	NS

Table 2: Gross returns (Rs. ha^{-1}), net returns (Rs. ha^{-1}) and B:C of cotton as influenced by different plant densities and growth regulators application

Treatments	Cost of cultivation (Rs. ha^{-1})	Gross returns (Rs. ha^{-1})	Net returns (Rs. ha^{-1})	BC ratio
Plant Densities (M)				
M_1 - 120 cm X 60 cm (13,888 pl. ha^{-1})	47301	88398	41097	1.87
M_2 - 60 cm X 30 cm (55,555 pl. ha^{-1})	65305	129559	64254	1.98
Plant Growth Regulators(S)				
S_1- PB@ 40 g *a.i.* ha^{-1} at 45 & 60 DAS	56900	111328	54428	1.96
S_2- NAA @ 20 ppm at 45 & 60 DAS	56100	107557	51457	1.92
S_3- MC @ 100 ppm at 45 & 60 DAS	56955	109594	52639	1.92
S_4- Boron @ 0.1% at 60 & 90 DAS	56210	121751	65541	2.17
S_5- Control	55350	94663	39312	1.71

Conclusion

Based on the above results and discussion it can be concluded that among the plant densities, high-density planting (M_2) recorded significantly higher seed cotton yield, stalk yield and economics. Among the subplots, boron nutrition (S_4) recorded significantly higher yield and economics. However, the Interaction effect of plant densities and plant growth regulators on seed cotton yield was found non-significant. Hence, it can be concluded that high-density planting and boron nutrition are advantageous for cotton cultivation on black cotton soils of Guntur region.

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