

OPTIMIZING NITROGEN RATES AND PLANT DENSITY FOR COTTON CULTIVARS (*Gossypium spp.*) IN THE NIGERIAN SAVANNA

ABSTRACT

Cotton production in Nigeria has been severely limited by low or blanket nutrient (especially nitrogen, N) input and poor crop management, involving use of low yielding varieties and sub-optimal plant spacing. Field experiment was conducted during the wet season (June-October) of 2013 at two locations within the Research Farm, College of Agriculture, Jalingo (longitude 11° 09' and 11° 30' East and latitude 8° 17' and 9° 01' North) to determine the (i) adaptability of three improved cotton cultivars to local climates, (ii) appropriate rate of N for optimizing cottonseed yield and (iii) optimal plant density for economic yield. The experiment was a 4 x 3 x 2 factorial arranged in a randomized complete block design (RCBD) replicated three times. The treatment combinations consisted of four nitrogen (N) rates (0, 120, 150, 200 kg ha⁻¹), three cotton varieties (Jalingo Local, Samcot-13, Sketch-8) and two plant densities [75 x 30 cm or 44,444 plants ha⁻¹ and 60 x 30 cm or 60,000 plants ha⁻¹]. Data were collected on plant height, boll weight, cottonseed yield, biological (biomass) yield and numbers of monopodial and sympodial branches. Data collected were subjected to analysis of variance using the StatView Software and LSD (Least Significant Difference Test) at the 5% level of probability was used for comparison of treatment means. Plant height, boll weight, cottonseed yield, biological yield, monopodial and sympodial branches increased significantly ($P < 0.05$) with N application. The growth and yield components of cotton were optimum at 150 kg N ha⁻¹. For cottonseed (lint and seed yield) yield per boll, Samcot-13 treated with 150 kg N ha⁻¹ was the best. Cottonseed yield was best at 150 kg N ha⁻¹ with Jalingo Local variety at 44,444 plants ha⁻¹ density. Therefore, Jalingo Local sown at 44,444 plants ha⁻¹ with application of 150 kg N ha⁻¹ as urea in two equal splits (21 and 50 DAS) is recommended in the study area.

Keywords: Biomass yield, cottonseed yield, cotton variety, monopodial/ sympodial branches, nitrogen rates, plant density

1. INTRODUCTION

Cotton (*Gossypium spp*) is considered one of the oldest fibre producing crops in the world. Its importance as protein, oil and fibre producing crop has long been recognized globally and its high commercial value is unarguably tremendous [1]. China, USA, India, Pakistan, Turkey, Australia, Greece, Brazil, Egypt, etc. have been recognized as the major

22 cotton producing countries [2]. These areas have suitable climatic conditions such as
23 adequate moisture, hot and dry weather conditions which favour cotton growth [2].

24 Nitrogen (N) is an important nutrient required by cotton for optimizing seed yield.
25 Nitrogen is the most limiting essential plant nutrient in the world and it needs to be supplied
26 in proper quantities and time [3]. Apart from water, N is the major nutrient element limiting
27 cotton production in most of the cotton growing regions of the world [4]. Nitrogen
28 management is essential and critical for cotton if its full yield potential is to be realized.
29 Therefore, too much or low application as well as wrong time of application of fertilizer can
30 result to poor growth and low yields [5, 3]. Too much nitrogen in the soil stimulates
31 vegetative growth and retards flowering, weakens fibre which negatively impacts the quality.

32 It is also prone to higher leaching losses, lower use efficiency and greater potential to pollute
33 the underground water. As [6] recognized the importance of nitrogen as an essential
34 macronutrient needed in larger quantities for cotton production, [4] reported that N
35 fertilization had a significant impact on plant growth, lint yield and fiber quality. Cotton usually
36 shows a good response to applied N fertilizer in soils low in N [7].

37 Nutrient management in cotton is difficult because of its vegetative re-growth and
38 reproductive structures during the growing period [8]. Shortage of nutrient reduces root
39 growth and ultimately, its capacity to absorb nutrients [9, 10]. For every 100 kg of cottonseed
40 produced, the crop depletes the soil of 6-7 kg N, 1.9-2.5 kg P, 6.8 kg K and 1.2-2.0 kg S [8].
41 High plant population and nitrogen rates would lead to more biomass yield but low seed
42 cotton yield [10, 11] while [12] reported that increased plant density or N rate delayed leaf
43 senescence but significantly reduced boll load.

44 According to [13], cotton cultivars developed in different ecological zones respond
45 differently to inorganic fertilizers. The varieties behave differently in respect to sympodial
46 branches under different fertilizer rates [14, 15].

47 In Nigeria, considerable attention and resources have been devoted to the
48 improvement of cotton production and utilization by both public and private organizations as

well as individuals [16]. As a result, there is intensification of the development and multiplication of improved cotton varieties and specification of cultural practices for increasing cotton yields [17]. The lack of fertilizer use, use of recycled seeds and high input cost as well as poor soil fertility are the major factors responsible for low yield of cotton in Nigeria [18]. Therefore, this research work was designed to compare the adaptability of two improved cotton cultivars imported from China with a local one in the Nigerian savanna cotton belt and to determine the optimum combination of N rate and plant density for optimizing fibre yield.

2. MATERIAL AND METHODS

2.1 Experimental site

The dry and rainy seasons prevailing in tropical regions are the common climatic features of the study area. The wet season usually commence in April, peak in August and ends in October while dry period begins in November and ends in March, with its peak in January and February when the dusty north-east trade winds blow across the entire area. The basement complex rock underlines the geology of Jalingo Local Government Area. The rocks are overlaid by sandy-loam soil characterized by hydromorphic and ferruginous soils derived from the parent materials.

The field experiment was conducted during the wet season (June -October) of 2013 at two locations within the Research Farm of the College of Agriculture, Jalingo (longitude $11^{\circ} 09'$ and $11^{\circ} 30'$ E and latitude $8^{\circ} 17'$ and $9^{\circ} 01'$ N), Taraba State, Nigeria. Jalingo lies within the northern guinea savannah region of Nigeria.

2.2 Experimental design and treatments

The experiment was a 4 x 3 x 2 factorial arrangement of treatments placed in a randomized complete block design (RCBD) and replicated three times. The treatment combinations consisted of four nitrogen rates (0, 120, 150 and 200 kg ha⁻¹), three cotton varieties (Jalingo Local, Samcot-13, Sketch-8) and two plant densities (44,444 and 60,000 plants ha⁻¹). Thus, there were 24 treatment combinations, giving a total of 72 plots.

77 **2.3 Land Preparation and Soil sampling and processing**

78 The site was manually cleared, stumped, raked and burnt. The land was then tilled manually.
79 Each plot measured 2 m by 2.5 m. Alleyways between blocks was 2 m while those between
80 plots were 1 m.

81 Composite soil samples were collected before sowing at 0-15 cm (topsoil) and 15-30
82 cm (subsoil) depths using soil auger. Each composite sample was properly bagged and
83 labeled. Thereafter, the soil samples were air dried, ground and sieved using a 2 mm sieve
84 before analysis.

85 The soil samples were analyzed in the laboratory using standard procedures as outlined by
86 [19]. Particle size distribution was determined by the Bouyoucous hydrometer method, using
87 sodium hexametaphosphate as a dispersant. Soil pH was determined in 1:2.5 soil: water
88 ratio with a pH meter. Organic carbon was determined by Walkley Black Dichromate
89 Oxidation Method. Total nitrogen (N) was determined by the microkjeldahl method. Available
90 phosphorus (P) was extracted by the Bray 1 extraction method, and the content of P was
91 determined colorimetrically using a Technico AAll auto analyser (Technico, Oakland, Calif).
92 Exchangeable cations (K, Na, Ca, and Mg) were extracted with 0.1N ammonium acetate, K
93 and Na were read with a flame photometer while Ca and Mg were determined through the
94 EDTA titration method.

95 Exchangeable acidity was determined by leaching the soils with 1N KCl and titrating
96 aliquots with 0.01 NaOH. Effective cation exchange capacity (ECEC) was calculated as the
97 sum of Ca, Mg, K and Na and exchangeable acidity. Base saturation was calculated by
98 dividing the sum of exchangeable bases by ECEC and multiplying by 100.

100

101 **Planting and cultural practices**

102 Seeds of the three cotton varieties (Samcot-13, Sketch-8 and Jalingo Local) were
103 sown on a well-prepared moist seedbed at 75 cm by 30 cm for a density of 44,444 plants ha⁻¹

104 ¹ (low density) and 60 cm by 30 cm apart for a density of 60,000 plants ha⁻¹ (high density).
105 Four seeds were sown per hole and the seedlings were thinned to one vigorous plant per
106 stand 10 days of after sowing (DAS). Nitrogen was applied as urea in two equal splits. The
107 first application was done 21-days after sowing (DAS) and the second at 50 DAS. According
108 to [8], nitrogen application to cotton should be completed on or before 60 days of sowing for
109 better utilization of the applied nutrient. Weeding was done manually at 14, 50 and 90 days
110 after sowing (DAS).

111 **2.4**

112 **Data collection**

113 Ten plants from the central rows were selected and tagged for the determination of
114 agronomic parameters. Plant height was measured with a measuring tape from the ground
115 level to the tip of the youngest mature shoot at 45 and 90 days after sowing. Boll weight was
116 determined by picking the boll from the tagged plants from each plot and weighed.
117 Cottonseed weight per boll was determined from the tagged plants using the weighing
118 balance. Sympodial/Monopodial branches were counted for all tagged plants in each plot at
119 60 and 100 DAS. Only sympodial (fruiting branches) and monopodial (vegetative branches)
120 branches on the main stem were counted and averaged for each plot. Cottonseed is the
121 seed of the cotton plant that are surrounded by fibres which grow from the surface of the
122 seed i.e. the seed with the lint still attached. This was determined after the remains of the
123 reproductive part were removed and the cottonseed weighed using weighing balance.

124 Biological (biomass) yield is the weight of all the reproductive parts and the cotton
125 seed and this was taken after the second picking. All the plants in each plot were cut down
126 from the ground level, sun-dried for two weeks to a constant weight and weighed including
127 all the reproductive parts and the cottonseed. The weight was expressed in kg per hectare.

128 **2.7 Statistical analysis**

129 Data collected were subjected to analysis of variance using the StatView Software
130 and LSD (Least Significant Difference Test) at the 5% level of probability was used for
131 comparison of treatment means.

132 **3. RESULTS AND DISCUSSION**

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134 **3.1 Properties of the experimental soil**

135 The preliminary analysis of the experimental soil in locations 1 and 2 were similar
136 (Table 1). The soil texture was loamy sand either at the topsoil or subsoil with clay content
137 increasing down the profile in both locations. The soil reaction (pH) was moderately acidic at
138 the topsoil but strongly acidic at the subsoil based on the ratings given by [20] for Nigerian
139 soils. The soil was characterized by low organic carbon and total nitrogen contents
140 suggesting that response to nitrogen fertilizer would be high. The low organic carbon and
141 total nitrogen is typical of arable lands in the northern savanna zone as crop residues are
142 usually used up by livestock after harvest, leaving no material on the surface for
143 decomposition. Therefore nutrient removal by both plants and livestock left little or no
144 material for organic carbon build up in the soil. The available phosphorus (P) content of the
145 soil was medium (8.12 mgkg^{-1} , 8.30 mgkg^{-1} in locations 1 and 2 respectively) for the topsoil
146 but low (7.42 mgkg^{-1} , 7.86 mgkg^{-1}) at the subsoil. Exchangeable potassium was low, while
147 exchangeable calcium and magnesium were high. High exchangeable calcium and
148 magnesium is a common feature of soils of the Nigerian savannah due to moderate rainfall.
149 The base saturation of the soil was high either at the top or sub soil.

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Table1: Background physico-chemical properties of the experimental soil

Property	Location 1		Location 2	
	Surface soil (0-15cm)	Sub soil (15-30cm)	Surface soil (0-15cm)	Sub soil (15-30cm)
Clay (%)	6.0	11.0	9.0	11.0
Silt (%)	10.7	11.7	12.1	12.7
Sand (%)	83.3	77.3	78.9	76.3
Textural Class	Loamy sand	Loamy sand	Loamy sand	Loamy sand
pH(H ₂ O)	5.70	5.40	5.74	5.38
Org. C (%)	0.29	0.24	0.29	0.23
Total N (%)	0.01	0.01	0.02	0.01
Av. P (mgkg ⁻¹)	8.12	7.12	8.30	7.86
Exch. Ca ⁺⁺ (cmolkg ⁻¹)	1.8	1.8	2.0	1.8
Exch. Mg ⁺⁺ (cmolkg ⁻¹)	1.4	1.0	1.5	1.2
Exch. K ⁺ (cmolkg ⁻¹)	0.19	0.15	0.18	0.15
Exch. Na ⁺ (cmolkg ⁻¹)	0.14	0.12	0.13	0.12
Exch. Acidity (cmolkg ⁻¹)	0.36	0.40	0.44	0.50
ECEC (cmolkg ⁻¹)	3.89	3.47	4.25	3.77
BS (%)	90.8	88.5	89.6	86.7

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155 **3.2 Plant growth and yield as influenced by nitrogen rates, cotton varieties** 156 **and plant densities**

157 **3.2.1 Plant height** 158

159 Table 2 shows the summary of analysis of variance for plant height and yield.
160 Nitrogen rates significantly affected plant height at 45 and 90 days after sowing (DAS)
161 whereas there were no significant effects of plant density, cotton varieties and their
162 interactions on cotton plant height (Table 2). At the early stages of cotton growth (45 DAS)
163 the 120 kg Nha⁻¹ rate produced slightly taller plants than the other rates (Figure 1a). At 90

164 DAS, plants receiving 150 kg Nha⁻¹ were significantly taller (118.67 cm) than plants treated
 165 with 120 kg Nha⁻¹ (112 cm) and 0 kg Nha⁻¹ (control) as shown in Figure 1 but height
 166 differences between 150 and 200 kg Nha⁻¹ rates were not significant. This is in line with the
 167 report of [7] who observed significant differences in cotton height at various nitrogen
 168 application rates. Although, [21] reported highest cotton plant height at 250 kg N ha⁻¹ when
 169 they used cattle manure for cotton production in Nigeria, [22] reported the highest cotton
 170 plant height at the highest application rate of 120 kg Nha⁻¹ whereas [3] noted highest plant
 171 height (147 cm) of cotton by using ½ N at sowing + ½ N at 52 DAS (2nd irrigation) at the rate
 172 of 153 kg Nha⁻¹ in Pakistan. It has been reported by [23] that nitrogen application increased
 173 cotton plant height.

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Table 2: Summary of analysis of variance for cotton plant height and yield

Source of variation	Plant height (cm)@45 DAS	Plant height (cm)@90 DAS	Boll weight (g)	Cottonseed yield (g/boll)	Cottonseed yield (kg/ha ⁻¹)
Nitrogen rate(N)	<.0001*	<.0001**	<.0001*	<.0001*	<.0001*
Plant density (PD)	0.5533 ^{NS}	0.8795 ^{NS}	0.3820 ^{NS}	0.0437*	<.0001*
Variety (V)	0.1260 ^{NS}	0.640 ^{NS}	<.0001*	<.0001*	<.0001*
N * PD	0.3785 ^{NS}	0.7897 ^{NS}	0.2650 ^{NS}	0.0609 ^{NS}	0.0620 ^{NS}
N * V	0.4197 ^{NS}	0.2493 ^{NS}	<.0001*	<.0001*	0.0101*
PD *V	0.4378 ^{NS}	0.8982 ^{NS}	0.0566 ^{NS}	0.0785 ^{NS}	0.0136*
N *PD* V	0.1169 ^{NS}	0.9914 ^{NS}	<.0001*	<.0001*	<.0001*

178 * = significant at $P < .05$; ^{NS} = not significant

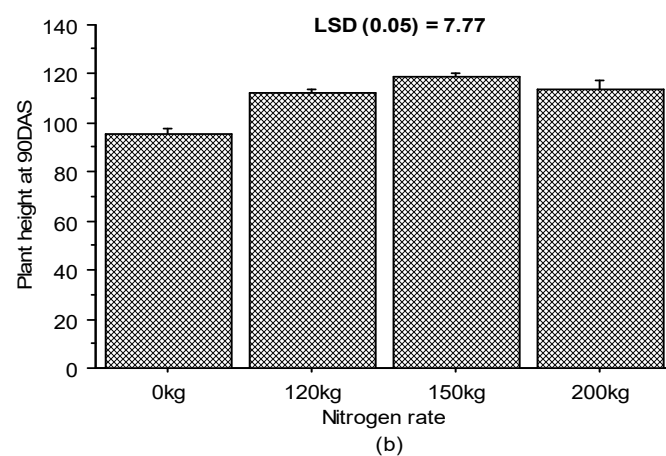
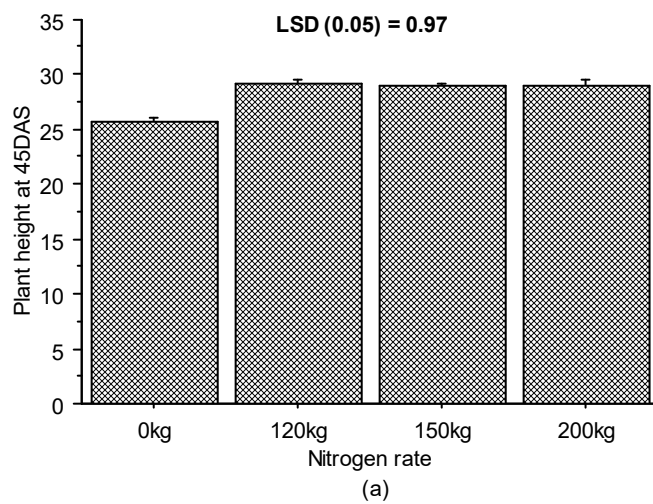


FIG 1: Effect of nitrogen rates on cotton plant height (cm) at (a) 45 DAS and (b) 90 DAS

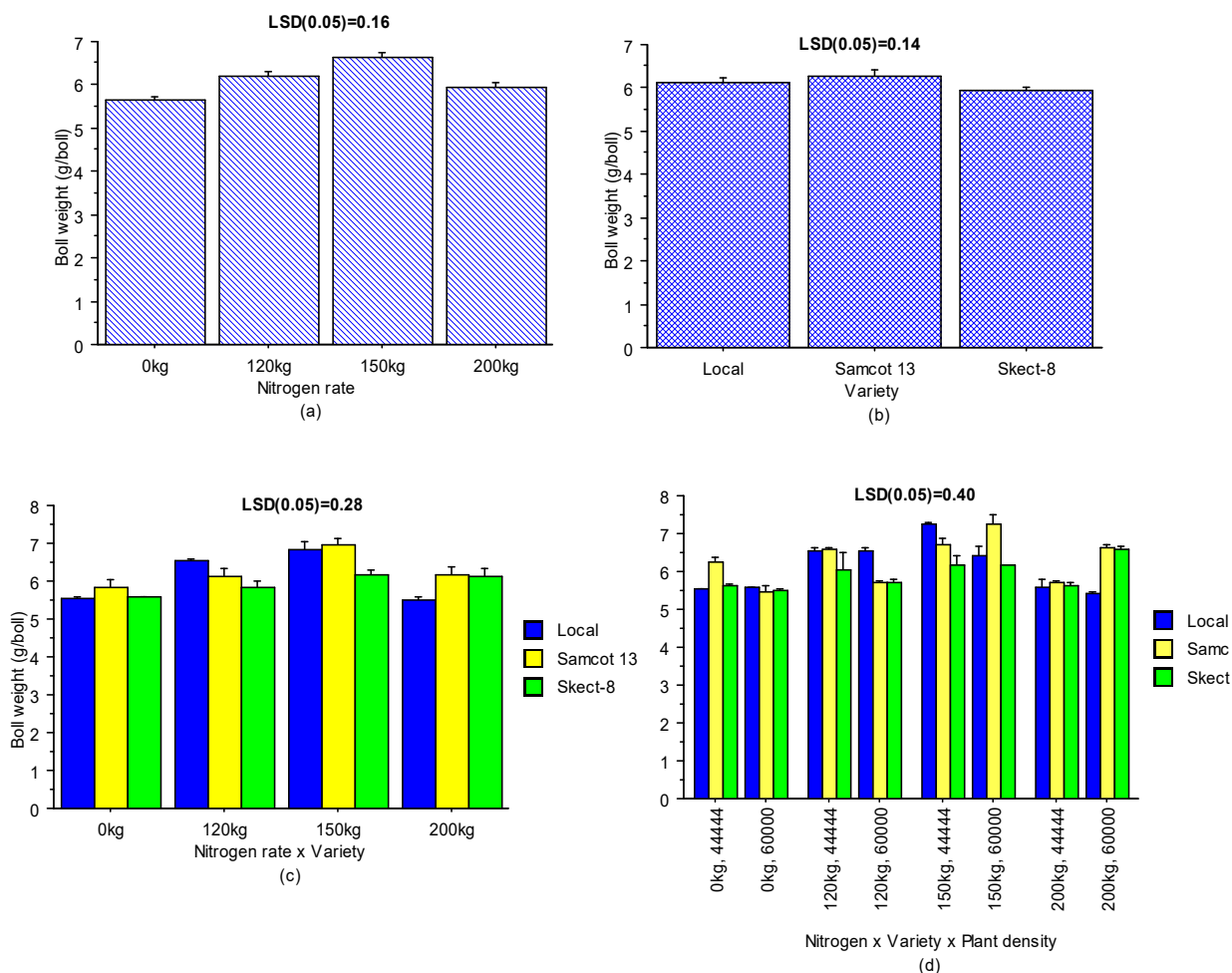
3.2.2 Boll Weight (g/boll)

A summary of analysis of variance of nitrogen rates, variety and plant density on cotton boll weight is presented in Table 2. Cotton boll weight was significantly increased by nitrogen rates (N), cotton variety (V), the interaction of nitrogen rates with cotton variety (N x V) and the interaction with nitrogen rates with cotton variety with plant density (N x V x PD) (Table 2). Plots receiving 150 kg Nha⁻¹ significantly produced heavier bolls (6.63 g/plant)

188 followed by the 120 kg N ha^{-1} (6.19 g), then 200 kg N ha^{-1} (5.92 g) compared with the control
189 (Figure 2a). It has been reported by [23] that nitrogen fertilizer application enhanced the
190 production of matured bolls in cotton. The main effect of variety on boll weight showed that
191 Samccot-13 produced heaviest boll weighting 6.27 g followed by Jalingo Local with boll
192 weight of 6.11 g while Sketch-8 boll weighed 5.93 g (Figure 2b).

193 Interaction of nitrogen rates of 150 kg N ha^{-1} with Samcot-13 produced the heaviest
194 boll of 6.96 g while the lowest boll weight of 5.49 g was produced by the plot treated with 200
195 kg N ha^{-1} and planted with Jalingo Local variety (Figure 2c). A significant difference in boll
196 weight was observed among the three varieties, it was evidence that Samcot-13 was very
197 responsive to nitrogen at 150 kg N ha^{-1} . Interaction of 150 kg N ha^{-1} with Samcot-13 under
198 high plant density (60,000 plants ha^{-1}) produced the heaviest boll weight of 7.25 g (Figure
199 2d). But the weight differences between the two plant densities (44,444 and 60,000 plants
200 ha^{-1}) at 150 kg N ha^{-1} using either Samcot-13 (7.25 g) or Jalingo Local variety interaction
201 (7.23 g) was not significant. An increase in boll weight by increasing nitrogen rate from 95 kg
202 N to 150 kg N ha^{-1} was recorded by [24]. Increasing nitrogen fertilization resulted in higher
203 accumulation of metabolites which impacted on boll weight. Similar increase in boll weight of
204 cotton when nitrogen was applied at 150 kg/ha has been reported by [7].

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207 FIG 2: Effects of (a) nitrogen rates, (b) variety, (c) the interaction of nitrogen with variety and
 208 (d) the interaction of nitrogen with variety with plant density on cotton boll weight (g/boll)
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211 **3.2.3 Cottonseed (seed with lint) yield per boll**

212 A summary of the analysis of variance of N rates, plant density and variety on
 213 cottonseed yield per boll as shown in Table 2 indicated that cottonseed yield per boll was
 214 highly significant at various nitrogen rates. Plots treated with 150 kg Nha⁻¹ yielded highest
 215 cottonseed per boll (4.24 g) followed by the 120 kg Nha⁻¹ (3.84 g) then the 200 kg Nha⁻¹
 216 treated plot (3.64 g) while the control plot recorded the least yield of 3.63 g (Figure 3a).
 217 However, [25] reported that cottonseed yield increased with increasing nitrogen application

218 rate while [26] reported that cottonseed yield was best when optimum doses of nutrients,
219 particularly of nitrogen were applied. Lower plant density produced slightly higher cottonseed
220 yield per boll relative to higher plant density (Figure 3b). Cottonseed yield was affected by
221 variety; Samcot-13 gave the highest yield (3.98 g) per boll followed by Jalingo Local (3.80 g)
222 while the least was from Sketch-8 variety (3.75 g) (Figure 3c).

223 Various interactions significantly affected cottonseed yield. For the interaction of
224 nitrogen rate with plant density, better cottonseed yield was obtained from plants treated with
225 150 kg N ha^{-1} using a density of 60,000 plants ha^{-1} (Fig. 4a). For the interaction of nitrogen
226 rate with variety, the best cottonseed yield was from plots treated with 150 kg N ha^{-1} yielded
227 (4.58 g) using Samcot-13 variety (Fig. 4b) while the interaction between nitrogen rate, plant
228 density and variety shows that cottonseed could be optimized at 150 kg N ha^{-1} with 60,000
229 plants ha^{-1} using Samcot-13 variety (Fig. 4c).

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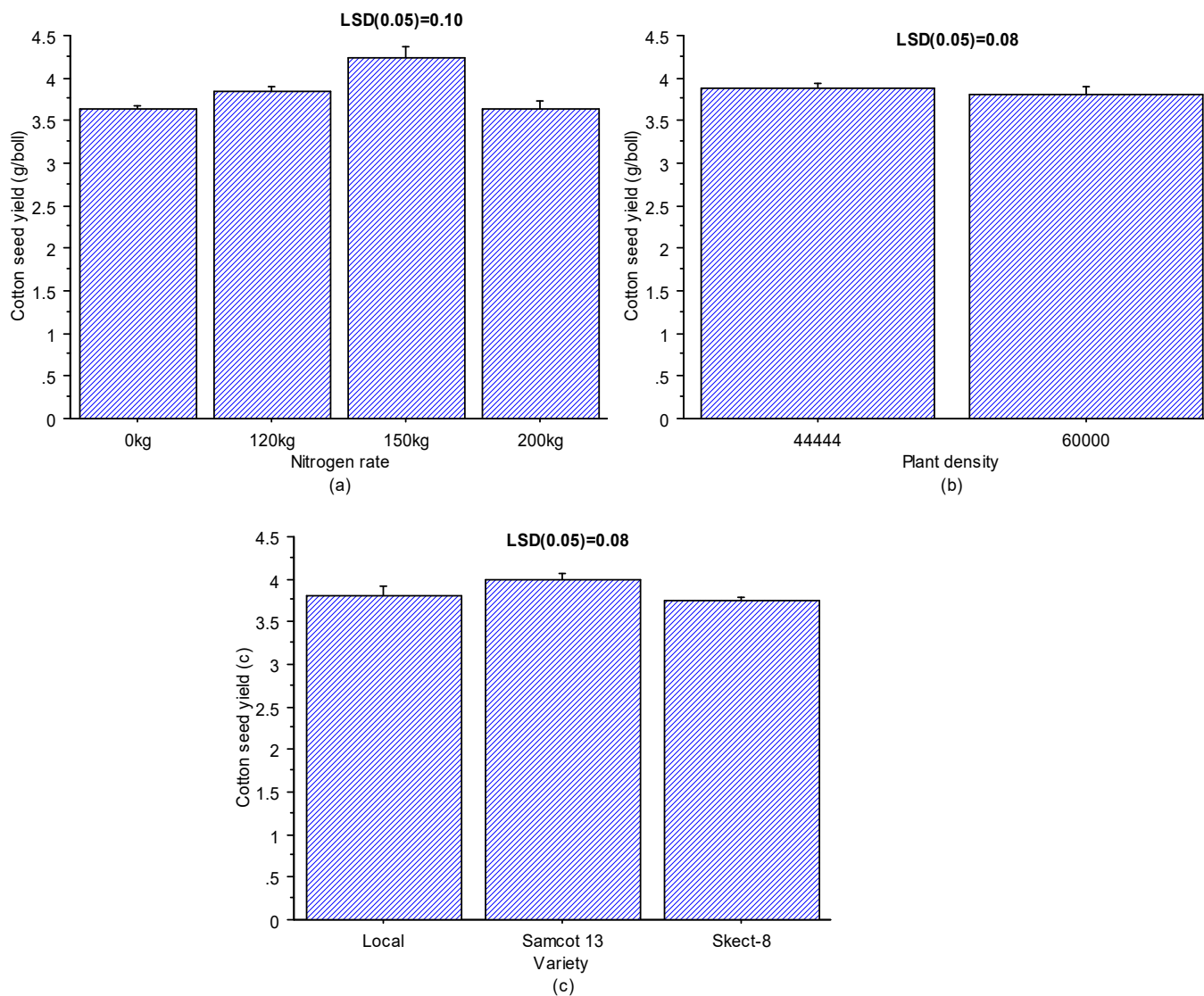


FIG 3: Effects of (a) nitrogen rates, (b) plant density and (c) variety on cottonseed yield (g/boll)

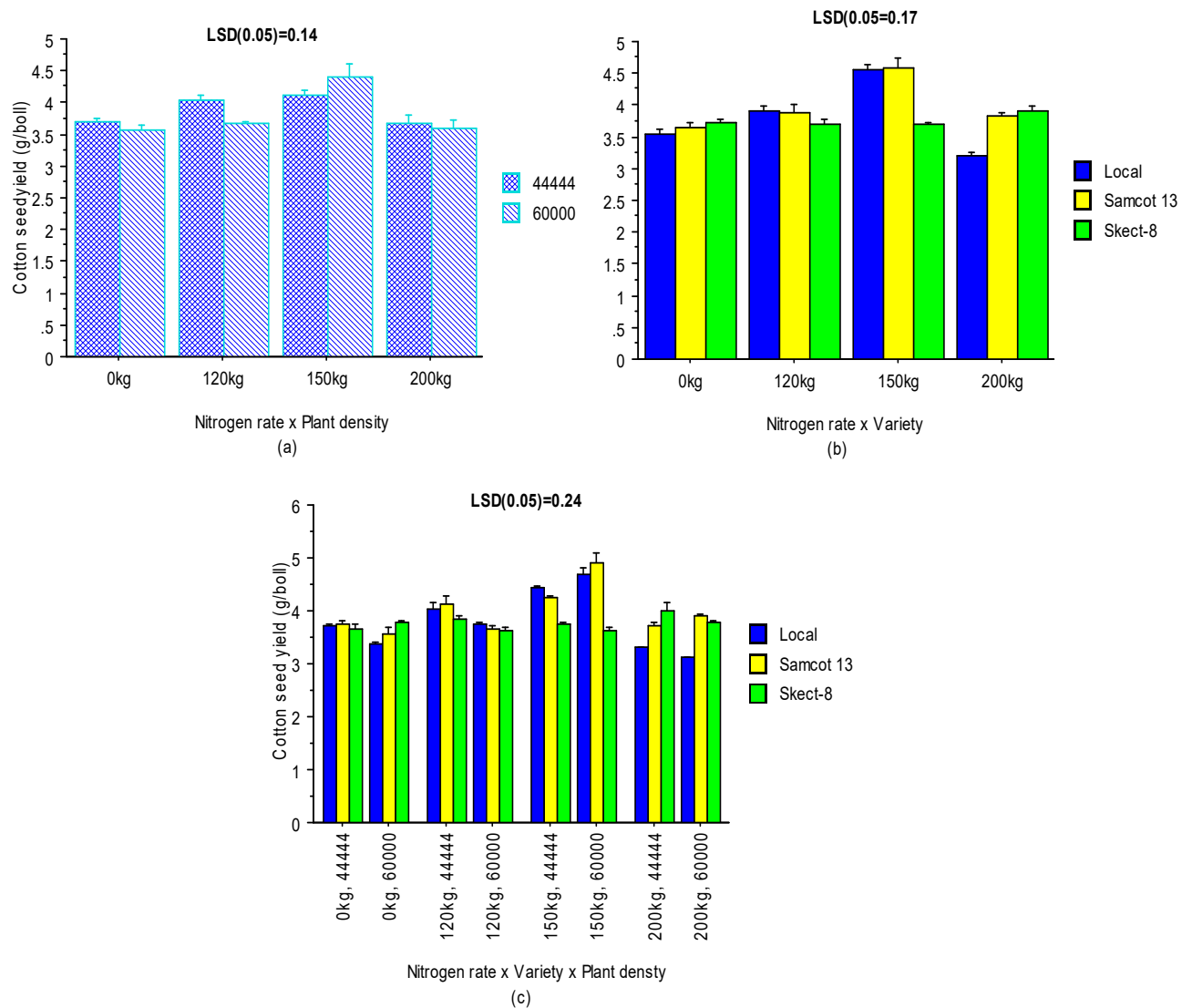


FIG. 4: Interactive effects of (a) nitrogen x variety, (b) nitrogen x plant density and (c) nitrogen x variety x plant density on cottonseed yield (g/boll).

3.2.4 Cottonseed (seed with lint) yield per hectare

A summary of the analysis of variance of nitrogen rates, plant density and variety on cottonseed yield per hectare as shown in Table 2 indicated that cottonseed yield was affected by nitrogen rates, plant density and variety. Plots treated with 200 kg Nha^{-1} were significantly ($P < 0.05$) higher in cottonseed yield (1171.2 kgha^{-1}) compared with the 120 kg

263 Nha^{-1} (723.4 kg ha^{-1}) and the control plots but not significantly ($P > 0.05$) higher than the yield
264 obtained from plots treated with 150 kg Nha^{-1} (1169.2 kg ha^{-1}), suggesting 150 kg Nha^{-1} as
265 the optimum level for maximizing cottonseed yield (Figure 5a). This is in agreement with the
266 results of [21, 27] who reported increased in cottonseed yield as a result of fertilizer
267 treatments in Bangladesh and in Nigeria respectively.

268 However, the highest cottonseed yield of 1171.2 kg ha^{-1} obtained from plants treated
269 with 200 kg N/ha in this study was lower than the yield of 3543 kg ha^{-1} obtained from cotton
270 plants treated with 100% N from urea by [27] in Bangladesh, 1559 kg ha^{-1} obtained by [3]
271 during 2011 planting season in Pakistan by using ten split application of N at each irrigation,
272 1453 kg ha^{-1} obtained from 250 kg Nha^{-1} of cattle manure in Nigeria by [21] but falls within
273 the yield of 1135.7 kg ha^{-1} obtained by [3] during 2012 planting seasons in Pakistan by using
274 ten split application of N at each irrigation. The disparity in yield could be as a result of the
275 prevailing climatic conditions in each location. This was also pointed out by several
276 researchers [7, 28] that the N need of cotton depends on its concentration and
277 mineralization, soil type and environmental factors.

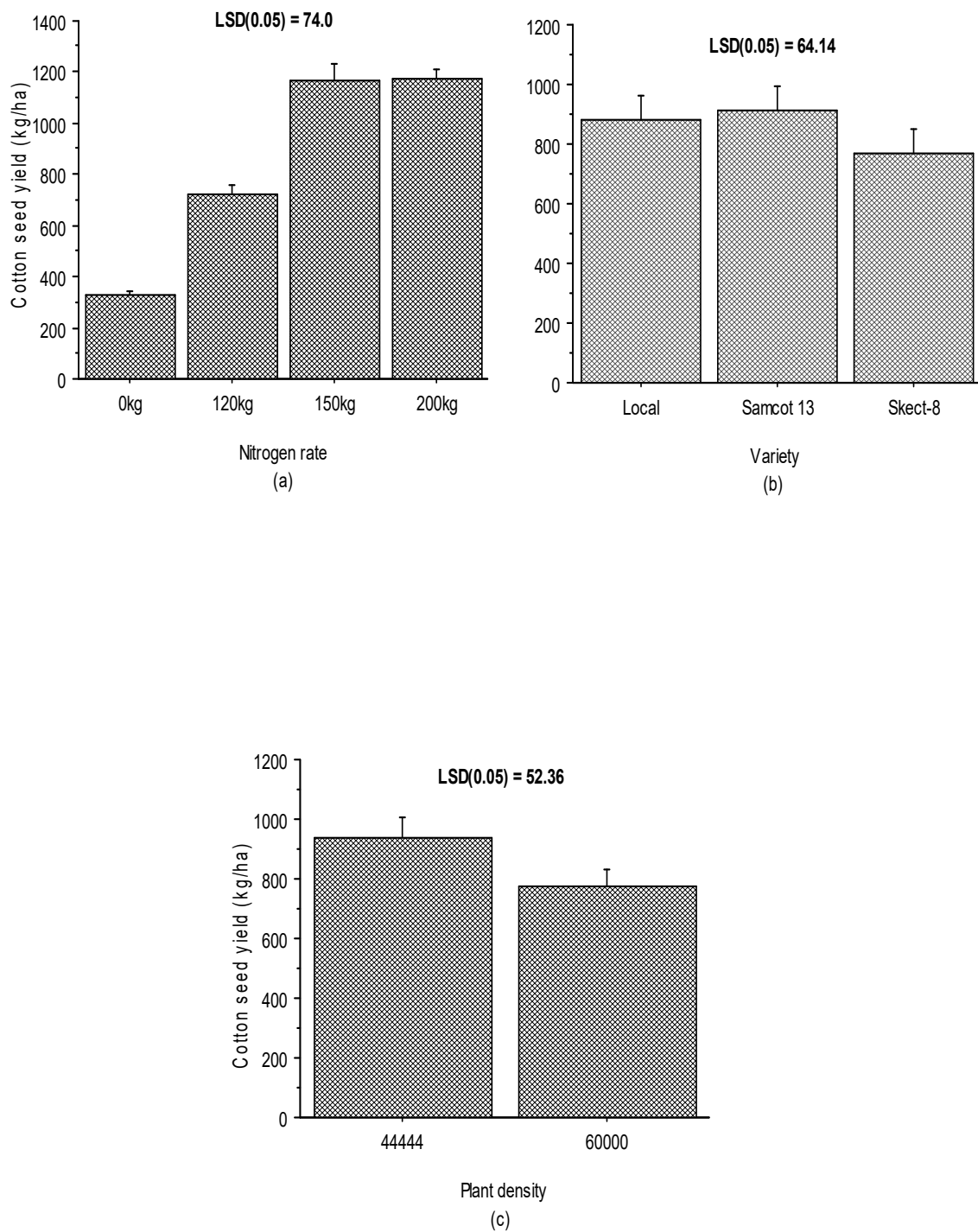
278 Among varieties, Samcot-13 produced the highest cottonseed yield per boll of 914.7
279 kg ha^{-1} followed by Jalingo Local (880.33 kg ha^{-1}) and the lowest was obtained from Sketch-8
280 (766.16 kg ha^{-1}) (Figure 5b). Cottonseed yield per boll was significantly affected by plant
281 density, plot with lower density (44,444 plants ha^{-1}) had the highest seed yield averaging
282 935.72 kg ha^{-1} compared with the yield of 772.27 kg ha^{-1} obtained at the density of 60,000
283 plants ha^{-1} (Figure 5c).

284 Interactions of nitrogen x variety, plant density x variety and nitrogen x plant density
285 x variety significantly ($P < 0.05$) affected cottonseed yield per hectare as shown in Table 2.
286 The combination of 150 kg Nha^{-1} with Jalingo Local produced the highest cottonseed ha^{-1}
287 compared with the control but was not significantly higher than the combination of 200 kg
288 Nha^{-1} with Samcot-13 (Figure 6a). The interaction of Jalingo Local with low plant density of
289 44,444 plants ha^{-1} significantly gave the highest cottonseed yield ha^{-1} (Figure 6b) while the

290 combination of 150 kg N ha^{-1} with Jalingo Local at 44,444 plants/ha produced the highest
291 cottonseed yield (Figure 6c). The lower plant population gave higher cottonseed yield than
292 the higher population. Several reports [29, 30, 31, 32, 33] also showed maximum cottonseed
293 yield at a density of 44, 444 plants ha^{-1} .

294 Although nitrogen at all levels increased the cottonseed yield relative to control (no
295 fertilizer application), the overall results suggested that 150 kg N ha^{-1} would be the rate for
296 cottonseed yield. This application rate of 150 kg N ha^{-1} was also reported by [7] but [21]
297 reported cattle manure rate of 250 kg N ha^{-1} while [34, 35] stressed that nitrogen application
298 above the optimum level will result in decreased yield.

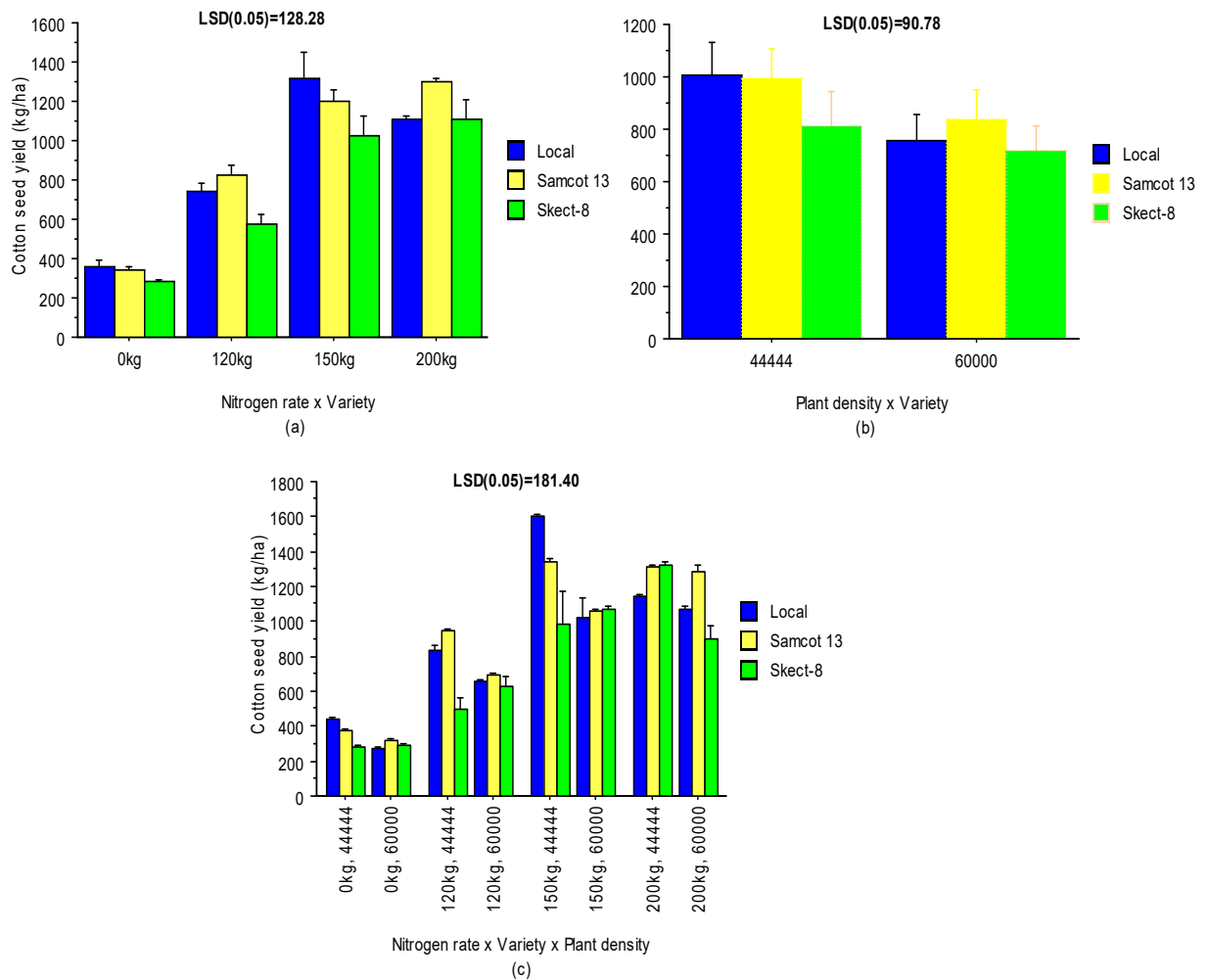
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301 FIG 5: Effects of (a) nitrogen rates, (b) variety and (c) plant density on cottonseed yield
 302 (kg/ha)
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307 FIG 6: Interactive effects of (a) nitrogen x variety, (b) plant density x variety and (c) nitrogen
 308 x plant density x variety on cottonseed yield (kg/ha)
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310 3.3 Monopodial and sympodial branches of cotton as influenced by nitrogen 311 rates, cotton varieties and plant densities

312 3.3.1 Monopodial branches

314 Table 3 shows a summary of analysis of variance of different nitrogen levels, plant
 315 density and cotton variety on monopodial branches of cotton plant. The effects of nitrogen
 316 rates were significant at 60 and 100 DAS for monopodial branches. Plots treated with 150 kg
 317 Nha^{-1} produced the highest number of monopodial branches at 60 (2.85) and 100 DAS

(3.37) as presented in Figures 7a and b. However, nitrogen at all levels had a significant effect on the monopodial branches, but the differences in the number of branches between 150 and 200 kg Nha⁻¹ rates were not significant, suggesting that 150 kg Nha⁻¹ could be the optimum rate. Effects of plant density on branches were significant at 60 and 100 DAS. At 60 DAS, higher density of 60,000 plants ha⁻¹ produced more number of monopodial branches (2.63) compared to 2.52 branches produced at low density of 44,444 plants ha⁻¹ (Figure 7c). At 100 DAS, plot with higher density of 60,000 plants/ha produced slightly higher number of branches averaging 3.63 compared with 3.47 at low density of 44,444 plants ha⁻¹ (Figure 7d).

Monopodial branches were also significantly affected by variety as shown in Table 3. Samcot-13 produced the highest number of branches (2.68) at 60 DAS followed by Jalingo Local with 2.52 and the least was from Sketch-8 (Figure 8a). Similar trend was observed at 100 DAS (Figure 8b). Interactively, at 60 DAS, nitrogen rates interaction with plant density was not significant. However, at 100 DAS it was significant, the lower plant density (44,444 plants ha⁻¹) under N- rate of 150 kg Nha⁻¹ produced the highest branches of 3.78 (Figure 8c). Nevertheless, the low plant density on control plot produced the least numbers of monopodial branches averaging 2.37 (Figure 8c). Plot sown to Samcot-13 and treated with N-rate of 150 kg Nha⁻¹ produced the highest number of branches (2.91) at 60 DAS while Sketch-8 variety in the control plot produced the least number of monopodial branches of 2.11 at 60 DAS (Figure 8d). This result is in line with that of [23, 36, 37], they have independently reported that different nitrogen levels have significant effect on cotton monopodial branches. Plant density had a significant effect on the sizes of plant, from this study, lower plants population produced plant with larger and very robust branches while higher density significantly produced plant with many but weak branches. The effect of variety on cotton branches as reported in this study is in agreement with that of [14, 15] who reported that cotton varieties behaved differently in respect to branches under different fertilizer rates.

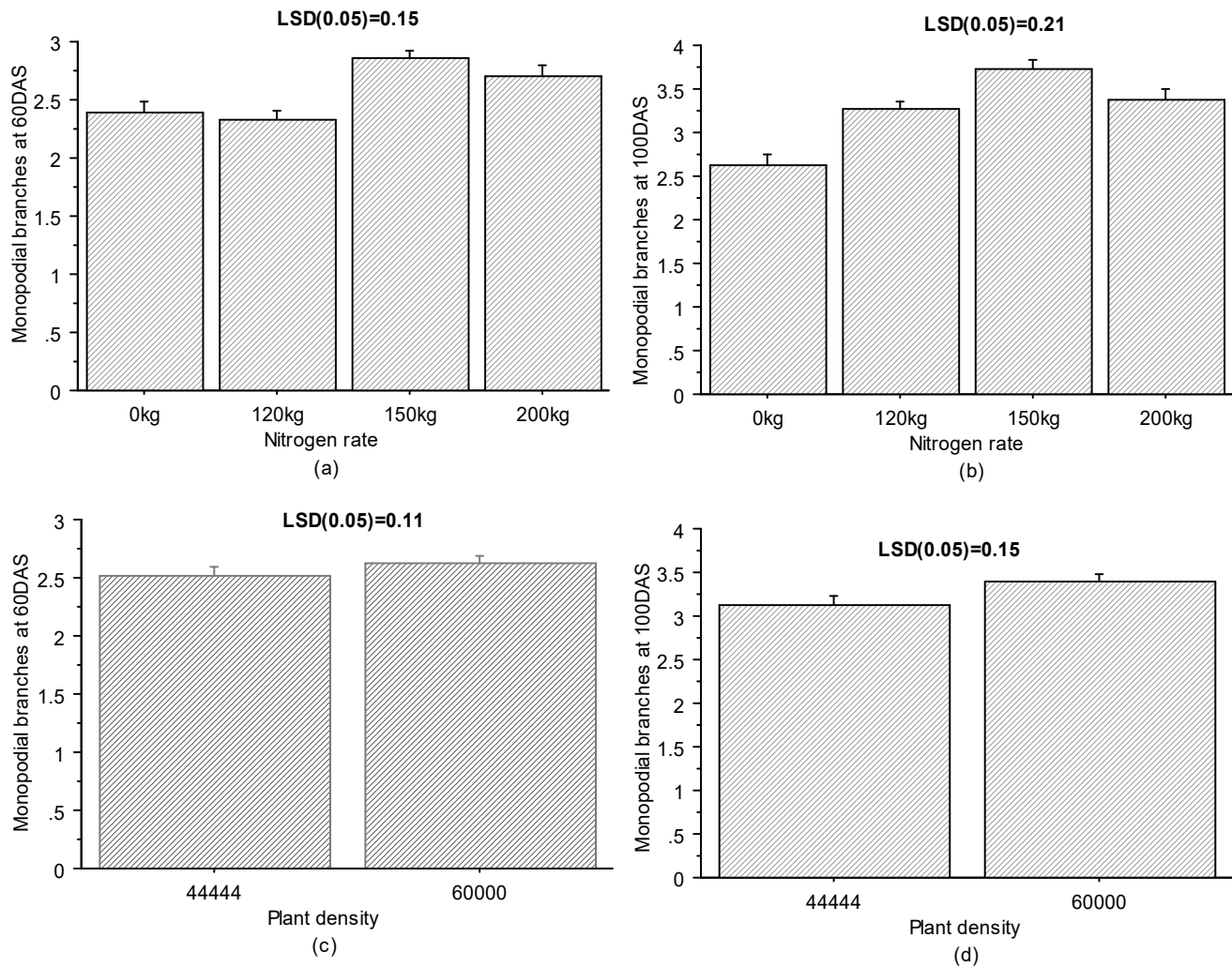
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Table 3: Summary of analysis of variance for monopodial, sympodial and biological yield

Source of variation	Monopodial branches @60 DAS	Monopodial branches @100 DAS	Sympodial branches @60 DAS	Sympodial branches @100 DAS	Biological yield (kg/ha)
Nitrogen rate(N)	<0.0001*	<0.0001*	<0.0001*	<0.0001*	<.0001*
Plant density (PD)	0.0261*	0.0004*	0.173 ^{NS}	0.0004*	0.0015*
Variety (V)	0.0133*	0.0109*	0.8402 ^{NS}	0.2143 ^{NS}	0.0887 ^{NS}
N * PD	0.0986 ^{NS}	0.0121*	0.4314 ^{NS}	0.0041*	0.3431 ^{NS}
N * V	<0.0001*	0.0001*	0.0753 ^{NS}	0.3005 ^{NS}	0.0040*
PD *V	<0.0001*	0.0006*	0.8619 ^{NS}	0.1825 ^{NS}	0.8507 ^{NS}
N *PD* V	0.2897 ^{NS}	0.6781 ^{NS}	0.1495 ^{NS}	0.1566 ^{NS}	<0.0001*

*=significant at $P < .05$; ^{NS} = not significant

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356 FIG 7: Effects of nitrogen rates at (a) 60 DAS, (b) 100 DAS and plant density at 60 DAS and

357 at 100 DAS (c and d) on monopodial branches

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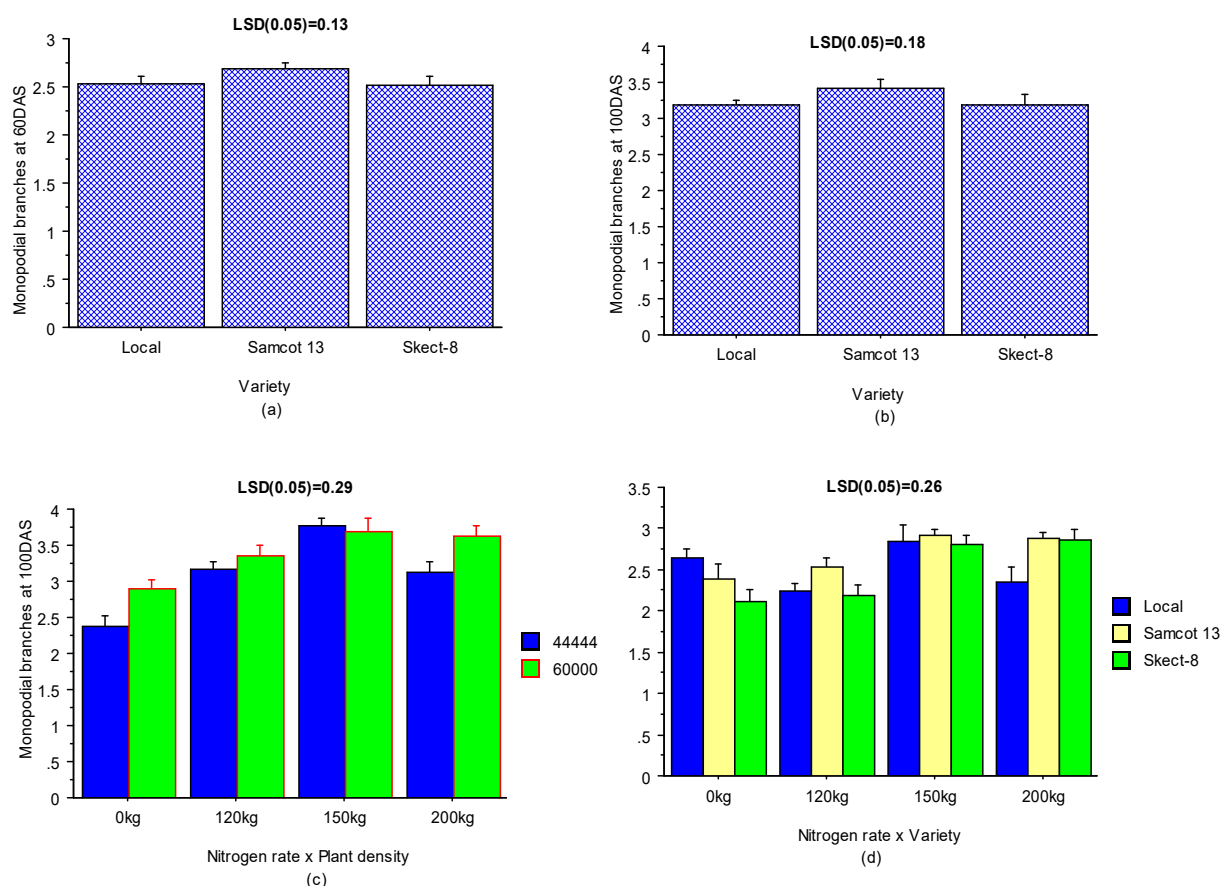


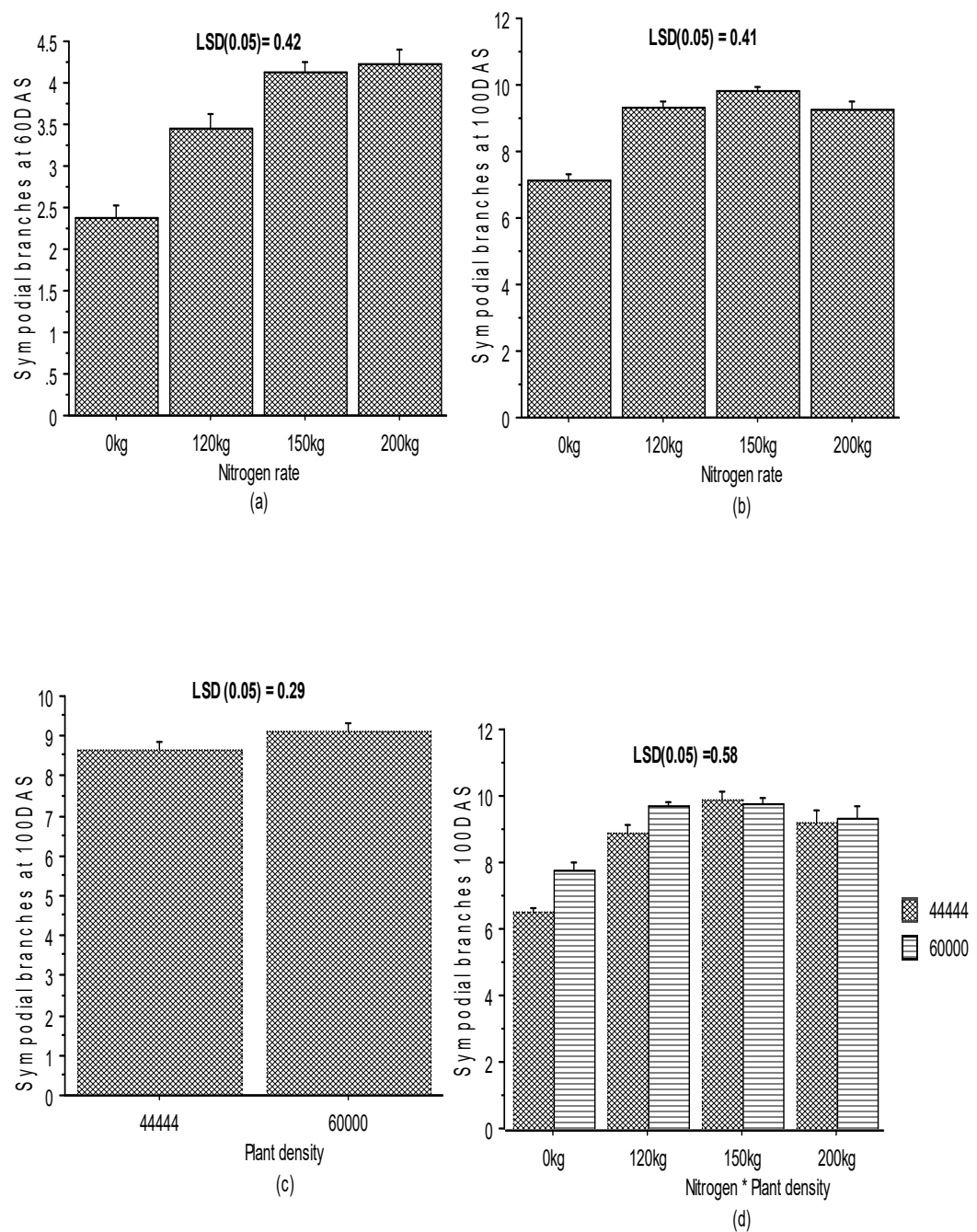
FIG 8: Effects of variety at (a) 60 DAS and (b) 100 DAS and the interaction of N with plant density variety at 100 DAS (c) and nitrogen with variety (d) on monopodial branches of cotton

3.3.2 Sympodial branches

A summary of the analysis of variance of the effects of various nitrogen rates, plant density and variety on number of sympodial branching as presented in Table 3 indicated that nitrogen rates were highly significant at 60 and 100 DAS. Plot treated with 200 kg Nha⁻¹ at 60 DAS had an average of 4.22 branches which was significantly higher compared with those treated with 120 kg Nha⁻¹, 150 kg Nha⁻¹ and control (Figure 9a). Plant density, variety

375 and the various interactions were not significant at 60 DAS. At 100 DAS, nitrogen rates,
376 plant density and the interaction of nitrogen rate with plant density was significant ($P < .05$).
377 Plot treated with 150 kg N ha⁻¹ produced the highest number of sympodial branches (9.80)
378 compared with other N rates and control plots (Figure 9b). Higher plant density (60,000
379 plants ha⁻¹) produced average of 9.13 sympodial branches at 100 DAS while lower density
380 (44,444 plants ha⁻¹) produced 8.63 sympodial branches (Figure 9c). Interaction of nitrogen
381 rates with density at 100 DAS showed that low density with N rate of 150 kg N ha⁻¹ produced
382 the highest sympodial branches (9.84) compared with other N rates x plant density
383 interaction and control plots (Figure 9d). Similar results for cotton fruiting branches have
384 been independently reported by [36, 37].

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387 FIG 9: Effects of nitrogen rates at 60 and 100 DAS (a and b), plant density at 100 DAS (c)
 388 and interaction of nitrogen with plant density at 100 DAS (d) on sympodial branches
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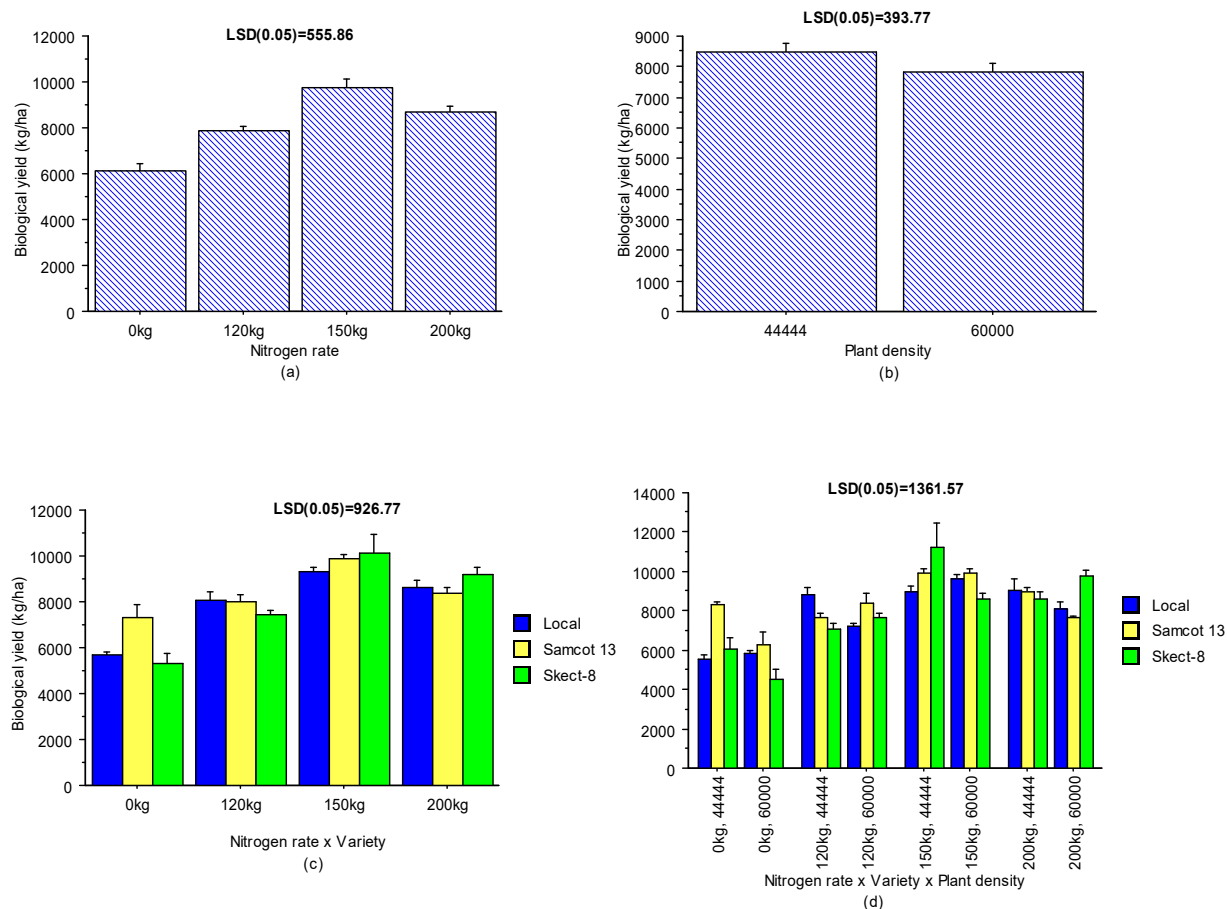
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392 **3.4. Biological (Biomass) Yield as influenced by nitrogen rates, cotton**
393 **varieties and plant densities**

394 A summary of the analysis of variance as shown in Table 3 indicated that N rate,
395 plant density, the interaction of N rate x variety and N x PD x V significantly affected the
396 biomass yield of cotton plant. The main effect of nitrogen rates indicated that biomass yield
397 was highest under the plot treated with 150 kg Nha⁻¹ (9778.94 kg ha⁻¹) while the control plot
398 produced the lowest yield of 6098.61 kg ha⁻¹ (Figure 10a).

400 Plant density showed a significant effect on biological yield. It was noted that lower
401 plant density of 44,444 plants ha⁻¹ produced more biomass (Figure 10b). Varietal effects on
402 biomass yield were not significant. Interactively, nitrogen rates interaction with variety was
403 significant. Sketch-8 treated with 150 kg Nha⁻¹ produced the largest quantity of biomass
404 (1,096.42 kg ha⁻¹) while the same variety in control plots produced the lowest biomass yield
405 of 5,300.00 kg ha⁻¹ (Figure 10c). Also, interaction of nitrogen rates at 150 kg Nha⁻¹ with
406 sketch-8 under low plant density significantly produced the largest biomass yield (Figure
407 10d). The result of this study on biomass yield showed that nitrogen application at all levels
408 contributed to increase in biological yield; this is because of the greater amount of vegetative
409 growth and robustness of plants resulting from the available nitrogen uptake. It has been
410 reported by [4] that nitrogen fertilization had a significant impact on plant biomass production
411 while [38] confirmed that nitrogen is essential for cotton canopy area development and
412 photosynthesis. Lower plant density produced larger plant size hence it resulted in larger
413 biological yields.

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416 FIG 10: Effect of (a) nitrogen rates, (b) plant density, (c) the interaction of nitrogen with
 417 variety and (d) nitrogen with variety with plant density on biological yield
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422 4. CONCLUSION

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424 The growth and yield components of cotton were optimum at N rate of 150 kg Nha⁻¹.

425 For cottonseed yield per boll, Samcot-13 treated with 150 kg Nha⁻¹ was the best in the study

426 area. Interactively, cottonseed yield per hectare was highest for Jalingo Local treated with

427 150 kg Nha⁻¹ and at the lower plant density (44,444 plants ha⁻¹). Nitrogen at all levels

428 significantly increased cottonseed yield, however, cottonseed yield per hectare (fibre and

429 seed yield) was best optimized at 150 kg Nha⁻¹ x Jalingo Local variety x low plant density.

Therefore, farmers may keep using the local variety (Jalingo Local) provided they sow at 44,444 plants ha⁻¹ and apply 150 kg Nha⁻¹ as urea in two equal splits (21 and 50 DAS). The improved varieties would need further fine-tuning to optimize their yield performance in the study area.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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