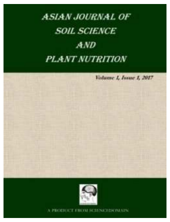

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Optimizing Nitrogen Rates and Plant Density for Cotton Cultivars (*Gossypium spp.)* in the Nigerian Savanna

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Authors' contributions

This work was carried out in collaboration between all authors. Author LIO wrote the first draft of the manuscript and managed the analyses of the study. Author OBI managed the literature searches and proof read the first draft of the manuscript. Author AEE designed the study and did the statistical analysis. All authors read and approved the final manuscript.

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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' Nor th) 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

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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 Nha^{-1}. For cottonseed (lint and seed yield) yield per boll, Samcot-13 treated with 150 kg Nha^{-1} was the best. Cottonseed yield was best at 150 kg Nha^{-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 (*Gossipium 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 cotton producing countries [2]. These areas have suitable climatic conditions such as adequate moisture, hot and dry weather conditions which favour cotton growth [2].

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

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

Nutrient management in cotton is difficult because of its vegetative re-growth and reproductive structures during the growing period [8]. Shortage of nutrient reduces root growth and ultimately, its capacity to absorb nutrients [9,10]. For every 100 kg of cottonseed 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]. High plant population and nitrogen rates would lead to more biomass yield but low seed cotton yield [10,11] while [12] reported that increased plant density or N rate delayed leaf senescence but significantly reduced boll load.

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

In Nigeria, considerable attention and resources have been devoted to the 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. MATERIALS 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° 09′ and 11° 30′ E and latitude 8° 17′ and 9° 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.

2.3 Land Preparation and Soil Sampling and Processing

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

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

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

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

2.4 Planting and Cultural Practices

Seeds of the three cotton varieties (Samcot-13, Sketch-8 and Jalingo Local) were sown on a well-prepared moist seedbed at 75 cm by 30 cm for a density of 44,444 plants ha^{-1} (low density) and 60 cm by 30 cm apart for a density of 60,000 plants ha^{-1} (high density). Four seeds were sown per hole and the seedlings were thinned to one vigorous plant per stand 10 days after sowing (DAS). Nitrogen was applied as urea in two equal splits. The first application was done 21-days after sowing (DAS) and the second at 50 DAS. According to [8], nitrogen application to cotton should be completed on or before 60 days of sowing for better utilization of the applied nutrient. Weeding was done manually at 14, 50 and 90 days after sowing (DAS).

2.5 Data Collection

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

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

2.6 Statistical Analysis

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.

3. RESULTS AND DISCUSSION

3.1 Properties of the Experimental Soil

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

3.2 Plant Growth and Yield as Influenced by Nitrogen Rates, Cotton Varieties and Plant Densities

3.2.1 Plant height

Table 2 shows the summary of analysis of variance for plant height and yield. Nitrogen rates significantly affected plant height at 45 and 90 days after sowing (DAS) whereas there were no significant effects of plant density, cotton varieties and their interactions on cotton plant height (Table 2). At the early stages of cotton growth (45 DAS) the 120 kg Nha^{-1} rate produced slightly taller plants than the other rates (Fig. 1a). At 90 DAS, plants receiving 150 kg Nha^{-1} were significantly taller (118.67 cm) than plants treated with 120 kg Nha^{-1} (112 cm) and 0 kg Nha^{-1} (control) as shown in Fig. 1 but height differences between 150 and 200 kg Nha^{-1} rates were not significant. This is in line with the report of [7] who observed significant differences in cotton height at various nitrogen application rates. Although, [21] reported highest cotton plant height at 250 kg N ha^{-1} when they used cattle manure for cotton production in Nigeria, [22] reported the highest cotton plant height at the highest application rate of 120 kg Nha^{-1} whereas [3] noted highest plant height (147 cm) of cotton by using ½ N at sowing + ½ N at 52 DAS (2nd irrigation) at the rate of 153 kg Nha^{-1} in Pakistan. It has been reported by [23] that nitrogen application increased cotton plant height.

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

Interaction of nitrogen rates of 150 kg Nha^{-1} with Samcot-13 produced the heaviest boll of 6.96 g while the lowest boll weight of 5.49 g was produced by the plot treated with 200 kg Nha^{-1} and planted with Jalingo Local variety (Fig. 2c). A significant difference in boll weight was observed among the three varieties, it was evidence that Samcot–13 was very responsive to nitrogen at150 kg Nha^{-1}. Interaction of 150 kg Nha^{-1} with Samcot-13 under high plant density (60,000 plants ha^{-1}) produced the heaviest boll weight of 7.25 g (Fig. 2d). But the weight differences between the two plant densities (44,444 and 60,000 plants ha^{-1}) at 150 kg Nha^{-1} using either Samcot-13 (7.25 g) or Jalingo Local variety interaction (7.23 g) was not significant. An increase in boll weight by increasing nitrogen rate from 95 kg N to 150 kg Nha^{-1} was recorded by [24]. Increasing nitrogen fertilization resulted in higher accumulation of metabolites which impacted on boll weight. Similar increase in boll weight of cotton when nitrogen was applied at 150 kg/ha has been reported by [7].

3.2.3 Cottonseed (seed with lint) yield per boll

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

Table 1. Background physico-chemical properties of the experimental soil

Property	Location 1		Location 2	
	Surface soil (0-15 cm)	Sub soil (15-30 cm)	Surface soil (0-15 cm)	Sub soil (15-30 cm)
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_2o)	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

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 ($kgha^{-1}$)
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*

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

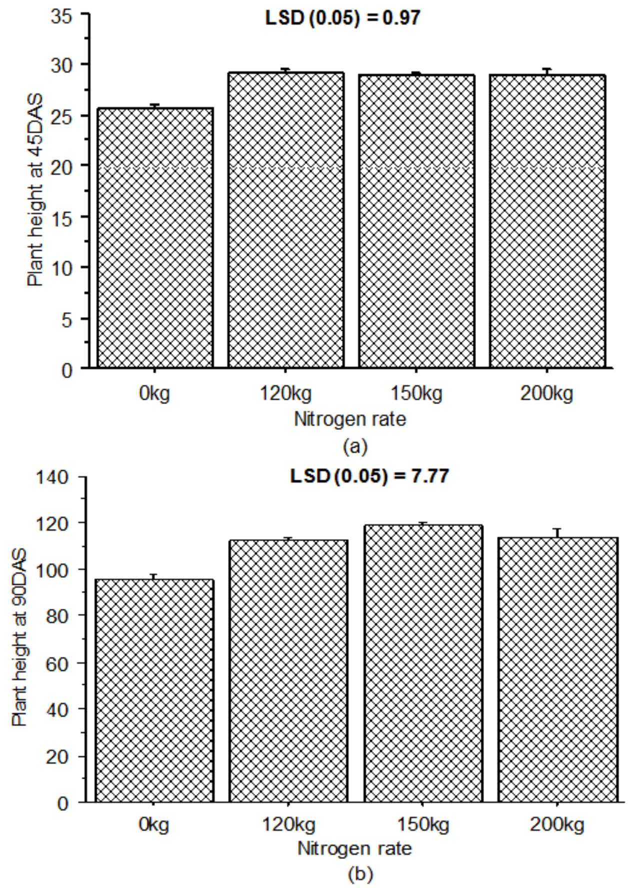

Fig. 1. Effect of nitrogen rates on cotton plant height (cm) at (a) 45 DAS and (b) 90 DAS

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

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

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

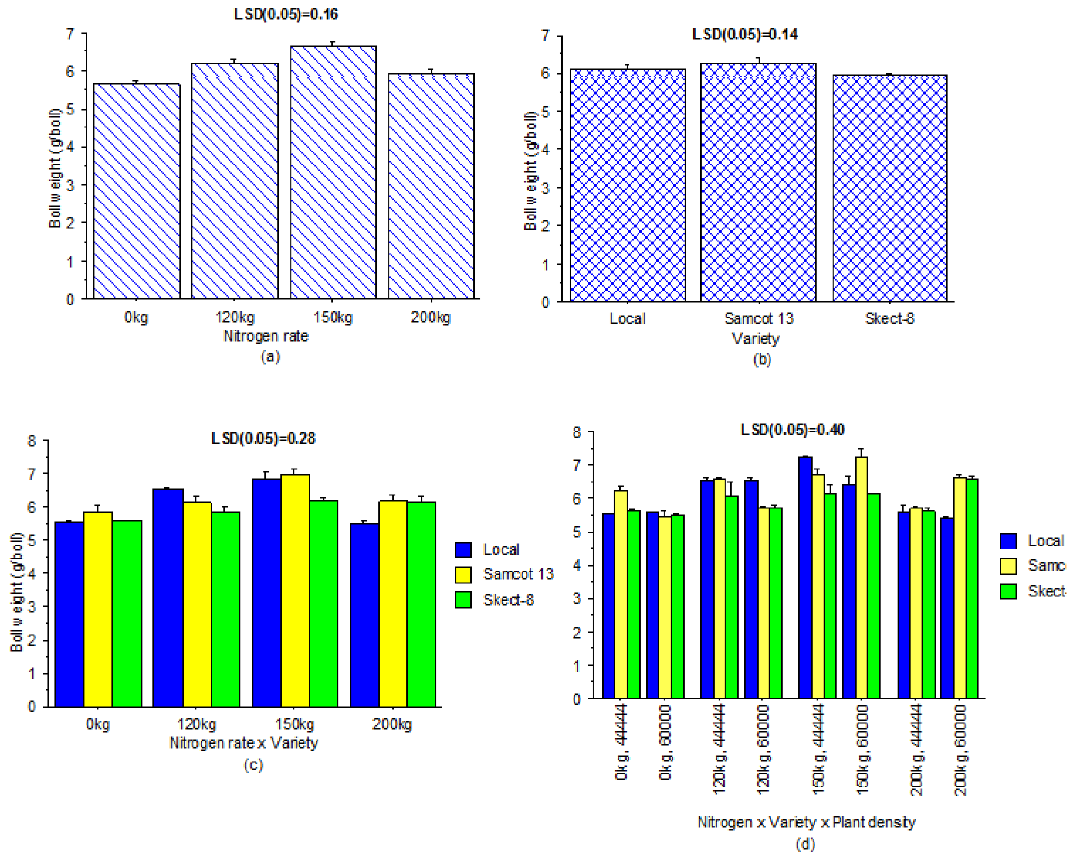

Fig. 2. Effects of (a) nitrogen rates, (b) variety, (c) the interaction of nitrogen with variety and (d) the interaction of nitrogen with variety with plant density on cotton boll weight (g/boll)

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

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

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

The lower plant population gave higher cottonseed yield than the higher population. Several reports [29,30,31,32,33] also showed maximum cottonseed yield at a density of 44, 444 plants ha^{-1}.

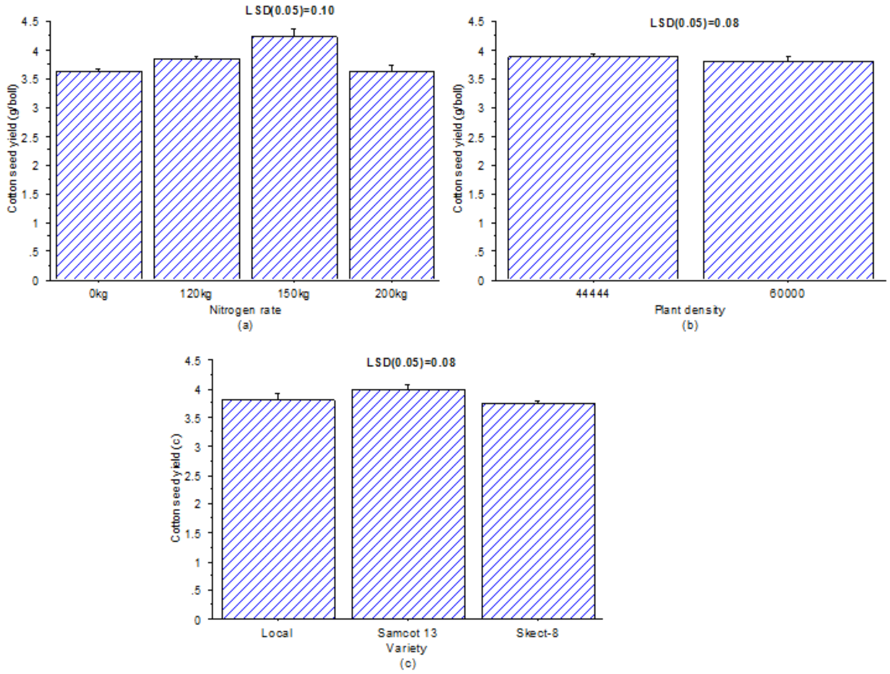

Fig. 3. Effects of (a) nitrogen rates, (b) plant density and (c) variety on cottonseed yield (g/boll)

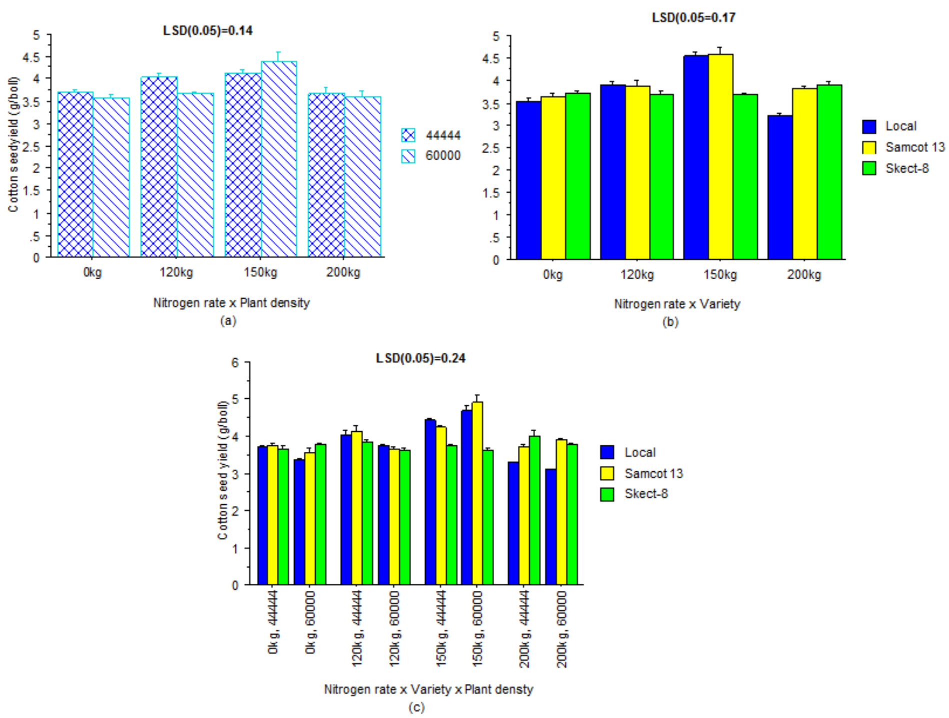

Fig. 4. Interactive effects of (a) nitrogen x variety, (b) nitrogen x plant density and (c) nitrogen x variety x plant density on cottonseed yield (g/boll)

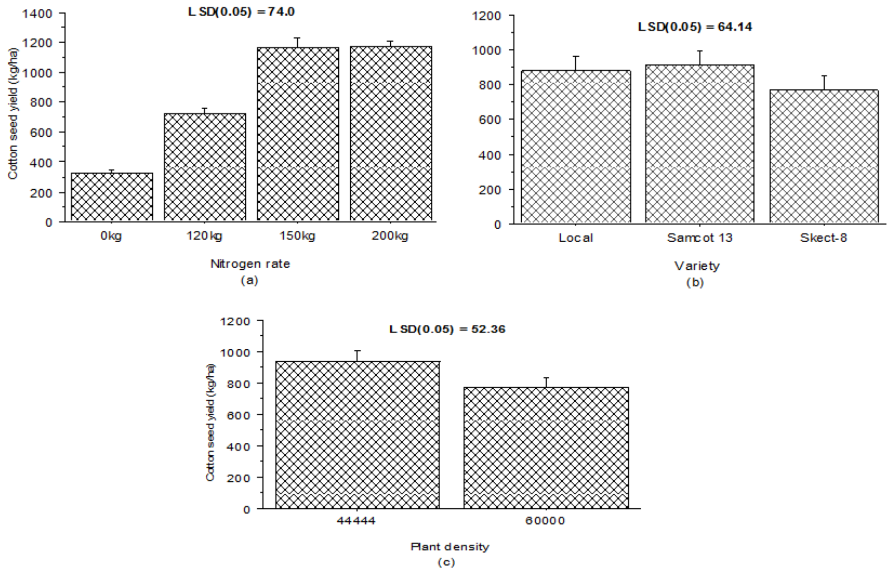

Fig. 5. Effects of (a) nitrogen rates, (b) variety and (c) plant density on cottonseed yield (kg/ha)

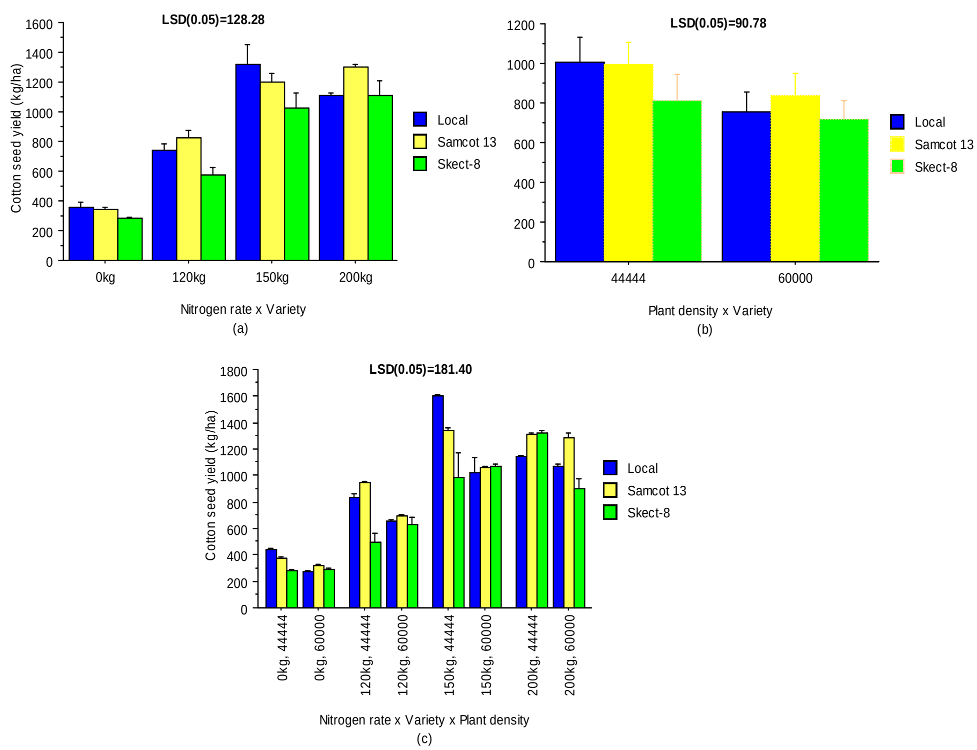

Fig. 6. Interactive effects of (a) nitrogen x variety, (b) plant density x variety and (c) nitrogen x plant density x variety on cottonseed yield (kg/ha)

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

3.3 Monopodial and Sympodial Branches of Cotton as Influenced by Nitrogen Rates, Cotton Varieties and Plant Densities

3.3.1 Monopodial branches

Table 3 shows a summary of analysis of variance of different nitrogen levels, plant density and cotton variety on monopodial branches of cotton plant. The effects of nitrogen rates were significant at 60 and 100 DAS for monopodial branches. Plots treated with 150 kg Nha^{-1} produced the highest number of monopodial branches at 60 (2.85) and 100 DAS (3.37) as presented in Fig. 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} (Fig. 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} (Fig. 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 (Fig. 8a). Similar trend was observed at 100 DAS (Fig. 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 (Fig. 8c). Nevertheless, the low plant density on control plot produced the least numbers of monopodial branches averaging 2.37 (Fig. 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 (Fig. 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.

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 (Fig. 9a). Plant density, variety and the various interactions were not significant at 60 DAS. At 100 DAS, nitrogen rates, plant density and the interaction of nitrogen rate with plant density was significant (*P < .05*). Plot treated with 150 kg Nha^{-1} produced the highest number of sympodial branches (9.80)

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

Source of variation	Monpodial branches @60 DAS	Monpodial 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*

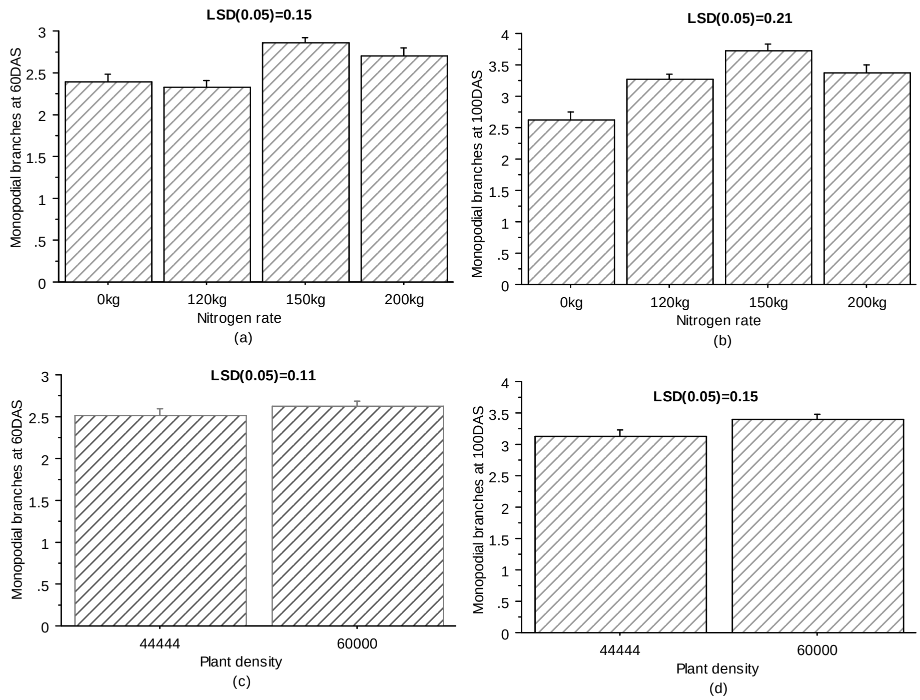

Fig. 7. Effects of nitrogen rates at (a) 60 DAS, (b) 100 DAS and plant density at 60 DAS and at 100 DAS (c and d) on monopodial branches

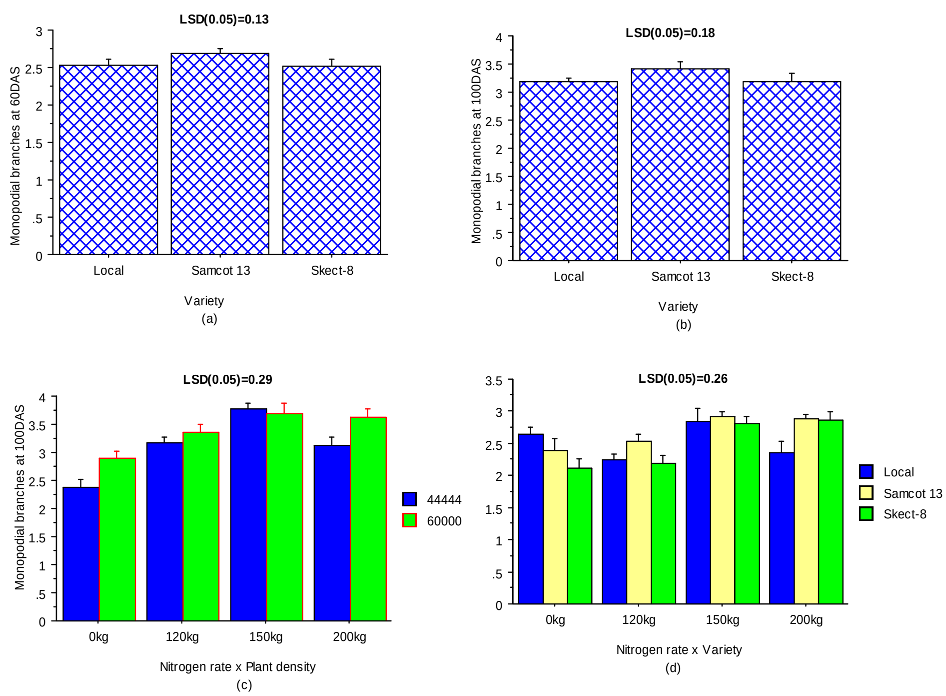

Fig. 8. Effects of variety at (a) 60 DAS and (b) 100 DAS and the interaction of N with plant density variety at 100 DAS (c) and nitrogen with variety (d) on monopodial branches of cotton

compared with other N rates and control plots (Fig. 9b). Higher plant density (60,000 plants ha^{-1}) produced average of 9.13 sympodial branches at 100 DAS while lower density (44,444 plants ha^{-1}) produced 8.63 sympodial branches (Fig. 9c). Interaction of nitrogen rates with density at 100 DAS showed that low density with N rate of 150 kg Nha^{-1} produced the highest sympodial branches (9.84) compared with other N rates x plant density interaction and control plots (Fig. 9d). Similar results for cotton fruiting branches have been independently reported by [36,37].

3.4 Biological (Biomass) Yield as Influenced by Nitrogen Rates, Cotton Varieties and Plant Densities

A summary of the analysis of variance as shown in Table 3 indicated that N rate, plant density, the interaction of N rate x variety and N x PD x V significantly affected the biomass yield of cotton plant. The main effect of nitrogen rates indicated that biomass yield was highest under the plot treated with 150 kg Nha^{-1} (9778.94 kgha^{-1}) while the control plot produced the lowest yield of 6098.61 kgha^{-1} (Fig. 10a).

Plant density showed a significant effect on biological yield. It was noted that lower plant density of 44,444 plants ha^{-1} produced more biomass (Fig. 10b). Varietal effects on biomass yield were not significant. Interactively, nitrogen rates interaction with variety was significant. Sketch-8 treated with 150 kg Nha^{-1} produced the largest quantity of biomass (1,096.42 kgha^{-1}) while the same variety in control plots produced

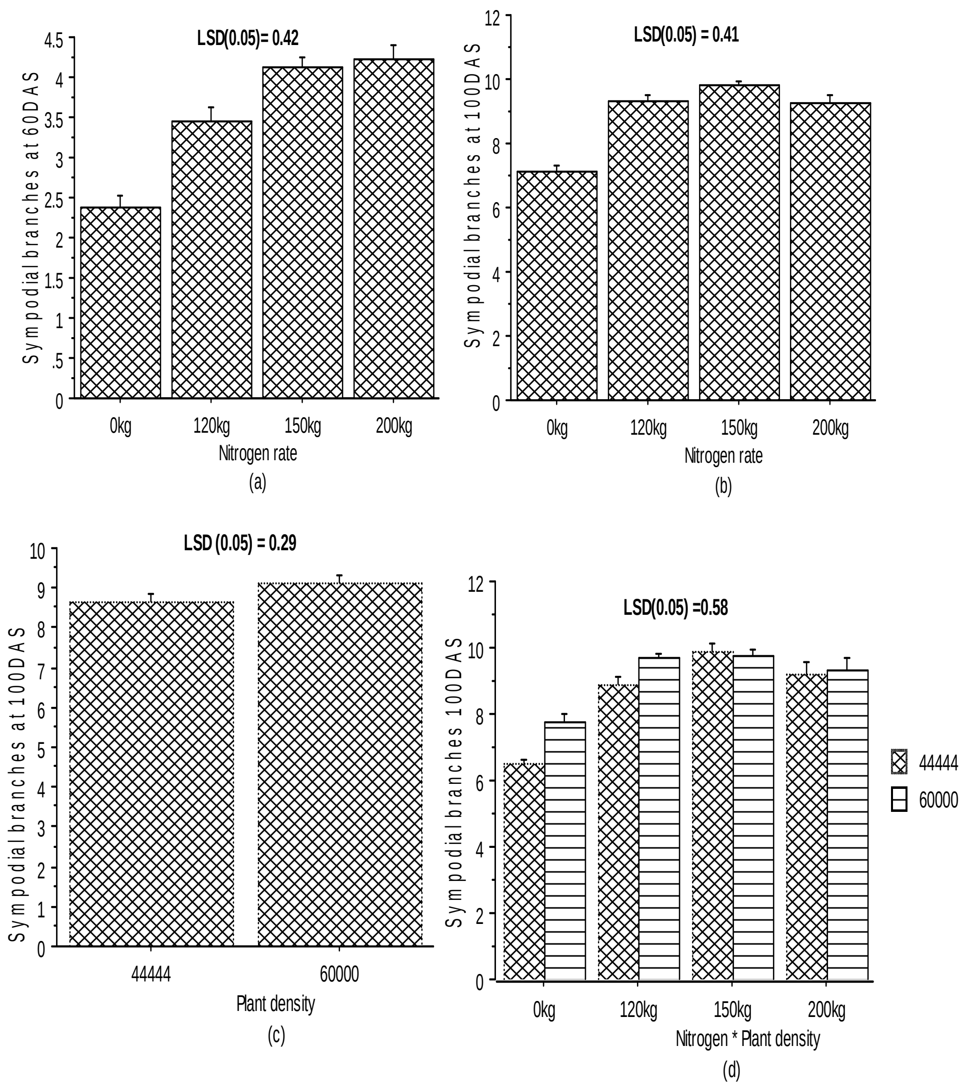

Fig. 9. Effects of nitrogen rates at 60 and 100 DAS (a and b), plant density at 100 DAS (c) and interaction of nitrogen with plant density at 100 DAS (d) on sympodial branches

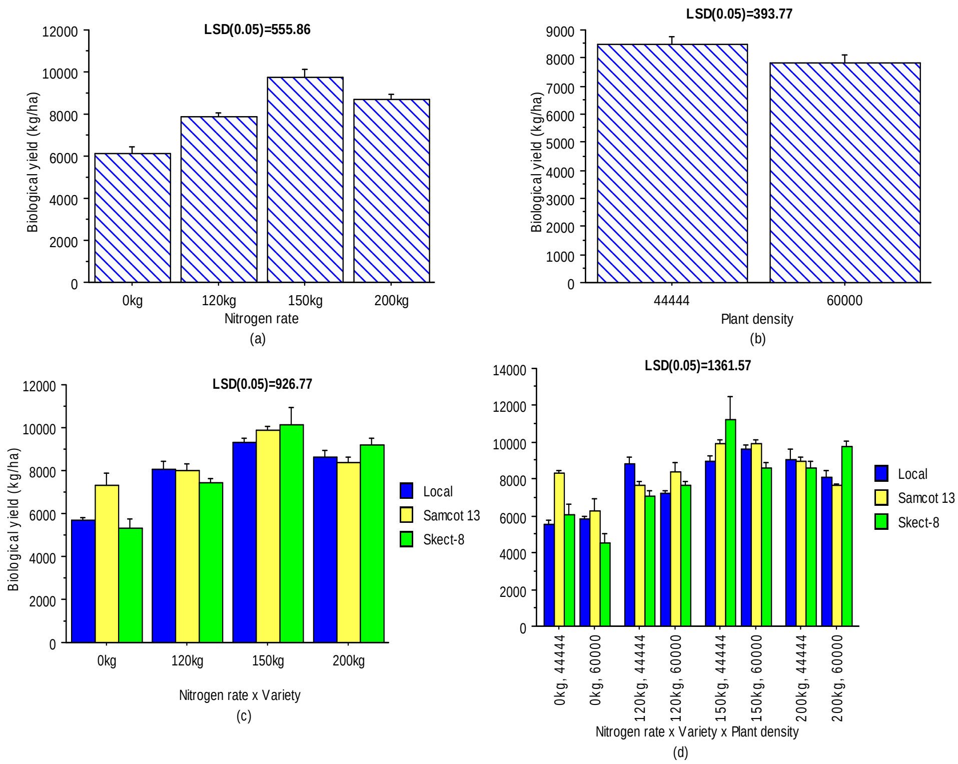

Fig. 10. Effect of (a) nitrogen rates, (b) plant density, (c) the interaction of nitrogen with variety and (d) nitrogen with variety with plant density on biological yield

the lowest biomass yield of 5,300.00 kgha^{-1} (Fig. 10c). Also, interaction of nitrogen rates at 150 kg Nha^{-1} with Sketch-8 under low plant density significantly produced the largest biomass yield (Fig. 10d). The result of this study on biomass yield showed that nitrogen application at all levels contributed to increase in biological yield; this is because of the greater amount of vegetative growth and robustness of plants resulting from the available nitrogen uptake. It has been reported by [4] that nitrogen fertilization had a significant impact on plant biomass production while [38] confirmed that nitrogen is essential for cotton canopy area development and photosynthesis. Lower plant density produced larger plant size hence it resulted in larger biological yields.

4. CONCLUSION

The growth and yield components of cotton were optimum at N rate of 150 kg Nha^{-1}. For cottonseed yield per boll, Samcot-13 treated with 150 kg Nha^{-1} was the best in the study area. Interactively, cottonseed yield per hectare was highest for Jalingo Local treated with 150 kg Nha^{-1} and at the lower plant density (44,444 plants ha^{-1}). Nitrogen at all levels significantly increased cottonseed yield, however, cottonseed yield per hectare (fibre and 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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