

Density and Cultivar Effects on the Biomass and Crop Growth Rate of Upland Rice in Uyo Southeastern Nigeria

Abstract

Aims: To evaluate population densities and cultivars on the biomass and crop growth rate (CGR) of upland rice and their correlation with grain yield.

Study design: A Factorial on randomized complete block design.

Place and duration of study: The Teaching and Research Farm of the Faculty of Agriculture, University of Uyo, between May 12, 2009 and September 30, 2010.

Methodology: Six sowing densities; 1,600,000, 1,066,666, 800,000, 640,000, 533,333, and 2,054,435 plants ha⁻¹ were combined with five cultivars of rice; FAROs 43, 46, 55, 56 and a local cultivar – *Otokongtian*. Treatment combinations were replicated three times. Destructive samples were collected at 3, 6, 9, 12, and 15 weeks after sowing (WAS), oven-dried at 80°C to constant weight and the biomass and CGR determined. Data were analyzed with Genstat Discovery Edition 4 and means compared by Fisher's protected least significant difference at 5% probability.

Results: Rice biomass for 2,054,435 and 1,600,000 densities increased significantly (8.77-12.55 and 7.08-11.44 g m⁻²) at 3 WAS in 2009 and 2010 respectively ($P=0.05$). Biomass increase was highest at 15 WAS across densities and cultivars in both years. FARO 46 produced the highest significant biomass in both years during the period but was replaced by *Otokongtian* at 15 WAS. At 3-6 WAS, 2,054,435 produced the highest significant CGR in both years (5.83 and 5.193 g m⁻² day⁻¹ for 2009 and 2010 respectively), while FARO 43 had the highest CGR during the period. Higher densities produced higher CGR. The CGR continued to increase across densities and cultivars up to 9-12 WAS and began to decline at 12-15 WAS. There was a positive correlation between rice biomass, CGR and grain yield.

Conclusion: Higher sowing densities produced higher rice biomass and CGR which correlated positively with grain yield.

Keywords: Plant density, crop growth rate, upland rice, biomass.

Introduction

Rice is classified as a food staple for over 60 percent of Nigerian homes [1]. According to [2], Nigeria has continued to experience rapid growth in per capita rice consumption ranging from 5 kg in the 1960s, 11 kg in the 1980s to 25 kg in the 1990s. Nigeria's annual demand for rice is about 5 million tones of milled rice and is far

46 greater than the supply, estimated at 3 million tonnes annually [3] with the result that
47 the rice self-sufficiency ratio is only 0.64 [4].

48 In Nigeria, rice yield averaged of 1.8 t ha⁻¹ [5], is far below that of many
49 countries. For instance, China, Japan, Korea and Egypt have been reported to have
50 average yield of 7.5, 5.9, 7.3 and 7.5 t ha⁻¹, respectively [5]. The current practice of
51 horizontal expansion of rice area in Nigeria is not sustainable due to competition for
52 land resources and high population growth rate. Increase in rice production by vertical
53 expansion through the adoption of good management practices and high yielding
54 varieties would lead to increased productivity per unit area of land. Rice continues to
55 gain prominence among the commodities produced in Nigeria. It occupied the 9th
56 position in 2005, 5th position between 2009 and 2011, and the current 4th position in
57 2012 [5].

58 Takai et al. [6] observed cultivar differences in the crop growth rate of rice during
59 the reproductive growth stage in a temperate climate (Japan) and reported that rice
60 genotypes having higher CGR during the late reproductive period produced a greater
61 number of spikelet per unit land area resulting in the highest grain yield. They also
62 observed a positive correlation between the biomass and CGR on the accumulation and
63 rapid translocation of non-structural carbohydrate to panicles in the initial period of
64 grain filling and concluded that improvement of canopy photosynthesis during the late
65 reproductive period may be essential as the first step toward increased yield potential in
66 rice. According to San-oh et al. [7], increasing the biomass productivity of rice is
67 critical for improving the yield potential. They observed greater biomass production
68 and grain yield in plots with high plant density per hectare. Factors responsible for high
69 biomass production were identified to include; vigorous tiller increase at the tillering
70 stage resulting in higher capture of solar radiation. Since most upland varieties have

low tiller production (3 – 5 tillers per hill) and constant leaf area [8], it was necessary to evaluate the effect of sowing densities and cultivars on the biomass and crop growth rate of upland rice in the humid rainforest agro-ecology of the southeastern zone of Uyo where no such study has been reported and to determine how these parameters correlate with grain yield.

Materials and Methods

Location of Experiment: Field experiments were conducted during the cropping seasons of 2009 and 2010 at the Teaching and Research Farm of the Faculty of Agriculture, University of Uyo, located at Use Offot, Uyo, Akwa Ibom State. The experimental sites were located between latitude $05^{\circ}, 01^1, 56.2''$ N and $05^{\circ}, 01^1 56.6''$ N and longitude $07^{\circ}, 58^1 20.2''$ E and $07^{\circ}, 58^1 20.6''$ E and 55 – 57 m above sea level. [9] reported that this humid rain forest zone received an annual rainfall of about 2,500 mm and a mean relative humidity of 87%. The mean annual temperature varies between 22 and 32°C and day length (sunshine hours) of 3 – 8 hours. The soil is acidic and belongs to broad soil classification group, ultisol, formed from acid plain sand [10]. Treatments consisted of six sowing densities fitted in a factorial arrangement with five cultivars of upland rice. The sowing densities were obtained by the following inter- and intrarow spacing with four seedlings per hill:

Spacing		Density ha ⁻¹
25cm x 10cm	=	1,600,000
25cm x 15cm	=	1,600,666
25cm x 20cm	=	800,000
25cm x 25cm	=	640,000
25cm x 30cm	=	533,333
25cm x drill (mean)	=	2,054,435

91 The rice cultivars were:

92 1. FARO 43, 2. FARO 46, 3. FARO 55, 4. FARO 56, 5. A local check –
93 *Otokongtian*.

94 The treatment combinations were laid out on a randomized complete block
95 design and replicated three times.

96 In both years, each experimental unit measured 3 m x 4 m and treatments were
97 assigned randomly to each plot within a block. Seeds were sown by dibbling (except 25
98 cm x drill), using six seeds hill⁻¹. At two weeks after sowing (WAS), seedlings were
99 thinned to four per hill. Weeds were controlled using *paraquat* at the rate of 1.0 kg
100 active ingredient ha⁻¹ pre-emergence and by hand hoeing at 3, 6, 9 and 12 WAS.

101 **Fertilizer application:** NPK 15-15-15 fertilizer was applied at 400 kg ha⁻¹ to supply 60
102 kg N, 60 kg P₂O₅ and 60 kg K₂O in split doses at 2, 6 and 9 WAS by side placement.
103 Human bird scarers were employed to chase birds.

104
105 **Data collection:** The biomass of rice was determined by sampling four hills per plot at
106 3, 6, 9, 12, and 15 WAS into four bags after separating them into leaves and stems.
107 They were dried in thermostatic ventilated oven model DHG 9202 at 80° C [11] for 48
108 hours. They were then weighed using Mettler Toledo (AB 204) and a mean of the four
109 samples was recorded as the mean biomass hill⁻¹. Crop growth rate (CGR) was
110 estimated with the equation given by Radford [12]:

$$111 \quad \text{CGR} = \frac{W_2 - W_1}{SA(t_2 - t_1)} \quad \text{gm}^{-2}\text{d}^{-1}$$

112

113 Where,

114 W_1 and W_2 = dry weight of plant at the beginning and end of the sampling interval

115 t_1 and t_2 = sampling times 1 and 2

116 SA = the soil area occupied by the plant at each sampling.

117 Data collected were analyzed using Genstat Discovery Edition 4 and significant
 118 means were compared with Fishers Least Significant Difference.

120 Results

122 **Rice Biomass:** At 3 WAS in 2009 and 2010, the biomass of rice increased significantly
 123 with increase in density with the highest biomass obtained from 2,054,435 followed by
 124 1,600,000. The least biomass was obtained from 533,333 density in both years (Table
 125 1).

126
 127 **Table 1:** Effects of plant density and cultivars on biomass of rice (g m^{-2}) at 3
 128 WAS in 2009 and 2010 in Uyo, Nigeria
 129

Density Plant/ha	Rice Cultivars					Mean
	FARO 43	FARO 46	FARO 55	FARO 56	Otokongtian	
2009						
1,600,000	5.64	7.80	5.84	4.68	11.44	7.08
1,066,666	5.05	4.94	4.24	4.54	3.51	4.46
800,000	3.22	4.62	2.88	2.82	2.88	3.28
640,000	2.69	2.00	1.65	2.67	2.14	2.24
533,333	1.43	1.79	1.76	2.11	1.50	1.72
25cm x drill ($\bar{x}$ = 2,054,435)	7.34	10.15	7.24	9.44	9.74	8.77
Mean	4.23	5.22	3.94	4.38	5.20	4.59
2010						
1,600,000	10.20	13.52	6.92	9.88	16.68	11.44
1,066,666	7.02	7.02	3.81	5.70	5.51	5.81
800,000	5.00	4.18	3.02	3.96	3.84	4.00

640,000	2.51	3.74	2.45	2.90	4.19	3.15
533,333	1.63	3.09	1.74	1.85	2.17	2.09
25cm x drill ($\bar{x}$ = 2,054,435)	12.55	15.66	13.97	10.56	9.89	12.55
Mean	6.49	7.87	5.32	5.81	7.05	6.51

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2009

2010

135 LSD ($P=0.05$) for population density means (P)

0.36

0.64

136 LSD ($P=0.05$) for cultivar means (C)

0.34

0.63

137 LSD ($P=0.05$) for P x C means

0.84

1.55

138 FARO 46 produced the highest significant biomass, followed by *Otokongtian* compared
 139 with FARO 55 which produced the lowest biomass during the period in both years. The
 140 interaction effect showed that cultivars produced higher biomass at higher densities
 141 than at lower densities.

142 At 6 WAS in 2009 and 2010, 1,600,000 density produced the highest significant
 143 biomass followed by 1,066,666 density (Table 2). The lowest biomass was produced by
 144 533,333 density in both years.

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146 **Table 2: Effects of plant density and cultivars on biomass of rice (g m^{-2}) at 6**
 147 **WAS in 2009 and 2010 in Uyo, Nigeria**

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Density Plant/ha	Rice Cultivars					Mean
	FARO 43	FARO 46	FARO 55	FARO 56	Otokongtian	
<u>2009</u>						
1,600,000	75.72	81.24	52.44	61.12	33.92	60.89
1,066,666	42.20	50.95	36.72	49.82	42.31	44.40
800,000	35.48	34.96	26.34	35.40	30.94	32.62
640,000	30.03	30.78	20.18	21.36	27.70	26.01
533,333	18.46	21.78	15.26	20.33	21.01	19.37
25cm x drill ($\bar{x}$ = 2,054,435)	49.06	41.57	35.65	34.43	41.87	40.52

Mean	41.83	43.55	31.10	37.08	32.96	37.30
	2010					
1,600,000	72.12	90.28	37.60	62.80	62.84	65.13
1,066,666	53.89	58.21	30.54	37.40	39.37	43.88
800,000	33.60	37.24	26.16	21.82	32.10	30.18
640,000	19.60	34.69	12.22	22.93	23.92	22.67
533,333	19.45	19.81	12.04	16.59	15.89	16.76
25cm x drill (X = 2,054,435)	41.46	39.68	35.60	40.09	40.09	39.38
Mean	40.02	46.65	25.69	33.61	35.70	36.33

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2009

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LSD ($P=0.05$) for population density means (P)

LSD ($P=0.05$) for cultivar means (C)

LSD ($P=0.05$) for P x C means

In 2009 FAROs 43 and 46 produced similar biomass that was significantly higher than other cultivars, followed by FARO 56 while the lowest biomass was produced by FARO 55. In 2010, FARO 46 produced the highest biomass followed by FARO 43. The lowest biomass was also obtained from FARO 55. Apart from the 2,054,435 density, cultivars always produced higher biomass at higher densities.

Biomass production at 9 WAS in 2009 and 2010 increased significantly with increase in density except the 2,054,435 density which produced similar biomass with 800,000 density. The 533,333 density produced the lowest biomass in both years (Table 3).

Table 3: Effects of plant density and cultivars on biomass of rice (g m^{-2}) at 9 WAS in 2009 and 2010 in Uyo, Nigeria

Density Plant/ha	Rice Cultivars					Mean
	FARO 43	FARO 46	FARO 55	FARO 56	Otokongtian	
	2009					
1,600,000	224.08	321.20	178.80	238.20	247.68	242.00

1,066,666	179.69	220.46	139.91	170.61	201.58	182.41
800,000	128.06	181.88	120.40	120.50	148.04	139.78
640,000	112.16	132.69	85.12	112.46	122.70	113.02
533,333	91.73	130.13	68.29	91.60	104.69	97.28
25cm x drill ($\bar{x}$ = 2,054,435)	140.96	158.76	114.55	135.15	147.95	139.47
Mean	146.11	190.85	117.85	144.75	162.11	152.33
2010						
1,600,000	253.28	294.88	201.72	293.84	258.84	260.51
1,066,666	194.94	203.23	141.35	169.29	205.34	182.83
800,000	131.46	151.76	106.96	143.72	145.48	135.88
640,000	105.98	132.62	81.33	114.74	117.50	110.43
533,333	95.11	112.09	67.95	97.11	92.04	92.86
25cm x drill ($\bar{x}$ = 2,054,435)	137.09	155.75	120.77	136.99	138.67	137.85
Mean	152.98	175.06	120.01	159.28	159.65	153.39

166			
167		2009	2010
168	LSD ($P=.05$) for population density means (P)	4.87	5.79
169	LSD ($P=.05$) for cultivar means (C)	3.95	4.75
170	LSD ($P=.05$) for P x C means	9.66	11.60
171	FARO 46 produced the highest significant biomass, followed by <i>Otokongtian</i> .		
172	With the exception of 2,054,435 density, higher densities produced significantly higher		
173	biomass during the period. However, in 2010 while FARO 46 produced the highest		
174	significant biomass, similar biomass was produced by FARO 56 and <i>Otokongtian</i> . In		
175	general, biomass production was greater at higher than at lower densities during this		
176	period of growth.		
177	The 1,600,000 density continued to produce the highest significant biomass at		
178	12 WAS in 2009 and 2010, followed by 1,066,666, while 533,333 produced the lowest		
179	biomass (Table 4).		

180 **Table 4:** Effects of plant density and cultivars on biomass of rice (g m⁻²) at 12
 181 WAS in 2009 and 2010 in Uyo, Nigeria
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Density Plant/ha	Rice Cultivars					Mean
	FARO 43	FARO 46	FARO 55	FARO 56	Otokongtian	
2009						
1,600,000	458.56	410.12	275.24	358.48	374.56	375.40
1,066,666	315.36	306.34	211.17	265.44	320.22	283.69
800,000	251.48	234.52	167.32	196.64	257.46	221.48
640,000	276.61	264.64	254.26	270.21	300.58	273.26
533,333	224.41	238.16	192.19	228.01	253.46	227.24
25cm x drill ($\bar{x}$ = 2,054,435)	232.87	306.61	197.47	237.86	243.07	243.58
Mean	293.22	293.40	216.28	259.44	291.56	270.78
2010						
1,600,000	615.28	461.72	393.36	553.76	589.16	522.66
1,066,666	411.05	409.10	321.98	360.40	417.99	384.10
800,000	302.06	264.70	235.50	303.40	323.60	285.85
640,000	279.47	260.14	211.01	253.33	239.97	248.78
533,333	208.57	228.53	160.85	231.57	234.82	212.87
25cm x drill ($\bar{x}$ = 2,054,435)	260.66	307.02	236.18	256.12	260.61	264.12
Mean	346.18	321.87	259.81	326.43	344.36	319.73

	2009	2010
183		
184 LSD ($P=0.05$) for population density means (P)	6.90	15.17
185 LSD ($P=0.05$) for cultivar means (C)	5.22	12.12
186 LSD ($P=0.05$) for P x C means	12.80	29.69

187 FAROs 43, 46 and *Otokongtian* produced similar biomass in 2009 that was
 188 significantly higher than the biomass for FAROs 55 and 56. The lowest biomass was
 189 obtained from FARO 55 in 2009. In 2010, FARO 43 was similar to *Otokongtian* in the
 190 biomass they produced per m². They were followed by FAROs 46 and 56 while FARO

191 55 produced the lowest biomass. In both years higher densities produced greater
192 biomass than lower densities at 12 WAS.

193 Higher densities produced higher biomass at 15 WAS in 2009 and 2010 with the
194 exception of 2,054,435 (Table 5).

195 **Table 5: Effects of plant density and cultivars on biomass of rice (g m⁻²) at 15**
196 **WAS in 2009 and 2010 in Uyo, Nigeria**
197

Density Plant/ha	Rice Cultivars					Mean
	FARO 43	FARO 46	FARO 55	FARO 56	Otokongtian	
<u>2009</u>						
1,600,000	754.44	596.12	668.32	715.04	828.76	712.56
1,066,666	531.23	455.68	510.95	562.71	616.19	535.36
800,000	451.90	414.36	403.92	438.36	509.08	443.52
640,000	365.20	348.11	313.81	368.13	378.94	354.83
533,333	289.91	294.05	262.47	296.26	299.49	288.43
25cm x drill ($\bar{x}$ = 2,054,435)	315.28	415.14	266.12	320.79	328.90	329.26
Mean	451.33	420.58	404.27	450.22	493.56	443.99
<u>2010</u>						
1,600,000	806.04	628.80	548.20	724.84	863.44	714.26
1,066,666	558.77	451.66	482.81	561.71	613.74	533.74
800,000	392.88	407.36	355.00	365.68	468.08	397.80
640,000	367.46	330.58	295.65	344.70	366.88	341.05
533,333	301.46	292.14	228.36	298.42	316.80	287.44
25cm x drill ($\bar{x}$ = 2,054,435)	366.23	425.44	336.75	361.59	377.71	373.54
Mean	465.47	422.66	374.46	442.82	501.11	441.31

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		2009	2010
201	LSD ($P=.05$) for population density means (P)	0.248	0.362
202	LSD ($P=.05$) for cultivar means (C)	0.226	0.330
203	LSD ($P=.05$) for P x C means	0.554	0.809

204 The check cultivar – *Otokongtian* produced the highest biomass followed by
 205 FARO 43 and FARO 56 while FARO 55 produced the lowest plant biomass. Higher
 206 rice biomass was produced by cultivars at higher than at lower densities in both years.

207 Crop Growth Rate (CGR)

208 The crop growth rate of rice between 3 and 6 WAS in 2009 and 2010 increased
 209 significantly with an increase in density (Table 6).

210 **Table 6: Effects of plant density and cultivars on the crop growth rate of rice**
 211 **(g/m²/day) at 3-6 WAS in 2009 and 2010 in Uyo, Nigeria**
 212

Density Plant/ha	Rice Cultivars					Mean
	FARO 43	FARO 46	FARO 55	FARO 56	Otokongtian	
2009						
1,600,000	3.337	3.497	2.220	2.587	2.976	2.923
1,066,666	1.747	2.163	1.526	2.129	1.824	1.878
800,000	1.536	1.445	1.117	1.553	1.336	1.398
640,000	1.282	1.370	0.882	0.890	1.216	1.128
533,333	0.831	0.976	0.660	0.890	0.953	0.862
25cm x drill ($\bar{x}$ = 2,054,435)	7.794	4.306	5.157	5.052	6.841	5.830
Mean	2.755	2.293	1.927	2.183	2.524	2.336
2010						
1,600,000	2.992	2.589	1.531	2.413	2.070	2.519
1,066,666	1.994	2.391	1.020	1.608	1.370	1.678
800,000	1.496	1.794	0.766	1.207	1.035	1.260
640,000	1.196	1.435	0.612	0.965	0.828	1.007
533,333	0.963	1.155	0.493	0.776	0.666	0.811
25cm x drill ($\bar{x}$ = 2,054,435)	5.748	3.935	3.883	5.990	6.411	5.193
Mean	2.398	2.383	1.384	2.160	2.065	2.078

213		2009	2010
214			
215	LSD ($P=.05$) for population density means (P)	0.140	0.185
216	LSD ($P=.05$) for cultivar means (C)	0.127	0.169
217	LSD ($P=.05$) for P x C means	0.312	0.413

218 FARO 43 increased CGR by 42.79% and *Otokongtian* by 30.98% compared
 219 with FARO 55 which had the lowest CGR in 2009, but in 2010, FARO 43 produced
 220 similar CGR with FARO 46 and they were significantly higher than other cultivars.
 221 Similar CGR was produced by FARO 56 and *Otokongtian* in 2010. Higher densities
 222 produced higher CGR than lower densities.

223 Apart from 533,333 and 640,000 densities with similar CGR in 2009, there was
 224 a significant increase in CGR with increase in plant density in both years between 6 and
 225 9 WAS, (Table 7).

226 **Table 7: Effects of plant density and cultivars on the crop growth rate of rice**
 227 **(g/m²/day) at 6-9 WAS in 2009 and 2010 in Uyo, Nigeria**
 228

Density Plant/ha	Rice Cultivars					Mean
	FARO 43	FARO 46	FARO 55	FARO 56	Otokongtian	
2009						
1,600,000	7.066	11.444	6.016	8.433	8.274	8.246
1,066,666	6.888	7.967	4.850	5.677	7.486	6.573
800,000	4.409	6.996	4.479	4.050	5.577	5.102
640,000	3.910	4.851	3.092	4.336	4.522	4.142
533,333	3.578	5.292	2.590	3.481	4.086	3.805
25cm x drill ($\bar{x}$ = 2,054,435)	17.159	10.070	13.710	18.508	19.710	17.031
Mean	7.168	8.770	5.789	7.414	8.276	7.483
2010						
1,600,000	11.368	9.514	7.714	11.638	9.867	10.020
1,066,666	7.574	6.3339	5.140	7.754	6.574	6.676
800,000	5.684	4.757	3.857	5.819	4.933	5.010
640,000	4.545	3.804	3.085	4.653	3.945	4.006
533,333	3.789	3.171	2.571	3.879	3.289	3.340
25cm x drill ($\bar{x}$ = 2,054,435)	18.993	19.014	15.296	19.665	20.923	18.778

	Mean	8.659	7.767	6.277	8.901	8.255	7.972
231							
232				2009	2010		
233	LSD ($P=0.05$) for population density means (P)			0.511	0.523		
234	LSD ($P=0.05$) for cultivar means (C)			0.467	0.477		
235	LSD ($P=0.05$) for P x C means			0.144	1.169		

236 During the period, FARO 46 produced the highest CGR, followed by
 237 *Otokongtian* compared with FARO 55. In 2010, FARO 56 produced the highest CGR,
 238 followed by FARO 43 and the least was produced by FARO 55. Cultivars produced
 239 higher CGR at higher than lower densities.

240 Between 9 and 12 WAS, higher densities produced significantly higher CGR,
 241 except in 2009 when 1,066,666 and 800,000 densities produced similar CGR, (Table 8).

242
 243 **Table 8: Effects of plant density and cultivars on the crop growth rate of rice**
 244 **(g/m²/day) at 9-12 WAS in 2009 and 2010 in Uyo, Nigeria**
 245

Density Plant/ha	Rice Cultivars					Mean
	FARO 43	FARO 46	FARO 55	FARO 56	<i>Otokongtian</i>	
	<u>2009</u>					
1,600,000	15.610	7.030	12.850	12.080	15.570	12.630
1,066,666	9.080	4.210	10.120	12.070	10.650	9.230
800,000	10.320	5.050	8.270	9.980	11.060	8.930
640,000	7.830	6.280	8.050	7.510	8.470	7.630
533,333	6.590	5.280	6.050	6.660	7.270	6.370
25cm x drill ($\bar{x} = 2,054,435$)	17.170	20.270	15.060	20.760	20.270	18.700
Mean	11.100	8.020	10.060	11.510	12.210	10.580
	<u>2010</u>					
1,600,000	14.851	8.927	10.640	9.221	16.724	12.053
1,066,666	9.895	5.881	7.089	6.143	11.142	8.030
800,000	6.845	4.528	4.832	5.013	7.219	5.687

640,000	6.257	3.718	4.482	3.885	7.046	5.078
533,333	4.950	2.942	3.547	3.074	5.575	4.018
25cm x drill ($\bar{x}$ = 2,054,435)	24.553	24.781	20.717	24.182	25.8777	24.022
Mean	11.225	8.446	8.551	8.586	12.264	9.815

246

247

2009

2010

248 LSD ($P=0.05$) for population density means (P)

1.171

0.680

249 LSD ($P=0.05$) for cultivar means (C)

2.618

1.520

250 LSD ($P=0.05$) for P x C means

2.618

1.520

251 During the growth stage, *Otokongtian*, FAROs 43 and 56 produced similar CGR
 252 that was significantly higher than FAROs 46 and 55, whereas in 2010, the CGR for
 253 *Otokongtian* and FARO 43 was similar, followed by FARO 56 while FAROs 46 and 55
 254 produced the lowest CGR. In both years, greater CGR was obtained from cultivars at
 255 higher than lower densities.

256 Between 12 and 15 DAS in 2009 and 2010, CGR increased with increase in
 257 sowing density with the exception of 640,000 and 533,333 densities which produced
 258 similar CGR in 2010, (Table 9).

259 **Table 9: Effects of plant density and cultivars on the crop growth rate of rice**
 260 **(g/m²/day) at 12-15 WAS in 2009 and 2010 in Uyo, Nigeria**

261

Density Plant ha	Rice Cultivars					Mean
	FARO 43	FARO 46	FARO 55	FARO 56	<i>Otokongtian</i>	
<u>2009</u>						
1,600,000	9.650	6.060	10.460	10.630	12.110	9.780
1,066,666	7.020	6.850	7.750	6.360	7.990	7.190
800,000	5.100	6.020	5.230	5.160	2.780	4.860
640,000	4.220	3.970	2.840	4.660	3.730	3.880
533,333	3.090	2.730	3.430	3.330	2.250	2.970
25cm x drill ($\bar{x}$ = 2,054,435)	15.380	14.880	12.460	16.770	18.290	15.560
Mean	7.410	6.750	7.030	7.820	7.860	7.370

	<u>2010</u>					
1,600,000	8.640	7.180	6.250	9.360	13.090	8.900
1,066,666	5.760	4.790	4.170	6.230	8.720	5.936
800,000	4.320	2.590	3.130	4.680	6.550	4.450
640,000	3.460	2.870	2.500	3.740	5.240	3.560
533,333	2.880	2.390	2.080	3.120	4.360	2.970
25cm x drill ($\bar{x}$ = 2,054,435)	21.690	19.400	18.060	21.41	24.850	21.080
Mean	7.790	6.700	6.030	8.090	10.470	7.820

262						
263			2009	2010		
264	LSD ($P=$.05) for population density means (P)		0.905	0.835		
265	LSD ($P=$.05) for cultivar means (C)		0.826	0.762		
266	LSD ($P=$.05) for P x C means		0.024	1.866		
267	<i>Otokongtian</i> produced the highest CGR in 2009 and 2010, followed by FARO					
268	56 and FARO 43; the lowest CGR was obtained from FAROs 56 and 55. Greater CGR					
269	was obtained from cultivars at higher than lower densities.					

270 **Correlation between Biomass, Crop Growth Rate and Grain Yield of Rice**

271 Positive correlation between the biomass, crop growth rate and grain yield was
 272 observed at various stages of measurement in 2009 and 2010, (Table 10).

273 **Table 10: Correlation coefficient between grain yield and growth parameters**
 274 **as influenced by plant density and upland rice cultivar (r)**
 275

Growth Parameters	Correlation 2009	Coefficient 2010
Rice biomass at (weeks after sowing)		
3	0.18NS	0.40NS
6	0.20NS	0.11NS
9	0.47NS	0.38NS
12	0.58*	0.40NS
15	0.34NS	0.38NS

Crop Growth Rate at (weeks after sowing)

3-6	0.52*	0.54*
6-9	0.41NS	0.62*
9-12	0.64*	0.61*
12-15	0.61*	0.65*

276
277 * = Significant at 5% probability level

278 NS = Non-significant at 5% probability level
279

280 Generally, in both years, the highest correlation between rice biomass and grain
281 yield was observed at 9 to 12 weeks after sowing while the correlation between crop
282 growth rate and grain yield was greater at 9 to 15 WAS in 2009 and 6 to 12 weeks in
283 2010.

284 Discussion

285 **Biomass Production:** Biomass production was very slow during the first
286 3 weeks of growth, followed by gradual but slow growth rate at 6 weeks after sowing.
287 This was followed by rapid biomass production from 9 to 15 weeks after sowing. The
288 increase in biomass at higher densities at 3 WAS was related to lower inter plant
289 competition as a result of smaller leaf area index and unlimited solar radiation
290 interception, soil moisture and nutrients. Similar observation was reported by Lack et
291 al. [13]. The difference in biomass production at different densities at 6 WAS could be
292 due to differences in the availability and utilization of adequate growth factors when
293 their canopies had begun to close. Takai et al. attributed high biomass production at
294 tillering stage to vigorous tiller increase and improvement in canopy photosynthesis [6].
295 However, competition effect had begun to occur among higher densities during this
296 growth stage. This was confirmed by the fact that the 2,054,435 density produced lower
297 biomass compared to 1,600,000 and 1,066,666 as a result of competition for below and
298 above ground growth factors. At 9 to 15 WAS, higher densities produced higher

299 biomass with the exception of 2,054,435 density. Lack et al. [13] reported that as
300 density increased, vegetative growth decreased in each hill because of reduction in free
301 space, diminishing radiation and competition for nutrients. In this study, competition
302 for space, and especially, solar radiation and soil nutrients would have been responsible
303 for the greater reduction in biomass production by 2,054,435 density at advanced
304 growth stages. It should be noted that Slus [9] reported low sunshine hours for the study
305 area which could be an important factor for competition beside edaphic factors.

306 Cultivar differences were observed on their biomass production throughout the
307 periods of observation. According to Aruna et al. [14], dry matter production and
308 remobilization in rice were affected by environmental conditions and cultivar
309 differences. It seemed likely that lower densities per hill due to low tillering ability for
310 FAROs 46 and 55 lowered the biomass they produced during the period of study. This
311 finding agreed with the report of Ntanos et al. [15] that the amount of dry matter
312 mobilized by rice was influenced by cultivar characteristics. The maximum vegetative
313 growth corresponded with the highest leaf area attainment (LAI) and thereafter started
314 to decline. Additionally, biomass production is also influenced by the photosynthetic
315 organ structure of the cultivar. San-oh et al. [7] noted that erect leaves in the canopy
316 improved light-intercepting character of the cultivar. In this study, FARO 46 with
317 characteristic droopy leaves could not capture solar radiation as efficiently as other
318 cultivars for biomass production while FARO 55 produced a lower number of tillers.

319 **Crop Growth Rate:** The crop growth rate of upland rice increased consistently
320 albeit gradually with increase in density in all the times of measurement. The soil
321 areahill⁻¹ constituted one of the major sources of variation in the CGR. The narrower
322 the spacing, the higher the CGR. The soil area for a hill using 1,600,000 density (0.025
323 m⁻²) was 5.10 times larger than the soil area for 2,054,435 density (0.0049 m⁻²); soil

324 area for 1,066,666 was 7.65 times as large as that for 2,054,435 while the soil area for
325 533,333 density was 15.31 times larger than the area for 2,054,435 density. However,
326 2,054,435 density was sown at one seed per hill while other densities were thinned to
327 four seedlings per hill. CGR generally increased rapidly from 3 to 12 WAS and started
328 declining between 12 and 15 WAS. According to Fageria [16], crop growth rate is
329 usually low in the early growth stages and increased with time, reaching a maximum
330 value at about the time of flowering before it started to decline. The maximum CGR
331 coincided with the maximum vegetative growth which corresponded with the highest
332 leaf area attainment (LAI) and thereafter started to decline.

333 Cultivars differed in their CGR throughout the period of observation. The
334 magnitude of difference became distinct from 9 to 15 WAS with *Otokongtian*, FAROs
335 43 and 56 having greater CGR compared with other cultivars. Takai et al. [6] reported
336 that a large genotypic variability in CGR during the late reproductive period was
337 mainly due to differences in radiation use efficiency. Therefore, it could be stated that
338 *Otokongtian* and FAROs 43 and 56 were more efficient in light capturing and
339 conversion abilities.

340 A positive and significant correlation was observed between CGR and grain
341 yield of rice between 9 to 12 and 12- 15 WAS in 2009 ($r = 64, 61$ respectively); and
342 between 6 – 9, 9 – 12 and 12-15 WAS in 2010 ($r = 0.62, 61$ and 65 , respectively)
343 indicating that factors that increased CGR enhanced grain yield during those periods of
344 growth. This finding agreed with the report of San-oh et al. [7] that grain yield was
345 most closely related to CGR during the late reproductive period (14-0 days before full
346 heading).

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Conclusion

352 It was concluded on the basis of research findings that higher densities produced
353 higher biomass and crop growth rate which correlated positively with grain yield.
354 Sowing density of low tillering upland rice should not be beyond 1,600,000 ha⁻¹.
355 Improving the biomass productivity of rice is very important for improving the
356 productivity of rice.

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