

## NODULATION, DRY MATTER ACCUMULATION AND YIELDS OF SOYBEAN (*Glycine max* L.) CULTIVARS AT VARYING PLANT SPACING IN A RAINFOREST AGRO-ECOLOGY

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### ABSTRACT

Field trials were conducted during 2017 and 2018 late cropping seasons at the Teaching and Research Farm of the Faculty of Agriculture, University of Benin, in the rainforest zone of Nigeria to evaluate soybean (*Glycine max* L. Merrill) cultivars for nodulation, dry matter accumulation and seed and fodder yields at varying plant spacings. The trial was laid out in a randomized complete block design with split-plot arrangement replicated four times. Four plant spacings (50 × 30 cm, 60 × 25 cm, 75 × 20 cm, and 100 × 15 cm) were evaluated on six soybean cultivars: TGX1835-10E and TGX1987-62F (early maturing), TGX1951-3F and TGX1955-4F (medium maturing) and TGX1448-2E and TGX1904-6F (late maturing). Results showed that varietal performance depended on plant spacing. TGX1904-6F nodulated best at plant spacing of 50 × 30 cm, TGX1835-10E at 60 × 25 cm, TGX1987-62F at 75 × 20 cm, TGX1448-2E at 75 × 20 cm, and TGX1951-3 at 100 × 15 cm. TGX1835-10E accumulated dry matter most at plant spacing of 60 × 25 cm and 75 × 20 cm, TGX1987-62 at 75 × 20 cm, TGX1951-3F at 60 × 25 cm, TGX1955-4F at 60 × 25 cm and 75 × 20 cm, TGX1904-6F at 50 × 30 cm, and TGX1448-2E at 60 × 25 cm and 75 × 20 cm. TGX1448-2E and TGX1904-6F had higher seed and fodder yields at plant spacing of 50 × 30 cm, TGX1951-3F and TGX1955-4F at 60 × 25 cm, and TGX1835-10E and TGX1987-62F at 75 × 20 cm, relative to other plant spacing. Therefore, for higher yields in rainforest agro-ecology, farmers should adopt the right cultivar-plant spacing combination for soybean.

**Key words:** plant spacing, soybean, nodulation, dry matter, yield

### INTRODUCTION

Soybean (*Glycine max* L. Merrill) is one of the most important grain legumes grown in sub-Saharan Africa (USDA/FAS, 2017). The planting area in SSA has increased dramatically, from 20,000 ha in the early 1970s to 1,500,000 ha in 2016 (USDA/FAS, 2017). The increase in this planting area is basically because of high demands for protein both in human and livestock diets, role in farming systems and ease of cultivation. Soybean cultivation in comparison to other vegetable legumes is on the increase in Nigeria. The crop has been introduced to other parts of the country from the southern Guinea Savanna region where it has been originally grown because of its nutritive and economic values (Kamara *et al.*, 2007; Dugje *et al.*, 2009; Lasisi and Aluko, 2009; Obalum *et al.*, 2011).

Nodules formation in soybean produces nitrogen compounds necessary for maximum growth and pod formation. Soybean nodulates freely with native rhizobia strains and supply a large proportion of their N requirement through biological N fixation (Okogun *et al.*, 2004) without depleting soil N reserves (Singh *et al.*, 2003). Nigeria has huge potential for soybean production but average yield nationwide is low (Kamara *et al.*, 2014). The low yield may be attributed to the combination of several

production constraints among which are poor nodulation of soybean cultivars with the indigenous *Rhizobium* sp. (Kamara *et al.*, 2014), limited use of P fertilizer (Kamara *et al.*, 2008), and poor crop management practices including low plant populations and untimely field operation (Kidane *et al.*, 1990) and lack of sustained rhizobia inoculant use (Woomer *et al.*, 2012). Over the years, however, significant progress has been made to overcome some of the major constraints and has improved soybean yields across most of the soybean producing countries in Africa (Kamara *et al.*, 2014). Farmers have adopted new cultivars developed by the International Institute for Tropical Agriculture (IITA) that store well and are freely nodulating to check low yields in soybean producing countries.

Nevertheless, plant spacing is one of the management practices most often considered by growers in increasing crop yields and profits (Adubasim *et al.*, 2017; Obalum *et al.*, 2017; Umeugokwe *et al.*, 2021). Plant spacing affects soybean yield. Meanwhile, most farmers grow soybean at plant spacing recommended for different environment. For this reason, optimum yields are often not met since different cultivars may vary with differences in the climatic conditions available in different agro-ecologies. Also, soybean presents great plasticity in response to plant spatial

arrangement which affects the number of branches, pods, grains per plant and stem diameter, all of which are inversely proportional to plant population (Silva *et al.*, 2010). Kibiru (2018) reported that farmers are advised to drill soybean at either 40 cm or 60 cm inter row spacing with 5 cm intra row spacing regardless of the maturity groups of the cultivars and agronomic conditions of the location. Kamara *et al.* (2014) reported that, several soybean cultivars have been released in Nigeria and are still being grown at the recommended population of 266,666 plants ha<sup>-1</sup> at 75 cm × 5 cm plant spacing in the Savanna region of Nigeria. This plant population may not assure good yield in the rainforest agro-ecology of Nigeria. Thus, it is important to determine appropriate plant spacing for the desired plant population for the rainforest agro-ecology. Moreover, soybean cultivars of contrasting maturities may differentially respond to varying plant spacing so that specific plant spacing that are compatible with the distinct soybean maturity groups could be required for good yield in the agro-ecology. Therefore, the objective of this study was to determine the performance of soybean cultivars of contrasting maturities for nodulation, dry matter accumulation, seed yield and fodder yield at varying plant spacing while maintaining same plant population in a rainforest agro-ecology.

## MATERIALS AND METHODS

### Experimental Site

The field experiments were conducted during the late growing seasons (Aug.-Nov.) of 2017 and 2018 at the Teaching and Research Farm of the Faculty of Agriculture, University of Benin, Benin City (06° 50'N, 5° 23'E; 78 meters above sea level) in the rainforest of South-South Nigeria. Soils in the research area are classified as Ultisols (Olatunji *et al.*, 2014, Umweni *et al.*, 2014). Rainfall is of high intensity and bimodal, beginning in Mar./Apr. and ending in Oct./Nov. with a short dry spell in Aug. Prior to the establishment of the field trial, the land was overgrown mostly with *Panicum maximum* Jacq. Twenty-four sample cores were collected randomly on the trial plot at a depth of 15 cm at the beginning of the trial. A composite soil sample was constituted and analyzed for particle size analysis, N, P, K, and pH at the Analytical Services Laboratory of the International Institute of Tropical Agriculture (IITA), Ibadan, Nigeria, according to IITA procedures (IITA, 1982). The soil had 730.0 g kg<sup>-1</sup> sand; 30.0 g kg<sup>-1</sup> silt; 240.0 g kg<sup>-1</sup> clay (sandy clay loam); organic C of 1.4 g kg<sup>-1</sup>; N, 0.12 g kg<sup>-1</sup>; P, 5.93 mg kg<sup>-1</sup>; K, 0.24 cmol kg<sup>-1</sup>; and pH of 5.2. Total rainfall was 1787.9 mm in 2017 and 1144.6 mm in 2018. In 2017, mean daily maximum temperature was 33.8°C with average minimum temperature of 23°C. In 2018, mean daily maximum temperature was 33°C with average minimum temperature of 23°C.

### Cultivars

Two early maturing cultivars (TGX1835-10E, TGX1987-62F), two medium maturing cultivars (TGX1951-3F, TGX1955-4F), and two late maturing cultivars (TGX1448-2E, TGX1904-6F) obtained from IITA, Kano Station, Nigeria, were evaluated in the study.

### Experimental Treatments and Design

The experiment was laid out in a randomized complete block design (RCBD) with a split plot arrangement replicated four times. Plant spacing was assigned to the main plot and cultivars were assigned to the subplots. The different plant spacing was 50 × 30 cm, 60 × 25 cm, 75 × 20 cm and 100 × 15 cm. The treatment plots measured 3 m × 4 m and were separated by 0.50 m and the replications separated by 0.75 m.

### Agronomic Practices

The experimental field was cleared manually using cutlass, and debris were removed from the field without burning. Same plots were used for the 2 years of trial. Sowing was done on 18 and 20 August in 2017 and 2018, respectively. Five seeds of the soybean cultivars were planted per hole at the various plant spacing. Seedlings were thinned to four plants per stand two weeks after sowing, giving a soybean plant population of 266,667 plants ha<sup>-1</sup> for each of the plant spacing evaluated. Mineral nutrients N, P and K in the form of NPK 15:15:15 at a rate of 40 kg ha<sup>-1</sup> was applied to all plots at emergence, 5 cm away from the seedlings. NPK 15:15:15 at the given rate was used because it was the only available fertilizer at the time and soybean needs high level of P. At sowing, paraquat (1, 1-dimethyl-bipyridilum dichloride 24% w/w paraquat dichloride, manufactured by Candel, Lagos, Nigeria) was applied at the rate of 1 litre per hectare using knapsack sprayer to kill emerged weeds. Further weeding was carried out using hoes at 4 and 6 weeks after planting.

### Data Collection

At flowering, 16 plants in four consecutive stands in a plot were cut at ground level. The roots of these plants were carefully dug out with clods of soil dissolved in water, while nodules were carefully removed, counted and average recorded. Nodules were dissected and number of effective nodules (nodules with pinkish coloration when dissected) was recorded. Number of branches and number of leaves on the plants were counted and recorded as number of branches per plant and number of leaves per plant, respectively. Fresh shoots and roots of the 16 plants were weighed separately. The dry weight was determined by air-drying the shoots and roots under shade to a constant weight, weighed and expressed as shoot dry matter or root dry matter in grams per plant.

At maturity when the pods were ripe and dry, another 16 plants from four consecutive stands were harvested per plot, and the pods air-dried for 14 days and threshed. The seeds were weighed and average recorded as seed yield in g plant<sup>-1</sup>. Above-ground parts of the 16 harvested plants consisting of leaves and stems were air-dried to a constant weight. Together with the threshed pods, these were weighed and average recorded as fodder yield in g plant<sup>-1</sup>.

### Statistical Analysis

The two-year data were subjected to analysis of variance (ANOVA) using the PROC ANOVA procedure of SAS (SAS Institute, 2011). The initial analysis did not reveal year × treatment interaction; so, data for the two years were pooled for final analysis. Differences among treatment means were compared by using the Least Significant Difference (LSD) test at  $p = 0.05$ . Pearson's correlation coefficient was used to test for a correlation among attributes using PROC CORR of SAS.

## RESULTS

### Number of Nodules and Effective Nodules

Number of nodules was influenced by plant spacing ( $p = 0.0462$ ), cultivar ( $p < 0.0001$ ) and spacing × cultivar interaction ( $p = 0.0018$ ). Number of nodules was higher at 75 × 20 cm plant spacing compared to others (Table 1). Mean number of nodules was high for TGX1904-6F and TGX1448-2E and low for TGX1951-3F and TGX1955-4F. The significant plant spacing × cultivar interaction showed that at 50 × 30 cm plant spacing, highest numbers of nodules per plant were obtained from TGX1904-6F and TGX1448-2E and TGX1835-10E. At 60 × 25 cm plant spacing, cultivars had high and comparable number of nodules except TGX1955-4F with a lower number. However, at 75 × 20 cm plant spacing, TGX1987-62F produced higher number of nodules per plant than other cultivars. At 100 × 15 cm plant spacing, performance of cultivars followed the same trend as with 60 × 25 cm plant spacing.

Number of effective nodules was influenced by plant spacing ( $p = 0.0224$ ), cultivar ( $p < 0.0001$ ) and spacing × cultivar interaction ( $p < 0.0001$ ). The

TGX1904-6F and TGX1448-2E gave the highest number of effective nodules followed by TGX1835-10E and TGX1987-62F with an average number of effective nodules, compared to the low values of TGX1951-3F and TGX1955-4F (Table 1). The significant spacing × cultivar interaction showed that at 50 × 30 cm plant spacing, number of effective nodules was highest for TGX1904-6F, followed by the other cultivars except TGX1951-3F which had the least effective nodules. At 60 × 25 cm plant spacing, TGX1904-6F, TGX1448-2E, TGX1951-3F and TGX1835-10E had the highest number of effective nodules while TGX1987-62F and TGX1951-3F had the lowest. At 75 × 20 cm plant spacing, with the exception of TGX1987-62F which produced the highest number of effective nodules, number of effective nodules was low and comparable among the cultivars. At 100 × 15 cm plant spacing, number of effective nodules differed only between TGX1955-4F and TGX1951-3F.

### Number of Branches and Leaves

Plant spacing did not influence number of branches ( $p = 0.0655$ ). Mean number of branches ranged from 1.0-1.5 branches per plant (Table 2). Numbers of branches tended to be higher with closer inter row spacing and wider intra row spacing. Varietal differences were recorded for number of branches ( $p < 0.0001$ ). TGX1955-4F, TGX1904-6F and TGX1448-2E had the highest number of branches, followed by TGX1835-10E and TGX1951-3F and then TGX1987-62F which gave the lowest number of branches (Table 2). Interaction between plant spacing and cultivar was significant for number of branches ( $p = 0.0031$ ). Analysis of the interaction showed that at 50 × 30 cm plant spacing, TGX1955-4F, TGX1904-6F and TGX1448-2E produced the highest number of branches, followed by TGX1835-10E and TGX1951-3F with average numbers of branches (Table 2). TGX1987-62F produced the least number of branches. This trend was similar for 60 × 25 cm and 100 × 15 cm plant spacing. At 75 × 20 cm plant spacing, number of branches was comparable for all cultivars.

**Table 1:** Number of nodules and effective nodules of early, medium and late maturing soybean cultivars at different plant spacing in a rainforest agro-ecology

Cultivar (C)	Number of nodule plant <sup>-1</sup>				Number of effective nodules plant <sup>-1</sup>					
	50 × 30 cm	60 × 25 cm	75 × 20 cm	100 × 15 cm	Plant spacing (S)					Mean
					Mean	50 × 30 cm	60 × 25 cm	75 × 20 cm	100 × 15 cm	
TGX1835-10E	1.20abc	1.50a	1.50bc	0.80ab	1.20bc	0.40bc	0.90a	0.80b	0.40ab	0.60ab
TGX1987-62F	0.80bc	0.60ab	3.80a	0.70ab	1.50abc	0.30bc	0.30bc	1.30a	0.40ab	0.60b
TGX1951-3F	0.30c	1.20ab	0.50c	1.50ab	0.90cd	0.10c	0.70ab	0.40b	0.70a	0.50b
TGX1955-4F	0.80bc	0.20b	0.60c	0.10b	0.40d	0.40bc	0.10c	0.40b	0.10b	0.20c
TGX1904-6F	2.30a	1.60a	2.30b	1.90a	2.00a	1.20a	0.90a	0.70b	0.40ab	0.80a
TGX1448-2E	1.60ab	1.30ab	2.30b	1.10ab	1.60ab	0.70b	0.70ab	0.80b	0.50ab	0.70ab
Mean	1.20b	1.10b	1.80a	1.00b		0.50b	0.60ab	0.70a	0.40b	
LSD <sub>0.05</sub> S	0.59					0.17				
LSD <sub>0.05</sub> C	0.61					0.20				
LSD <sub>0.05</sub> S × C	1.22					0.41				

Within each column, means followed by the same letter are not significantly different according to LSD ( $p \leq 0.05$ )

**Table 2:** Number of branches and leaves of early, medium and late maturing soybean cultivars at different plant spacing in a rainforest agro-ecology

Cultivar (C)	Number of branches plant <sup>-1</sup>				Plant spacing (S) Mean	Number of leaves plant <sup>-1</sup>				Mean
	50 × 30	60 × 25	75 × 20	100 × 15		50 × 30	60 × 25	75 × 20	100 × 15	
	cm	cm	cm	cm		cm	cm	cm	cm	
TGX1835-10E	1.00c	1.00c	0.90a	0.60bc	0.90b	22.30bc	21.90c	21.20b	20.50bc	21.50b
TGX1987-62F	0.30d	0.10d	1.00a	0.40c	0.40c	18.50c	23.00c	24.20b	16.30c	20.50b
TGX1951-3F	1.50bc	1.30bc	0.90a	0.60bc	1.10b	23.50abc	33.10a	22.60b	24.80ab	26.00a
TGX1955-4F	1.80ab	2.30a	0.80a	1.20ab	1.50a	23.50abc	32.00ab	32.50a	25.00ab	28.20a
TGX1904-6F	2.40a	1.80ab	1.20a	1.10ab	1.60a	28.80a	22.80c	24.60b	27.20a	25.80a
TGX1448-2E	2.00ab	2.00a	1.40a	1.50a	1.70a	27.00ab	25.80bc	23.20b	24.50ab	25.10a
Mean	1.50	1.40	1.00	0.90		23.90b	26.40a	24.70ab	23.10b	
LSD <sub>0.05</sub> S	ns					1.89				
LSD <sub>0.05</sub> C	0.34					3.23				
LSD <sub>0.05</sub> S × C	0.65					6.46				

Within each column, means followed by the same letter are not significantly different according to LSD ( $p \leq 0.05$ ), ns - not significant

Plant spacing influenced the number of leaves per plant ( $p = 0.0220$ ). Higher number of leaves was obtained at  $60 \times 25$  cm followed by  $75 \times 20$  cm and then others (Table 2). Varietal differences were recorded for number of leaves ( $p < 0.0001$ ). TGX1951-3F, TGX1955-4F, TGX1904-6F and TGX1448-2E produced comparable number of leaves. TGX1835-10E and TGX1987-62F also produced comparable number of leaves. But the former was higher than the latter. There was significant interaction between plant spacing and cultivar for number of leaves ( $p = 0.0127$ ). Analysis of the significant interaction showed that at  $50 \times 30$  cm plant spacing number of leaves per plant was high and similar for TGX1951-3F, TGX1955-4F, TGX1904-6F and TGX1448-2E but low and similar for TGX1835-10E and TGX1987-62F. At  $60 \times 25$  cm plant spacing, TGX1951-3F and TGX1955-4F had high and similar number of leaves while others had low and similar number of leaves. At  $75 \times 20$  cm plant spacing, TGX1955-4F produced higher number of leaves than other cultivars having comparable values. At  $100 \times 15$  cm plant spacing, TGX1951-3F, TGX1955-4F, TGX1904-6F and TGX1448-2E had high and similar number of leaves, while TGX1835-10E and TGX1987-62F produced low and similar number of leaves.

### Root and Shoot Dry Matter

Root dry matter differed due to plant spacing ( $p = 0.0069$ ). Similar but higher dry matter was achieved at  $60 \times 25$  cm,  $75 \times 20$  cm and  $100 \times 15$  cm compared to the low value achieved at  $50 \times 30$  cm plant spacing (Table 3). There were differences among the cultivars for root dry matter ( $p < 0.0001$ ). TGX1955-4F, TGX1904-6F and TGX1448-2E had comparable root dry matter. Similarly, TGX1951-3F, TGX1835-10E and TGX1987-62F had comparable root dry matter. However, the former was higher than the later (Table 3). The significant interaction between plant spacing and cultivar ( $p = 0.0086$ ) for root and shoot dry matter are summarized in Table 3. At  $50 \times 30$  cm plant spacing, TGX1951-3F, TGX1955-4F, TGX1904-6F and TGX1448-2E accumulated higher root dry matter compared with TGX1835-10E and TGX1987-62F. At  $60 \times 25$  cm plant spacing, TGX1951-3F and TGX1955-4F had higher root dry matter than the other cultivars. At  $75 \times 20$  cm plant spacing, TGX1987-62F, TGX1955-4F and TGX1448-2E accumulated high root dry matter while TGX1835-10E, TGX1951-3F and TGX1904-6F had low root dry matter. Also, at  $100 \times 15$  cm plant spacing, root dry matter differed only between TGX1448-2E and TGX1951-3F with the later having the least root dry matter.

**Table 3:** Root and shoot dry matter of early, medium and late maturing soybean cultivars at different plant spacing in a rainforest agro-ecology

Cultivar (C)	Root dry matter (g plant <sup>-1</sup> )				Plant spacing (S) Mean	Shoot dry matter (g plant <sup>-1</sup> )				Mean
	50 × 30	60 × 25	75 × 20	100 × 15		50 × 30	60 × 25	75 × 20	100 × 15	
	cm	cm	cm	cm		cm	cm	cm	cm	
TGX1835-10E	0.40bc	0.50c	0.60bc	0.70ab	0.60b	1.20bc	1.50bc	1.60b	1.30b	1.40c
TGX1987-62F	0.30c	0.70bc	0.90ab	0.70ab	0.60b	0.90c	1.40c	1.70b	1.50b	1.30c
TGX1951-3F	0.50abc	0.90ab	0.40c	0.60b	0.60b	1.60abc	3.50a	1.40b	1.80b	2.10b
TGX1955-4F	0.70ab	1.20a	1.20a	0.70ab	0.90a	2.30a	3.50a	2.90a	2.60a	2.80a
TGX1904-6F	0.80a	0.60bc	0.70bc	0.70ab	0.70b	2.30a	1.50bc	1.70b	1.80b	1.80b
TGX1448-2E	0.80a	0.80bc	0.90ab	1.00a	0.90a	1.80ab	2.20b	2.70a	1.30b	2.00b
Mean	0.60b	0.80a	0.80a	0.70a		1.70c	2.30a	2.00b	1.70c	
LSD <sub>0.05</sub> S	0.10					0.20				
LSD <sub>0.05</sub> C	0.17					0.39				
LSD <sub>0.05</sub> S × C	0.34					0.78				

Within each column, means followed by the same letter are not significantly different according to LSD ( $p \leq 0.05$ )

Significant differences occurred among plant spacing for shoot dry matter ( $p = 0.0012$ ). Plant spacing of  $65 \times 25$  cm gave the highest shoot dry matter followed by  $75 \times 20$  cm and then by  $50 \times 30$  cm and  $60 \times 25$  cm (Table 3). Shoot dry matter differed among the cultivars ( $p < 0.0001$ ). It was highest for TGX1955-4F with average shoot dry matter for TGX1951-3F, TGX1904-6F and TGX1448-2E and low dry matter for TGX1835-10E and TGX1987-62F (Table 3). There was significant plant spacing  $\times$  cultivar interaction for shoot dry matter ( $p < 0.0001$ ). At  $50 \times 30$  cm plant spacing, TGX1951-3F, TGX1955-4F, TGX1904-6F and TGX1448-2E had higher shoot dry matter than TGX1835-10E and TGX1987-62F. At  $60 \times 25$  cm plant spacing, shoot dry weight was highest for TGX1951-3F and TGX1955-4F, followed by TGX1448-2E and then by TGX1835-10E, TGX1987-62F and TGX1904-6F. At  $75 \times 20$  cm plant spacing, TGX1955-4F and TGX1448-2E had similar shoot dry matter that was higher than for the rest. At  $100 \times 15$  cm plant spacing, TGX1955-4F accumulated higher shoot dry matter than others.

#### Seed and Fodder Yields

Plant spacing did not influence seed yield ( $p = 0.2258$ ). Seed yield ranged from 1.2 to 1.7 g plant<sup>-1</sup>, increasing from wide inter-row and narrow intra-row spacing to narrow inter-row and wide intra-row spacing (Table 4). Significant differences existed among cultivars ( $p = 0.0008$ ). TGX1955-4F, TGX1904-6F and TGX1448-2E had comparable seed yield. Seed yield was also comparable among TGX1835-10E, TGX1987-62 and TGX1951-3F. However, between the former and later groups, TGX1448-2E had seed yield that was superior to those of the later (Table 4). Significant interaction occurred between plant spacing and cultivar for seed yield ( $p = 0.0004$ ). Analysis of the interaction showed that at  $50 \times 30$  cm plant spacing, TGX1448-2E and TGX1904-6F produced higher yields than TGX1835-10E, TGX1987-62, TGX1951-3F and TGX1955-4F (Table 4). At  $60 \times 25$  cm plant spacing, TGX1951-3F, TGX1955-4F, TGX1904-6F and TGX1448-2E had comparable

seed yields that were higher than those of TGX1835-10E and TGX1987-62F. Seed yields obtained at a spacing of  $75 \times 20$  cm plant spacing were comparable among cultivars excepting TGX1987-62F which had higher seed yields. At  $100 \times 15$  cm plant spacing, cultivars had similar seed yields with exception of TGX1835-10E which had lower yield than TGX1955-4F and TGX1448-2E.

Fodder yield did not differ among plant spacing ( $p = 0.1078$ ). Performance had the same trend as in seed yield (Table 4). However, fodder yield differed among cultivars ( $p < 0.0001$ ). Mean value was highest for TGX1448-2E and TGX1955-4F and lowest for TGX1835-10E and TGX1987-62F. Significant interaction occurred between plant spacing and cultivar ( $p = 0.0002$ ). Analysis of the interaction showed that at  $50 \times 30$  cm plant spacing, TGX1904-6F had the highest fodder yield while TGX1835-10E and TGX1987-62F had the lowest. At  $60 \times 25$  cm plant spacing, fodder yield was highest for TGX1955-4F and TGX1448-2E and lowest for TGX1987-62F. TGX1987-62F and TGX1448-2E had comparable and higher fodder yields than others at  $75 \times 20$  cm plant spacing. At  $100 \times 15$  cm plant spacing, TGX1448-2E and TGX1955-4F had higher fodder yields than others.

#### Relationship between the Attributes

Correlations between the observed attributes of the soybean cultivars are summarized in Table 5. There were strong and positive correlations between number of nodules and effective number of nodules ( $r = 0.878^{***}$ ), number of branches ( $r = 0.214^*$ ), root dry matter ( $r = 0.226^{**}$ ), seed yield ( $0.404^{**}$ ) and fodder yield ( $r = 0.331^{**}$ ). Number of effective nodules related positively and significantly with number of branches ( $r = 0.245^*$ ), number of leaves ( $r = 0.186^*$ ), root dry matter ( $r = 0.233^{**}$ ), shoot dry matter ( $r = 0.174^*$ ), seed yield ( $r = 0.431^{**}$ ) and fodder yield ( $r = 0.404^{**}$ ). Number of branches had positive and significant relationship with number of leaves ( $r = 0.390^{**}$ ), root dry matter ( $r = 0.357^{**}$ ), shoot dry matter ( $r = 0.470^{**}$ ), seed yield ( $r = 0.773^{**}$ ) and fodder yield ( $r = 0.748^{**}$ ). Number of leaves related positively and significantly with

**Table 4:** Seed and fodder yields of early, medium and late maturing soybean cultivars at different plant spacing in a rainforest agro-ecology

Cultivar (C)	Seed yield (g plant <sup>-1</sup> )				Plant spacing (S)	Fodder yield (g plant <sup>-1</sup> )				Mean
	50 × 30	60 × 25	75 × 20	100 × 15		50 × 30	60 × 25	75 × 20	100 × 15	
	cm	cm	cm	cm		cm	cm	cm	cm	
TGX1835-10E	0.70b	1.30bc	1.00b	0.80b	0.90d	2.10c	2.90bc	3.00b	1.30c	2.30d
TGX1987-62F	1.00b	0.60c	2.60a	1.00ab	1.30cd	1.80c	2.20c	6.30a	2.60c	3.20d
TGX1951-3F	1.50b	1.90ab	1.20b	1.00ab	1.40bcd	4.30bc	6.00ab	1.90b	2.50c	3.70cd
TGX1955-4F	1.60b	2.40a	1.40b	1.80a	1.80ab	5.40b	8.00a	4.90ab	5.90ab	6.10ab
TGX1904-6F	2.70a	1.60ab	1.00b	1.10ab	1.60abc	10.60a	4.30bc	3.00b	3.10bc	5.30bc
TGX1448-2E	2.60a	1.90ab	1.70ab	1.80a	2.00a	6.90b	7.80a	6.30a	7.10a	7.00a
Mean	1.70	1.60	1.50	1.20		5.20	5.20	4.20	3.70	
LSD <sub>0.05</sub> S	ns				ns					
LSD <sub>0.05</sub> C	0.49				1.60					
LSD <sub>0.05</sub> S × C	0.98				3.20					

Within each column, means followed by the same letter are not significantly different according to LSD ( $p \leq 0.05$ ), ns - not significant

**Table 5:** Correlation coefficients between traits of soybean cultivars grown in a rainforest agro-ecology

Traits	Number of nodules	Number of effective nodules	Number of branches	Number of leaves	Root dry matter	Shoot dry matter	Seed yield
Number of effective nodules	0.878**						
Number of branches	0.214*	0.245**					
Number of leaves	0.152	0.186	0.390**				
Root dry matter	0.226**	0.233**	0.357**	0.453**			
Shoot dry matter	0.113	0.174	0.470**	0.708**	0.663**		
Seed yield	0.404**	0.431**	0.773**	0.465**	0.499**	0.537**	
Fodder yield	0.331**	0.404**	0.748**	0.483**	0.512**	0.603**	0.862**

\*significant at 5% level of probability; \*\*significant at 1% level of probability.

root dry matter, seed yield, fodder yield ( $r = 0.453-0.483^{**}$ ) and shoot dry matter ( $r = 0.708^{**}$ ). There were significant positive relationship between root dry matter and shoot dry matter ( $r = 0.663^{**}$ ), seed yield ( $0.499^{**}$ ) and fodder yield ( $r = 0.512^{**}$ ). Shoot dry matter had positive and significant relationship with seed yield ( $r = 0.537^{**}$ ) and fodder yield ( $0.603^{**}$ ). Seed yield correlated with fodder yield ( $0.537^{**}$ ). However, number of nodules had no significant correlation with number of leaves and shoot dry matter.

## DISCUSSION

This study has focused on the nodulation, dry matter accumulation and yield performance of soybean cultivars of contrasting maturities at varying plant spacing with fixed plant population in a rainforest agro-ecology of Nigeria. The significant interactions between plant spacing and cultivar for both number of nodules and number of effective nodules suggest that cultivars responded differently to plant spacing for these variables. For example, TGX1904-6F had higher nodule production at a spacing of  $50 \times 30$  cm, TGX1835-10E at  $60 \times 25$  cm, TGX1987-62F at  $75 \times 20$  cm and TGX1951-3F at  $100 \times 15$  cm. Higher number of effective nodules were achieved for TGX1904-6F at  $50 \times 30$  cm, for TGX1835-10E at  $60 \times 25$  cm and for TGX1987-62F at  $75 \times 20$  cm. Thus, these cultivars will need the differing specific plant spacing for good performance. However, plant spacing of  $75 \times 20$  cm, irrespective of maturity period appear to favour high nodulation in all cultivars. The higher number of nodules recorded for the late maturing cultivars may be due to the fact that these cultivars spend more time on the field accumulating dry matter. And in the present study, nodulation depended on root dry matter; the higher the root dry matter, the higher the number of nodules. Similarly, nodulation depended on number of branches; the higher the number of branches the higher the number of nodules. This is because increase in the number of branches led to increase in the number of leaves. Higher number of leaves increased the capacity of the plants to photosynthesize more, leading to higher root dry matter that supported higher nodule production. Mahasi *et al.* (2010) and Ngalamu *et al.* (2013) reported that late maturing cultivars have enough time to utilize available resources optimally.

The significant interactions between plant spacing and cultivar for number of branches and number of leaves suggest that the cultivars depended on plant spacing for their performance. For leguminous and hence nodulating crop, plant spacing and cultivar can interact to influence such indices of soil fertility as soil pH and available phosphorus including contents of exchangeable calcium and magnesium (Umeugokwe *et al.*, 2021). The dependence of number of branches and leafiness on plant spacing and cultivar may, therefore, be linked to the associated changes in these soil fertility indices. The higher number of branches and number of leaves obtained for cultivars grown at a closer inter row spacing and wider intra row may be attributed to more interception of sunlight for photosynthesis since the plants and their leaves were more evenly distributed over the ground. This favoured mostly the late maturing cultivars, followed by the medium maturing cultivars. In contrast, Mahama (2012) reported that row spacing and soybean cultivars showed significant effect on the number of primary branches per plant and gave higher number of primary branches at wider spacing than narrow spacing. Wide inter row spacing may be a waste of sunlight reaching uncultivated soil surface. However, it is important to note that wide inter-row spacing may provide opportunity for intercropping soybean with cereal crops, such as maize.

Variations in root and shoot dry matter of cultivars depended on plant spacing. The early maturing cultivars (TGX1835-10E and TGX1987-62F) produced as much dry matter as the medium (TGX1951-3F and TGX1955-4F) and late maturing (TGX1904-6F and TGX1448-2E) cultivars at narrower intra spacing because they had wide inter row spacing for fuller expansion of roots and shoots. The high root and shoot dry matter achieved by the medium and late maturing cultivars planted at a spacing of  $50 \times 30$  cm and  $60 \times 25$  cm indicated that increase in number of branches gained at closer inter row spacing resulted to increase in the root and shoot dry matter. Leaves, which are the main photosynthetic apparatus, had their production in terms of number dependent on number of branches. However, root and shoot dry matter of these cultivars were not less favourable at a plant spacing of  $75 \times 20$  cm in particular. The significantly higher root and shoot dry matter recorded for

TGX1955-4F (medium maturing cultivar) as against TGX1951-3F (medium maturing cultivar) at plant spacing of 75 × 20 cm and 100 × 15 cm is an indication of varietal differences that can occur within a maturity group. The low root and shoot dry matter of early maturing cultivars may be due to their low number of branches and leaves. This is because results showed that performance in dry matter accumulation depended on performance in branch and leaf production. These findings suggest that cultivars with longer maturity period produce higher amount of dry matter. Vanlauwe *et al.* (2003) reported high biomass of soybean was in late maturing than in early maturing cultivars.

The significant plant spacing × cultivar interactions for seed yield and fodder yield showed that soybean cultivars depended on plant spacing for seed and fodder production. For example, whereas the late maturing cultivars had higher seed yield at 50 × 30 cm plant spacing; the medium maturing cultivars had higher seed yield at 60 × 25 cm spacing while early maturing cultivars had higher seed yield at 75 × 20 cm spacing. This trend was similar for fodder production. This finding showed that optimum seed yield in soybean will be obtained with proper combination of cultivar and plant spacing. Cultivars, therefore, should be planted at appropriate plant spacing. This was in agreement with Kibiru (2018) who reported response of soybean cultivars to different plant spacing.

Seed yield and fodder yield were influenced by number of nodules, number of branches, number of leaves and dry matter. This accounted for the higher seed yield and fodder yield obtained from the late maturing cultivars and the lower yields from the early maturing cultivars. The late and medium maturing cultivars had longer growing period that led higher branch and higher leaf production as well as higher dry matter accumulation.

## CONCLUSION

Plant spacing influenced soybean nodulation, number of leaves and dry matter production. Plant spacing of 60 × 25 cm and 75 × 20 cm gave superior performance in nodulation, number of leaves and dry matter production compared to 50 × 30 cm and 100 × 15 cm plant spacing. Variety influenced nodulation, number of branches and leaves, dry matter production, seed and fodder yields. Late maturing cultivars (TGX1904-6F and TGX1448-2E) gave the highest number of nodules and effective nodules followed by early maturing cultivars (TGX1835-10E and TGX1987-62F), compared to low number of nodules of the medium maturing cultivars (TGX1951-3F and TGX1955-4F). Medium and late maturing cultivars had higher number of branches, higher number of leaves and higher dry matter yield compared to those of the early maturing cultivars. TGX1955-4F, TGX1904-6F and TGX1448-2E gave the highest seed and fodder

yields compared to the low yields of others. However, varietal performance for all the studied traits depended on plant spacing. TGX1904-6F nodulated best at plant spacing of 50 × 30 cm, TGX1835-10E at 60 × 25 cm, TGX1987-62F at 75 × 20 cm, TGX1448-2E at 75 × 20 cm, and TGX1951-3 at 100 × 15 cm. TGX1835-10E accumulated dry matter most at plant spacing of 60 × 25 cm and 75 × 20 cm; that of TGX1987-62 was at 75 × 20 cm, TGX1951-3F at 60 × 25 cm, TGX1955-4F at 60 × 25 cm and 75 × 20 cm, TGX1904-6F at 50 × 30 cm, and TGX1448-2E at 60 × 25 cm and 75 × 20 cm. TGX1448-2E and TGX1904-6F had higher seed and fodder yields when grown at 50 × 30 cm plant spacing, TGX1951-3F and TGX1955-4F at 60 × 25 cm spacing, and TGX1835-10E and TGX1987-62F at 75 × 20 cm spacing, relative to other plant spacing. Therefore, for higher yields in rainforest agro-ecology, farmers should adopt the right cultivar-plant spacing combination for soybean.

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