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Effect of Spacing on Grain Yield and Yield Attributes of Three Rice (*Oryza sativa L.*) Varieties Grown in Rain-fed Lowland Ecosystem in Ghana

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Authors' contributions

This work was carried out in collaboration between all authors. Author BMM designed the study, wrote the protocol and wrote the first draft of the manuscript. Authors BMM and IRN managed the literature searches and analyses of the study while author EAM managed the experimental process. All authors read and approved the final manuscript.

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ABSTRACT

Row transplanting is one of the good agronomic practices being promoted for lowland rice production in Ghana. The recently introduced 'Sawah' system promotes effective land preparation, good water management and row transplanting as well as the use of hand tools for weed control in lowland rice production. To determine the appropriate crop density, a trial was conducted to evaluate the effect of different spacing on three rice varieties (Sikamo, Jasmine 85, Marshall). The experimental design was a split plot with four replications. Spacing which served as main treatments included: S_1 (20 cm x 20 cm); S_2 (20 cm x 25 cm); S_3 (25 cm x 15 cm); S_4 (15 cm x 15 cm) and S_5 (30 cm x 10 cm). Rice was transplanted at 2 seedlings per stand. Results showed that spacing significantly affected tiller production, number of panicles per m^2, total biomass and paddy yield. Both the number of tillers per stand and number of panicles per m^2 were significantly reduced under closer spacing than wider spacing in the order: $S_1 = S_2 > S_3 > S_4 = S_5$. Highest grain yield was obtained at 20 cm x 25 cm (11.4 t ha^{-1}) and 20 cm x 20 cm (10.9 t ha^{-1}) for all the three varieties while lowest grains yield (3.0" t ha^{-1}) was recorded at 30 cm x 10 cm spacing. For

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increased yields and easy adoption of simple hand tools for weed control, wider spacing of 25 cm x 20 cm and 20 cm x 20 cm is recommended for rain-fed lowland rice production in Ghana.

Keywords: Ghana; grain yield; plant density; rain-fed lowland; row transplanting; yield attributes; sawah technology.

1. INTRODUCTION

Even though rice has been listed as one of the commodities for increased food security and import substitution for Ghana under the National Rice Development Strategy of Ministry of Food and Agriculture, the country still produces less than 40% of her domestic requirements [1]. The country, however, possesses a huge and vastly untapped potential for lowland rice production with an estimated irrigable land area of over seven hundred thousand ha, out of which less than 20,000 ha is currently under rice cultivation [1]. Rice is cultivated in virtually all the agro-ecological zones across the country.

Rice production in Ghana is categorized according to agro-ecology namely: Irrigated, rain-fed lowland and rain-fed upland. The lowland rain-fed system covers 78% of the arable area; the irrigated system covers 6% while the upland system covers 16%. Maximum levels of production are expected to be obtained through increased cultivation of lowlands, particularly inland valleys using appropriate and affordable technologies. Even though rice production seems to be picking up over a couple of years now, there still remains a considerable gap between production and demand levels. Currently the national rice supply demand gap is bridged by importation. The annual per capita rice consumption in Ghana was 17.5 kg (1999-2001) rising to 22.6 kg (2002-2004) and it is expected to further rise to 63.0 kg by 2015 with demand increasing to 1, 680,000 tons per year by the same period [1].

The forest agro-ecological zone is one of the major rice growing areas and is more endowed with higher rainfall and guaranteed water availability throughout the growing season. The zone has the potential for achieving national self-sufficient in rice production. However, rice producers in Ghana are mostly peasant farmers who are poorly resourced. Production is constrained by such factors as lack of modern technology and/or machinery. Yields are still relatively low. Promoting the local rice industry will therefore enhance output and income of small holder farmers' thus promoting economic growth in these communities. While the national average paddy yield is about 2.0 t ha^{-1}, rice production in some parts of the country has recorded paddy yields of over 5.0 t ha^{-1} with the introduction of the 'Sawah' system [2-5]. The "Sawah" system (bunded, puddled and levelled fields) which employs simple but effective water harvesting and improved land preparation methods leads to high use of nutrients. An evaluation of rice production where "Sawah" was introduced showed significant increases in rice grain yields and higher returns on investment for farmers [4]. There was over a fourfold increase in grain yields from less than 1.0 t ha^{-1} grain under the traditional system of rice cultivation to over 4.0 t ha^{-1} under the "Sawah" system at the end of the first year of its introduction.

Efforts to ensure increases in rice yield through proper water, crop and soil management have been going on for some time now in the country and results have been positive. However, lack of knowledge and/or necessary information on plant population density management practices is still a major constraint. Rice growth is known to be affected both qualitatively and quantitatively by plant population densities. However, many contradictions exist regarding the correct spacing of rice. Many authors [6-8] have indicated that closer spacing of 15 cm x 10 cm, 15 cm x 15 cm and 15 cm x 20 cm were superior to wider spacing of 30 cm x 10 cm, 20 cm x 20 cm and 15 cm x 25 cm by producing more effective tillers per unit area, higher plant height, higher leaf area index and total dry matter accumulation. However, other authors [9,10] on the other hand have reported that wider spacing (25 cm x 25 cm, and 30 cm x 30 cm) produced significantly higher rice tillers, panicles per m^2, longer and weighty panicles, and higher grain yield than closer spacing (15 cm x 15 cm). In Ghana, most rice farmers' practice random spacing and also do not transplant in rows. In the savannah agro-ecological zone, where water limitations are high, direct seeding either through broadcast or dibbling are the preferred methods, while within the forest agro-ecological zone where water is easily available, random transplanting and dibbling are the commonest method. With the introduction of "Sawah" system and other good agricultural practices, row transplanting is being encouraged and promoted. For maximum yields, farmers need to plant at optimum densities. With the introduction of improved varieties and promotion of row transplanting which is being rapidly adopted by farmers coupled with the desire to promote/encourage mechanization (introduction of hand tools for weed control), there is therefore the major challenge of providing options on spacing (planting density options) so that farmers can plant at optimum plant densities if maximum yields are to be obtained.

2. MATERIALS AND METHODS

2.1 Location

The experiment was conducted in a rain-fed valley in Kumasi in the Forest agro-ecological zone of Ghana. The valley lies on latitudes 6º 40' 59'' and longitude 1º 37' 0''. It is a long valley that runs several kilometres but measures less than 300 m across.

2.2 Experimental Design and Land Preparation

The design was a randomized complete block arranged in a split plot arrangement with four replications. The site was initially slashed and vegetative cover removed. The area was then ploughed using a power tiller. The ploughed site was then divided into four main blocks using bunds (about 100 cm high) to represent four replications. Each block was then divided into five (5) main plots by using bunds to represent the different spacing of S_1 (20 cm x 20 cm), S_2 (20 cm x 25 cm), S_3 (30 cm x 15 cm), S_4 (25 cm x 15 cm) and S_5 (15 cm x 15 cm). Each main plot was again sub-divided to three micro-plots measuring 2.0 m x 2.0 m for the three rice varieties (Sikamo, Jasmine 85, Marshall). Each sub-plot was then manually puddled and levelled.

2.3 Transplanting

Three weeks old rice seedlings of the three varieties were manually transplanted to each micro-plot. Seedlings were transplanted at two per stand (hill) for all the different spacing adopted.

2.4 Mineral Fertilizer Application

Mineral fertilizer was applied at 90 kg N ha^{-1} as Urea, 60 kg P_2O_5 ha^{-1} as Triple Super Phosphates and 60 kg K_2O ha^{-1} as Muriate of Potash. All P and K and 50% N were applied immediately after transplanting. The remaining 50% N was applied at panicle initiation stage.

2.5 Weed Control

Weeds were manually controlled through occasional hand picking.

2.6 Data Collection

2.6.1 Growth characteristics

Number of tillers was counted after maximum tiller formation stage and mean number of tillers determined while plant height was measured at harvest.

2.6.2 Yield characteristics

At maturity, an area of 1.0 m^2 excluding border rows was measured out in each sub-plot, number of panicles counted and harvested (grain and stover). Grain and stover yield were measured and yield per ha estimated. Panicles were also collected from non-border rows and mean individual weight per panicle determined. The weight of 1000 grains was measured using an electronic balance. Grain harvest index (GHI) was calculated as ratio of grain yield to total yield (grain + stover).

2.7 Statistical Analysis

The statistical software STATISTIX 8 was used to analyse the data and LSD at 5% probability level was used as the mean separator.

3. RESULTS AND DISCUSSION

The forest agro-ecological zone has a bimodal rainfall pattern as shown in Fig. 1. Soils of the site have low to moderate levels of soil nutrients. Organic Carbon level was 21 g kg^{-1}, total Nitrogen level was 2.3 g kg^{-1} while available Phosphorus was 5 mg kg^{-1}. Exchangeable Potassium was 0.24 cmol (+) kg^{-1} with effective Cation Exchange Capacity (eCEC) being 11.5 cmol (+) kg^{-1}. Soil clay content was also very low (80 g kg^{-1}). With such low contents of both clay and organic matter, water and nutrient retention capacities are most likely low. Under such conditions, not only is it essential to adopt water and nutrient conservation methods but also the establishment of optimum plant populations if higher grain yields are to be achieved.

3.1 Effect of Spacing on Growth Factors

3.1.1 Tiller number and plant vigour

The number of tillers produced per stand under the different spacing adopted is presented in Fig. 2. Tiller number was significantly affected by spacing. Highest mean tiller number per hill (12.1) was recorded in the 20 cm x 25 cm spacing for all the varieties which was significantly higher than all the spacing but similar to the 20 cm x 20 cm spacing. The 20 cm x 20 cm spacing (10.6) and 25 cm x 15 cm spacing (10.1) had similar number of tillers per hill but the 20 cm x 20 cm spacing produced significantly more tillers than the 30 cm x 10 cm spacing. All the different spacing produced significantly more tillers than the 15 cm x 15 cm spacing. As the distance between plant stands decreases competition for space, light and soil nutrients sets in, resulting in lower tiller production. The number of tillers formed is a major factor that affects grain yield in rice hence grain yield decreases with decreasing number of tillers per hill. In addition, plants under wider spacing (25 cm x 20 cm and 20 cm x 20 cm) exhibited more vigorous growth than plants under closer spacing (30 cm x 10 cm and 15 cm x 15 cm). Growth attributes were significantly affected by spacing. Wider spacing resulted in the production of more tillers per stand than closer spacing. There was a significant increase in the number of tillers per stand with increased spacing. Larger plants with more vigorous growth were produced under wider spacing than closer spacing. Between varieties, however, spacing showed no significant effect as trend was similar.

3.1.2 Plant height

The effect of spacing on plant height is presented in Fig. 3. Mean plant height across the different spacing ranged from a lowest of 97.1 cm (15 x 15 cm) to the highest of 100.1 cm (20 x 20 cm). Between varieties, Sikamo recorded a fairly uniform plant height for all the spacings ranging from 98.5 cm to 102.6 cm. Plant height under Marshall ranged from 95.6 cm (30 cm x 15 cm) to 100.1 cm (20 cm x 25 cm) while Jasmine recorded plant height ranging from 93.1 cm (15 cm x 15 cm) to 102.3 cm (25 cm x 15 cm). Spacing seemed to have a little effect on plant height with no significant differences. While Ogbodo et al. [11] observed that plant height and number of tillers were significantly higher when crops were transplanted at 30 cm x 30 cm than at 10 cm x 10 cm and 20 cm x 20 cm, Nwokwu [12], on the contrary, reported that plant spacing at 40 cm x 40 cm only produced higher number of tillers, number of leaves, shorter days to 50% heading and 1000 grain weight whereas plant spacing at 30 cm x 30 cm recorded longest panicles, more number of panicles and paddy yield but with no significant differences in plant height for the two different spacing. The authors attributed the observation to the presence of adequate plant nutrients in the soil for normal growth. In this study, plant height was less affected by spacing. As indicated earlier, adequate mineral fertilizer was applied to all treatments and therefore adequate nutrients were provided for optimum crop nutrition and growth. Hence such factors that affect plant height were probably not limiting.

3.2 Effect of Spacing on Yield Factors

3.2.1 Number of panicles per m^2

The effect of spacing on the number of panicles produced per m^2 is presented in Table 1. The 20 cm x 25 cm (605) and 20 x 20 cm (563) spacing produced significantly higher panicles per m^2 than all the spacing (15 cm x 15 cm; 30 cm x 10 cm; 20 cm x 15 cm). The lowest number of panicles per m^2 was recorded under 30 cm x 10 cm spacing (318) which was similar to panicles per m^2 under 15 cm x 15 cm spacing. The three varieties, however, recorded similar number of panicles per m^2. For spacing by variety interaction, all the varieties interacted with 20cm x 20 cm and 20 cm x 25 cm spacing to give significantly higher number of panicles per m^2 than the other spacing. Mirza et al. [13] observed that closer spacing reduced the number of effective tillers and increased tiller mortality, hence lower number of panicles. In this study, the more vigorous plants and greater tiller numbers produced under wider spacing would have a better photosynthetic ability with a wider feeding area, more accessibility to soil nutrients and increased availability of nutrient. While under closer spacing, plants were denied more access to solar radiation due to closeness of plant canopies, wider spacing provided a more conducive environment where plants are exposed to more solar radiation which promotes more photosynthetic production and better growth due to increased nutrient availability and uptake.

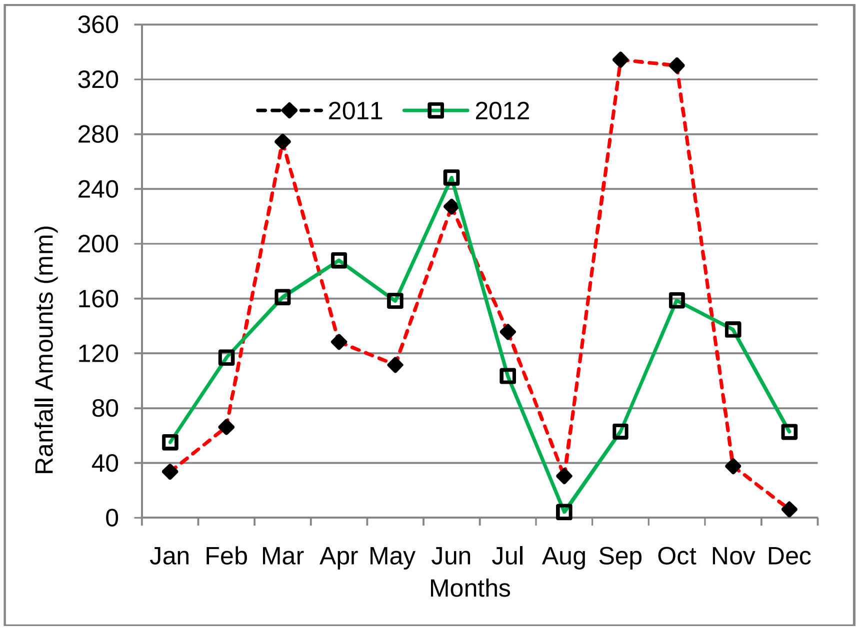

Fig. 1. Rainfall amounts and distribution during the experimental period

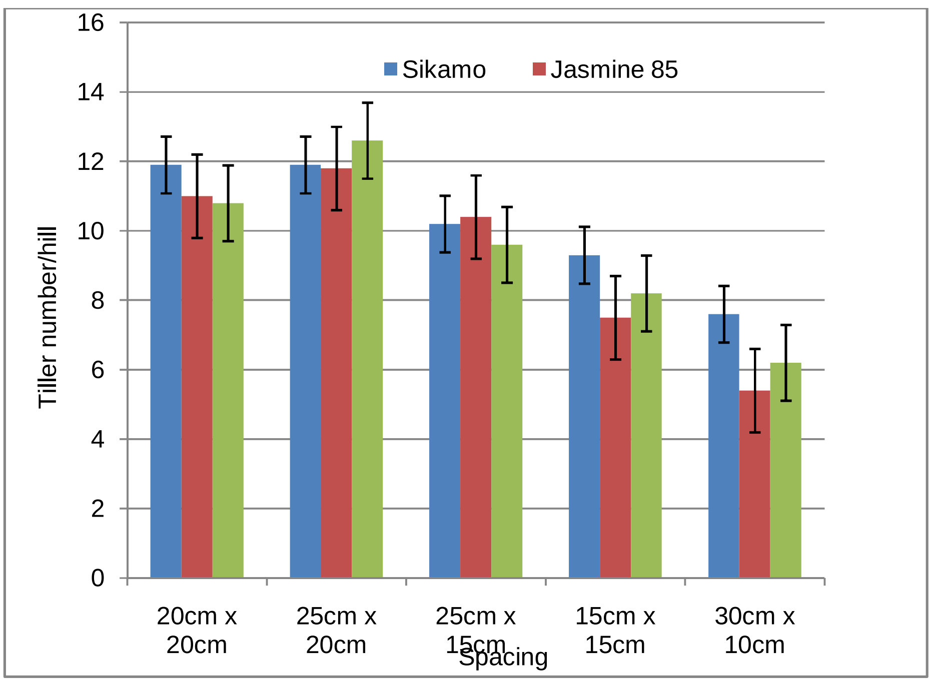

Fig. 2. Effect of spacing on number of tillers per hill of three lowland rice varieties in a rain-fed ecosystem in Ghana

3.2.2 Weight per panicle

The effect of spacing on individual panicle weight is presented in Table 2. Highest mean panicle weight was 5.33 g at a spacing of 20 cm x 25 cm which was similar to mean panicle weight under 20 cm x 20 cm spacing (5.19 g) which were significantly heavier than the panicle weight of the three lower spacing. Mean panicle weight was significantly affected by spacing. The effect of spacing in individual panicle weight was in the order: S2 = S1 > S3 = S4 = S5. Between varieties there was no significant difference in panicle weight. All the three varieties interacted with 25 cm x 20 cm and 20 cm x 20 cm spacing to produce panicles which were significantly heavier than panicles produced under closer spacing of 30 cm x 10 cm sand 15 cm x 15 cm. The general observation was that wider spacing produced heavier panicles than closer spacing.

3.2.3 Weight of 1000 grains

Table 3 shows the effect of spacing on the weight of 1000 grains. There were no significant differences between spacing and varieties. The interaction between spacing and variety gave similar results (no significant difference) between 1000 grain weight.

3.2.4 Grain yield

The effect of spacing on paddy yield is presented in Fig. 4. Higher grain yields were produced under wider spacing (20 cm x 25 cm; 20 cm x 20 cm) than closer (20 cm x 15 cm; 15 cm x 15 cm, 30 cm x 10 cm) spacing. The three varieties interacted with wider spacing (25 cm x 20 cm and 20 cm x 20 cm) to give similar paddy yields of over 10.0 t ha^{-1} which was significantly higher than grain yields produced for any interactions at closer spacing. Grain yield is the ultimate product that is of value and economic importance to the producer or consumer. The three varieties interacted with 25 cm x 20 cm and 20 cm x 20 cm spacing to give significantly heavier and more panicles per m^2. Among others factors, these two combinations of heavier and more panicles per m^2 under wider spacing (25 cm x 20 cm, 20 cm x 20 cm) largely explains the significantly higher grain yields observed for these combinations. Grain yield showed a similar pattern to tiller production and number of panicles per m^2. Grain yield increased significantly with decreasing plant density (Fig. 4). According Ogbodo et al. [11] rice transplanted at 30 cm x 30 cm spacing yielded 2.36 and 1.32 t ha^{-1} significantly higher grains than those transplanted at 10 cm x 10 cm and 20 cm x 20 cm respectively. In this study, a similar observation was made where wider spacing of 25 cm x 20 cm and 20 cm x 20 cm, produced 8.06 and 7.56 t ha^{-1} more grain over the closer spacing of 30 cm x 10 cm and 15 cm x 15 cm. There was less than a 1.0 t ha-^{1} yield difference between 15 cm x 15c m and 30 cm x 10cm spacing. This is in conformity with earlier observations of Bishnu et al. [10] and Mondal and Putch [14] who reported that lower seeding density resulted in the formation of more productive tillers, superior performance for all morpho-physiological and yield components, resulting in higher grain yields over higher

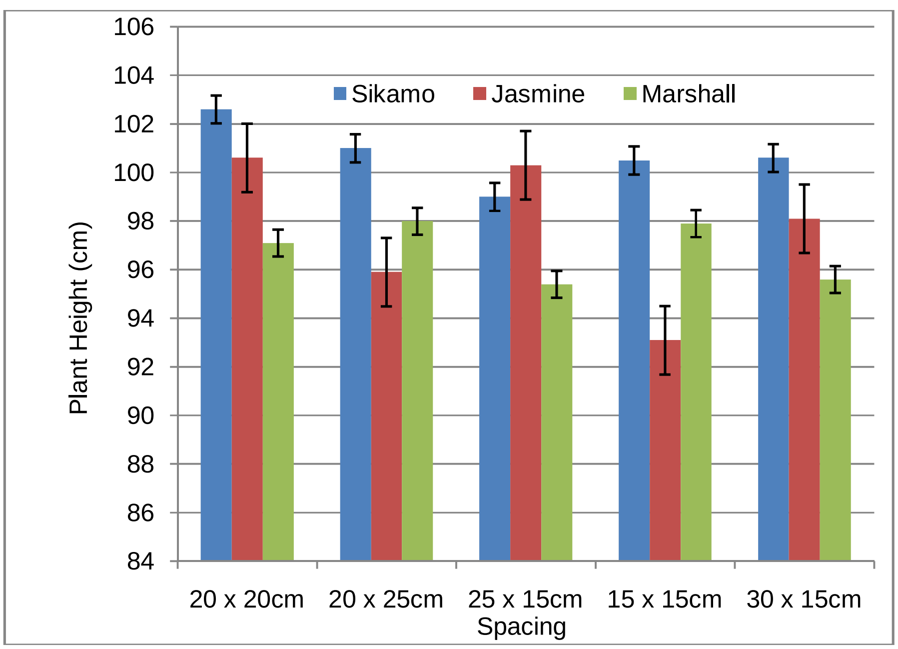

Fig. 3. Effect of spacing on plant height of three lowland rice varieties in a rain-fed ecosystem in Ghana

Table 1. Effect of spacing on number of panicles per m^2 of three lowland rice varieties in a rain-fed ecosystem in Ghana

Spacing	Rice variety			
	Sikamo	Jasmine 85	Marshall	Mean
20 cm x 20 cm (S1)	597	552	542	563
20 cm x 25 cm (S2)	595	592	630	605
25 cm x 15 cm (S3)	510	522	480	504
15 cm x 15 cm (S4)	467	375	427	423
30 cm x 10 cm (S5)	378	268	308	318
Mean	509	462	477	

LSD ($p \leq 0.05$): Spacing = 96.2; Variety = 73.1; Spacing x Variety = 163.8

Table 2. Effect of spacing on individual panicle weight (g) of three lowland varieties in a rain-fed ecosystem in Ghana

Spacing	Rice variety			
	Sikamo	Jasmine 85	Marshall	Mean
20 cm x 20 cm (S1)	4.93	5.25	5.41	5.19
20 cm x 25 cm (S2)	5.59	5.07	5.34	5.33
25 cm x 15 cm (S3)	4.52	3.93	4.52	4.32
15 cm x 15 cm (S4)	4.46	4.44	4.02	4.31
30 cm x 10 cm (S5)	4.06	3.99	3.94	4.00
Mean	4.71	4.54	4.65	

LSD ($p \leq 0.05$): Spacing = 0.592; Variety = 0.449; Spacing x Variety = 1.011

Table 3. Effect of spacing on 1000 grain weight (g) of three improved lowland varieties in a rain-fed ecosystem in Ghana

Spacing	Rice variety			
	Sikamo	Jasmine 85	Marshall	Mean
20 cm x 20 cm (S1)	26.18	26.50	24.96	25.88
20 cm x 25 cm (S2)	26.92	26.08	25.00	26.17
25 cm x 15 cm (S3)	26.89	24.32	26.12	25.78
15 cm x 15 cm (S4)	25.83	27.51	24.72	26.02
30 cm x 10 cm (S5)	26.77	25.04	25.04	25.62
Mean	26.52	25.89	25.27	

LSD ($p \leq 0.05$): Spacing = 1.877; Variety = 1.313; Spacing x Variety = 3.042

seeding density. As outlined earlier, more vigorous plants and greater number of tillers were produced under wider spacing. This resulted in the production of more dry matter (more photosynthetic material) than the less vigorous plants under closer spacing, thus accounting for the significantly higher grain yields that were recorded under the wider spaced crops over the closer spaced crops.

3.2.5 Dry matter yield (straw + grain)

This is a measure of the total above ground dry matter produced (Fig. 5). Generally, the three varieties interacted with 20 cm x 25 cm spacing to give the highest dry matter which was significantly higher than all the other spacing and varietal combinations. This was followed by dry matter produced due to interaction between any of the varieties and 20 cm x 20 cm spacing. Interaction between the varieties and the three closer spacing gave similar dry matter which was significantly lower than dry matter produced under the two wider spacing. Between varieties, Sikamo produced the highest biomass with Marshall and Jasmine 85 following in that order respectively. Mirza et al. [13] studying the effect of tiller dynamics and dry matter production in transplanted rice as affected by spacing and number of seedlings per hill, observed that wider spacing coupled with higher number of seedlings per hill accumulated maximum amount of dry matter, emphasizing that productivity of tillers as well as dry matter yield was lower with closer spacing and transplanting single seedlings per hill.

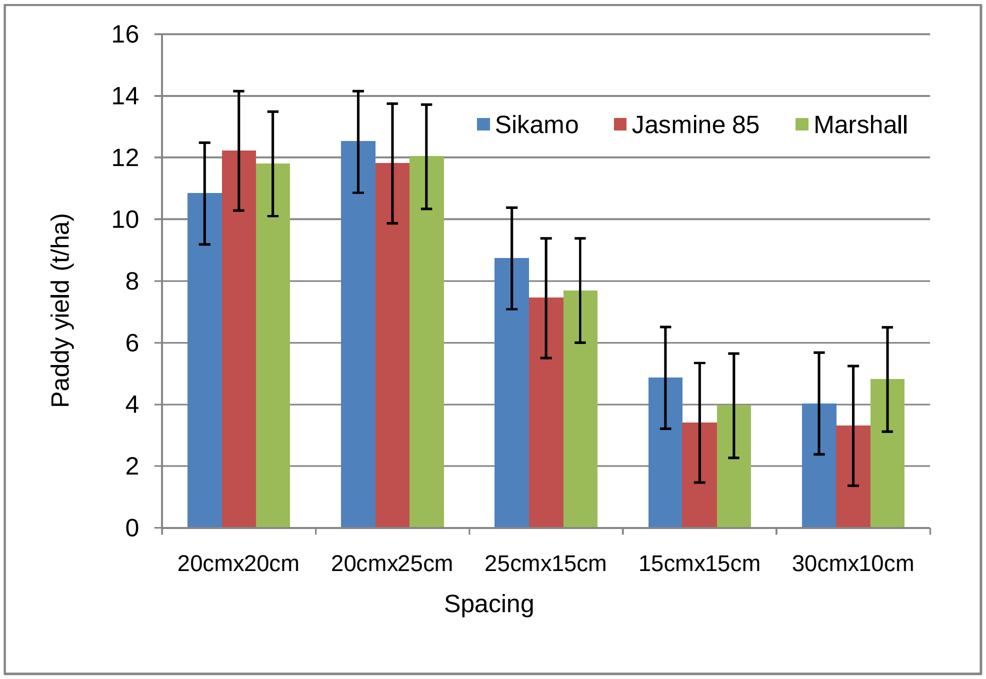

Fig. 4. Effect of spacing on grain yields of three lowland rice varieties in a rain-fed ecosystem in Ghana

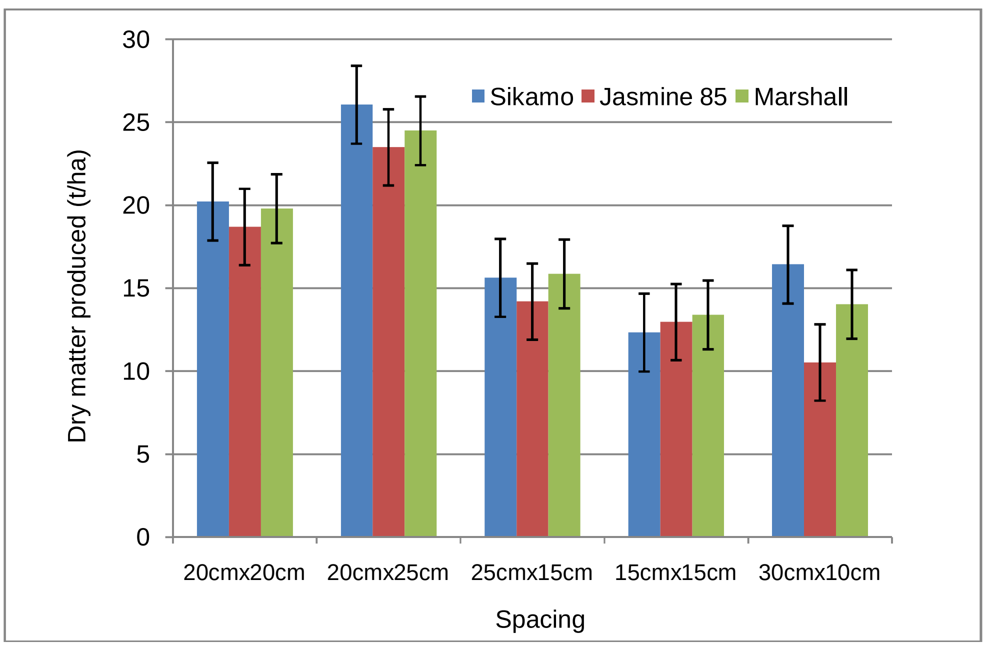

Fig. 5. Effect of spacing on total dry matter production (t/ha) of three lowland rice varieties in a rain-fed ecosystem in Ghana

3.3 Soil and Plant Analysis Development (SPAD) Values

The effect of spacing on SPAD (photosynthetic activity) values during the growth period is presented in Fig. 6. During the first week after transplanting (WAT), SPAD values were relatively similar across the different spacing adopted ranging from 39 (30 x 10 cm) to 41 (20 cm x 25 cm). Increase in SPAD values became rapid

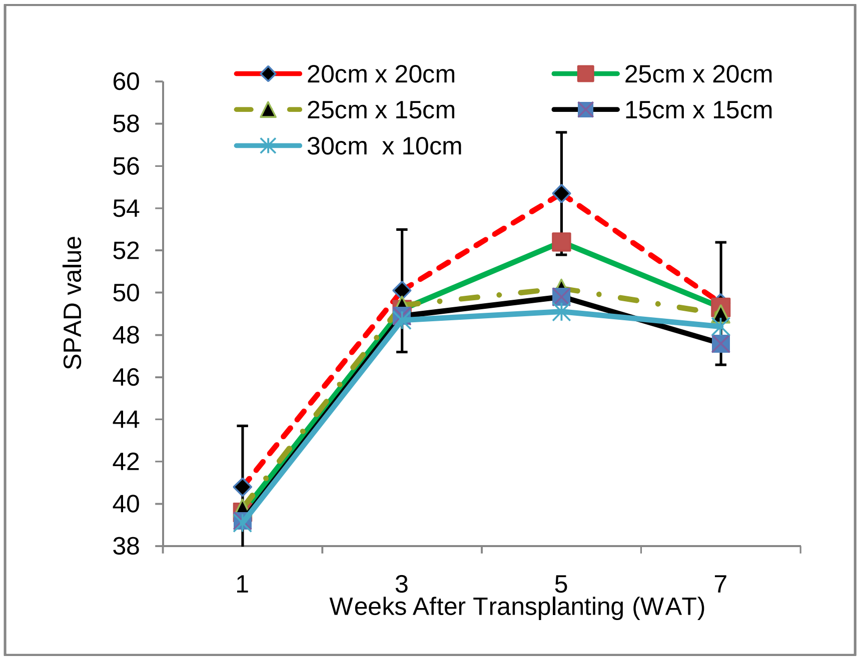

Fig. 6. Effect of spacing on SPAD values of three lowland rice varieties in a rain-fed ecosystem In Ghana

for all spacing up to the third week after transplanting. After the third week after transplanting, wider spacing showed higher SPAD values for the two wider spacing (25 cm x 20 cm, and 20 cm x 20 cm) up to the fifth week and begun to fall sharply till the seventh week after transplanting. Spacing at 25 cm x 20 cm recorded the highest SPAD values throughout the growth period, increasing from 41 during week 1 to 51 in week 3 and to a peak during week 5. This trend was similar to the 20 cm x 20 cm spacing. However, 3 WAT SPAD values for closer spacing showed minimal increases in value in the order: (25 cm x 15 cm) > (15 cm x 15 cm) > (30 cm x 10 cm). By inference, the more vigorous plants and greater number of tillers recorded under wider spacing resulted in more leaves exposed to sunlight, higher and more effective mobilization of photosynthetic matter and better grain filling compared to closer spacing.

4. CONCLUSION

Transplanting at wider spacing produced significantly higher panicles per m^2, heavier individual panicle weights and higher yields than closer spacing. The spacing of 20 cm x 20 cm and 20 cm x 25 cm which corresponds to 20 and 25 stands per m^2 produced significantly higher grain yields and therefore were recommended for the rain-fed lowlands (inland valleys and flood plains). The three varieties, however, showed a similar response pattern to spacing.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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