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Vol. 12(35), pp. 2713-2721, 31 August, 2017
DOI: 10.5897/AJAR2014.9455
Article Number: 69A439B65785
ISSN 1991-637X

http://www.academicjournals.org/AJAR

African Journal of Agricultural Research

Full Length Research Paper

Effect of planting density on growth, yield and yield attributes of rice (*Oryza sativa* L.)

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Received 17 December, 2014; Accepted 16 July, 2015

The study was conducted during 2012 from May to August cropping year at paddy field of Tsukuba International Training Center (TBIC), Japan. The main purpose of the experiment was to investigate the effect of planting density on the growth, yield and yield attributes of rice. The experiment comprised of five planting densities (16.7, 22.2, 25, 33.3 and 50 hills m^{-2}). It was arranged in Randomized Complete Block Design with three replications. The results showed that the effect of planting density was highly significant in influencing panicle number m^{-2}, spikelet number per panicle and ripening percentage. Higher panicle number was obtained in 50 hills m^{-2} and followed by 33.3 hills m^{-2} over the standard density. On the other hand, a decrease in density brought a significant increase in spikelet number per panicle over the preceding population density. Spikelet number per panicle increase of 44, 32, 26 and 9% were obtained in 16.7 hills m^{-2} over 50, 33.3, 25 and 22.2 hills m^{-2}, respectively. Higher grain yield was obtained in 50 hills m^{-2} and followed by 16.7 hills m^{-2}, but it was not significantly different among density treatments. The paddy yield record obtained due to high planting density over 16.7, 22.2, 25 and 33.3 hills m^{-2} were 4.0, 9.5, 4.8 and 6.9% respectively. With an increasing plant density from 16.7 to 50 hills m^{-2} panicle length and stem diameter decreases by 12 and 29.2%, respectively. In most of the evaluated traits, highest values were obtained from 16.7 and 50 hills m^{-2}. Therefore, 16.7 and 50 hills m^{-2} were more appropriate densities for cultivation of Nerica-4 variety.

Key words: Planting density, rice, growth, yield, yield attributes.

INTRODUCTION

Rice accounts for 27% of all cereal grains production worldwide, second only to wheat at 30% and slightly more than maize which comprises 25% of cereal production (Wayne Smith, 1995). However, the productivity of the crop per unit area is much lower. Among different production factors which constraints rice production, planting density is the most important agronomic practice which need due attention (Baloch et al., 2002). The rice yield rises with an increase plant density to some maximum value and then start decline. The density that results a maximum yield depends on temperature, solar radiation, moisture, soil fertility and other factors. There is an optimum plant density for every crop.

Plants grown in wider spacing increases the performance of individual plants. They have wider space

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around them to extract more nutrients, absorb solar radiation for better photosynthetic process as individual plant (Baloch et al., 2002). In the area where the environment does not limit yield, higher plant densities resulted in higher yield. In such situation, high density produces small number of spikelet per panicle (Uddin et al., 2011) and shorter panicle length. However, the greater number of panicles m^{-2} gave higher grain yield (Mobasser et al., 2007; Chandrankar and Khan, 1981). Over increasing of plant population beyond the optimum density results unnecessary stress on the plants and then affects tiller formation, sun light interception, nutrient uptake, rate of photosynthesis and other physiological phenomena and ultimately affects the growth and development of rice plant (Bozorgi et al., 2011). Unsuitable population of crop may have limitation in maximum availability of these factors. It is necessary to determine the optimum density of plants per unit area for maximizing rice yield. Use of optimum planting density per unit area ensures plants to grow properly both in the upper ground and underground parts of the plant through better utilization of solar radiation and nutrients (Bozorgi et al., 2011). Therefore, the objective of this study was to investigate the effect of plant density on the growth, yield and yield attributes of Nerica-4.

MATERIALS AND METHODS

Experimental site and design

The study was conducted in the experimental paddy field of Tsukuba International Center (TBIC), Japan. The experiment was laid out in Randomized Complete Block Design (RCBD) with three replications. Each experimental plot had a plot size of 3.6 m × 4.4 m, separated by a distance of 50 cm between blocks and 50 cm between plots within a block.

Five different planting densities were used for the study. The desired planting densities were created by changing the spacing between rows and plants. The treatments were 16.7, 22.2, 25, 33.3 and 50 hills m^{-2}. The treatments and their corresponding spacing within rows and plants are presented in Table 1.

Table 1. Planting density treatments

Treatment/density m^{-2}	Spacing
16.7 hills	30 cm × 20 cm
22.2 hills	30 cm × 15 cm
33.3 hills	30 cm × 10 cm
25 hills	20 cm × 20 cm
50 hills	20 cm × 10 cm

Seed treatment and seedling nursery

Seeds were selected using a salt solution at specific gravity of 1.13 by using hydrometer. The selected seeds were rinsed and disinfected with Healthied (Pefurazoate) fungicide solution in 200 times dilution (100 g in 20 l water) for 24 h. The selected and disinfected seeds were air dried by spreading on newspaper for 24 h and then soaked in a sprouting machine to initiate germination. The pre-germinated seeds were sown in seedling boxes (60 cm × 30 cm × 30 cm) at the rate of 80 gm per box. The seedling boxes were incubated for 42.5 h for uniform germination. Then after, seedlings were raised in a green house for about 25 days before transplanting.

Fertilizer application

All plots were fertilized uniformly with Nitrogen, Phosphorus and Potassium in the form of ammonium sulfate (N-21%), potassium chloride (K_2O-60%) and super phosphate (P_2O_5-17.5) which were applied at the rate of 80, 90 and 100 kg/ha, respectively. Nitrogen and Potassium were applied in two split doses as basal a week before transplanting and top dressing at the panicle initiation stage of the crop about 20 days before heading. In case of Phosphorous, all fertilizer was applied as basal before transplanting.

Field preparation and transplanting

The experimental field was ploughed with a power tiller two times. After application of ammonium sulfate, super phosphate and potassium chloride as basal, fertilizers were mixed with the soil, puddled and leveled with a hand power tiller eight days prior to transplanting.

Seedlings were transplanted manually by hand at the age of 3.5 leaves with 3 seedlings per hill at a depth of 2 to 3 cm on May 14th of 2012. The spacing was maintained according to the treatment.

Field management

After transplanting, the irrigation water was maintained at a depth of 3 to 4 cm until seedlings established well. A week after transplanting a herbicide (Zark D17: Bensulfuron-mehyl+mefenacet) was applied for weed controlling at a rate of 30 kg per ha. Water management, disease and insect control and other management recommendations were applied based on Japanese standards.

Data collected

Growth parameters

Growth observations sampling were made 7 times at 29 DAT (active tillering stage), 37 and 46 DAT (maximum tillering), 54 (panicle initiation stage), 74 DAT (full heading), 91 DAT (Grain filling stage), 104 (physiological maturity stage). Growth observations sampling were made 7 times at 29 (12 June), 37 (20 June), 46 (29 June), 54 (07 July), 74 (27 July), 91 (13 August), 104 (26 August) days after transplanting. These sampling times include most important stages such as active tillering (29 DAT), maximum tillering (37-46 DAT), and panicle initiation (54 DAT), full heading (74 DAT) and physiological maturity (104 DAT) stage of rice crop. Data recorded were plant length, number of tillers per hill, leaf area, SPAD value and dry matter weight. During sampling time, 6 samples (hills) from the center of the row, were uprooted from each plot for growth observation. The roots of every sample were removed after washing. The whole samples were used for plant height, tiller number and SPAD value. Plant length was measured from the ground surface to the full stretched tip of the longest leaf (panicle). The SPAD values were measured using SPAD (SPAD 502, Minolta Co., Ltd.) machine.

Sub samples of two hills were selected from six hills based on average tiller number for measuring leaf area and dry matter. Plants within the selected hills were cut and separated in to leaf, stem, panicle and dead leaves. Leaf area was measured using an automatic leaf area machine (AAM-8, Hayashi Denko Co., Ltd.). Dry matter of the four plant part components were measured after drying in an oven at temperature of 80°C for two days.

Yield and yield components

At maturity stage of the crop, a total of 32 hills were uprooted from the center of each plot for yield components observation. A sub sample of average hills were selected based on panicle number. This was also further sub sampled in two hills based on average panicle weight to determine spikelet number per panicle. Spikelet number per panicle was counted using automatic counter (Fujiwara Seisakusho Co., Ltd.). Filled grains were separated by using water (specific gravity: 1.00) and counted to compute ripening percentage. The weight of thousand grains was determined from filled grains adjusted to 14% moisture content. In addition, panicle length and stem diameter were also measured from selected two hills.

To determine the partial paddy yield, 2 m^2 areas were harvested from the center of each plot. After drying (> 10 days) and threshing, the paddy yield and straw were weighed to determine grain straw ratio. The paddy yield was determined after adjusting to 14% moisture content.

Statistical analysis

All data collected were subjected to analysis of variance (ANOVA) following Microsoft excel based statistical software. Turkey’s test (honestly significant different test) was used for mean separation.

RESULTS

Growth observations

Plant length

The result of the influence of planting density on Nerica-4 plant length is depicted in Figure 1. Plant length was not significantly influenced by planting densities at active tillering, reproductive and ripening stages. However, it was significant ($p<0.01$) at maximum tillering and panicle initiation stages. In all observation time, the highest average mean plant length was recorded in plots treated with low density (16.7 hills m^{-2}) and shorter plants were observed in high density treatments. At last observation time, the tallest plants (122 cm) were recorded in sparsely planting plots (16.7 hills m^{-2}) while shorter plants (110.53 cm) in 50 hills m^{-2}. Irrespective of planting density treatments, the increase in plant length from full heading stage till harvesting was very small.

Tiller number per meter square

The effect of planting density on tiller number m^{-2} is presented in Figure 2. High density plots 50 and 33.3 hills m^{-2} attained maximum tillering stage earlier than 16.7, 22.2 and 25 hills m^{-2}. High density plots reached maximum tillering at 37 days after transplanting while low density plots attained at 46 days after transplanting.

Higher number of tillers at maximum tillering stage was observed under plots treated with 50 hills m^{-2} (722 tillers) and 33.3 hills m^{-2} (511 tillers) as compared to 22.2 hills m^{-2} (393 tillers) and 16.7 hills m^{-2} (407 tillers) treatments. However, the reduction in number of tillers at last sampling time was higher in 50 hills m^{-2} and followed by 25 hills m^{-2} and 16.7 hills m^{-2}, respectively.

Chlorophyll content

Chlorophyll content of Nerica-4 was recorded using SPAD value meter. Chlorophyll content started increasing up to active tillering stage, then decreased at maximum tillering stage. After Top dressing the SPAD value showed again an increase up to full heading stage and then decreased very sharply at reproductive and ripening stage (Figure 3). The trend of chlorophyll content respond due to planting densities starting from active tillering till ripening stage was found similar. The differences with different densities were more pronounced at ripening stage (the last sampling time). At 107 DAT, the highest SPAD value record obtained was 34.78 at 16.7 hills m^{-2} whereas the lowest was 25.75 in 50 hills m^{-2}. At all growth stages, higher chlorophyll content was recorded at sparse planting density (16.7 hills m^{-2}) while lower chlorophyll content was showed at high planting density (50 hills m^{-2}) treatment.

Dry matter weight

The change in dry matter production within different growth stages was depicted in Figure 4. At the vegetative growth stage, the total dry matter production was found higher in 50 hills m^{-2} and followed by 33.3 hills m^{-2}. At the last sampling time, slightly similar higher total dry matter weight was recorded in 16.7 hills m^{-2} (14.6 t/ha), 33.3 hills m^{-2} (14.6 t/ha) and 50 hills m^{-2} (14.4 t/ha). However, slightly lower total dry matter yield was obtained in 22.2 hills m^{-2} and 25 hills m^{-2}, respectively. At vegetative stage, lower total dry matter weight was obtained in lower densities. However, no significant difference among low and high density treatments at reproductive and ripening stages.

Leaf area index

There was no significant difference in leaf area index due to variation in density. Leaf area index increased from active tillering stage up to panicle initiation stage in all planting densities (Figure 5). This increase continued up to full heading stage in case of 16.7 and 33.3 hills m^{-2}. After which started decreasing and then a progressive

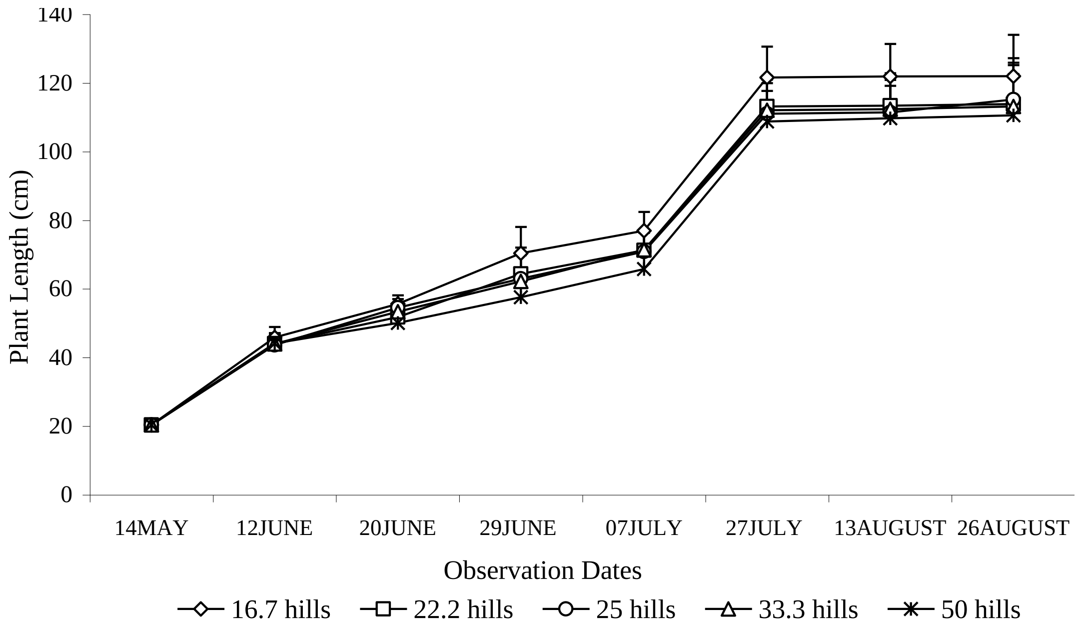

Figure 1. Effect of planting densities on plant length of Nerica-4.

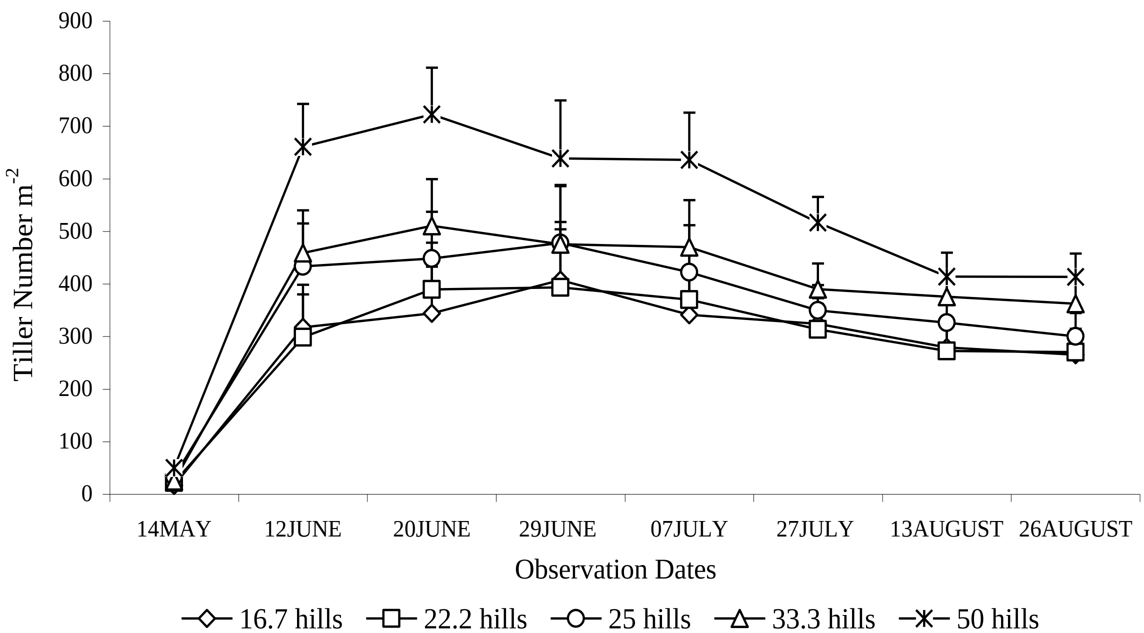

Figure 2. Effect of planting densities on tiller number m^{-2} of Nerica-4.

decrease was observed at ripening stage of the crop.

The highest mean leaf area index was found in 50 hills m^{-2} (4.72 m^{-2}) and followed by 33.3 hills m^{-2} (4.12 m^{-2}). At maturity stage of the crop, 50 hills m^{-2} showed higher leaf area index record (1.49 m^{-2}) and followed by 33.3 hills m^{-2} (1.3 m^{-2}) and 16.7 hills m^{-2} (1.26 m^{-2}), respectively. However, the lowest record was obtained in 22.2 hills m^{-2} (0.95 m^{-2}). Higher population densities achieved higher leaf area index as compared to low population densities.

Yield and yield components

Panicle number per meter square

There was significant ($p<0.01$) difference among planting

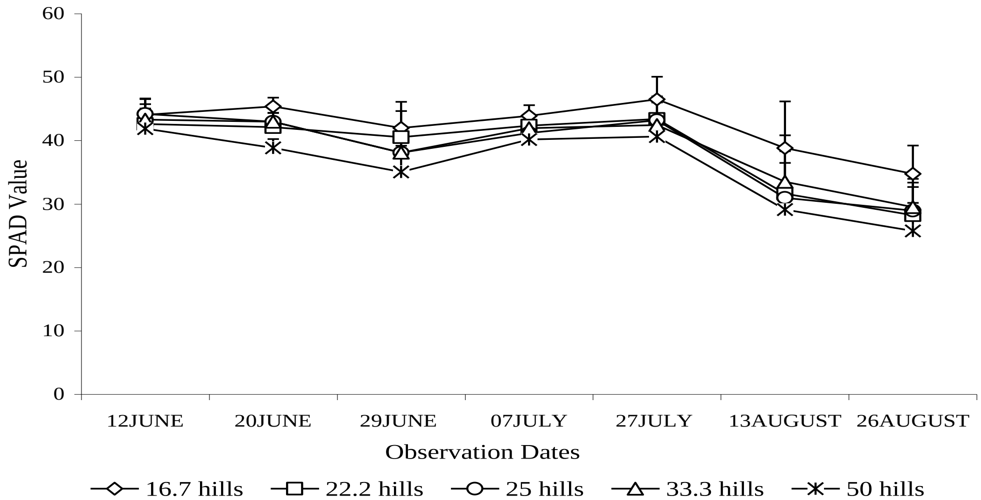

Figure 3. Effect of planting densities on chlorophyl content of Nerica-4.

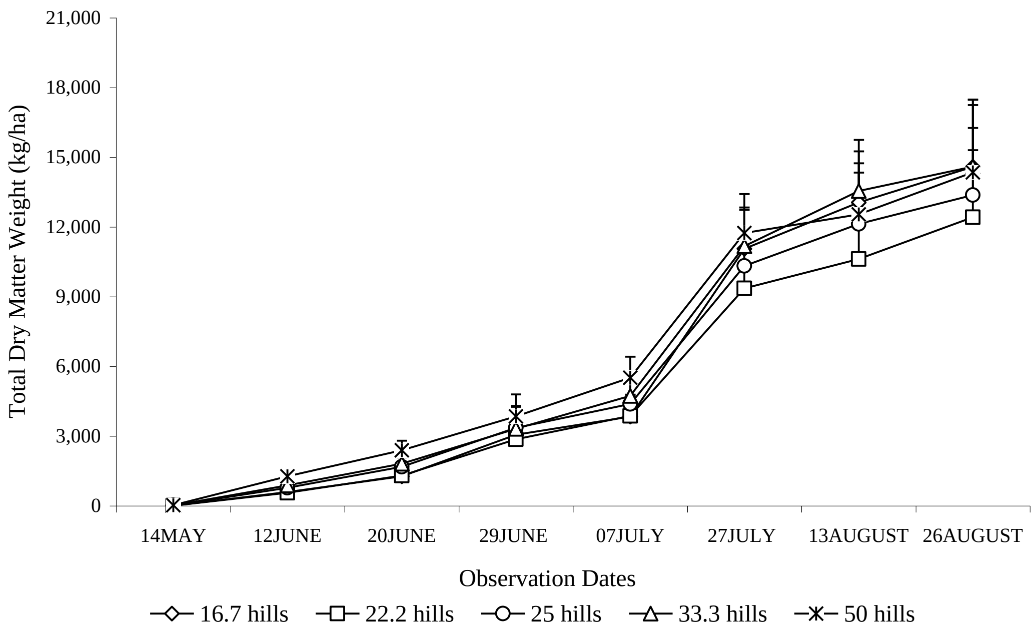

Figure 4. Effect of planting densities on total dry matter weight of Nerica-4.

density treatments in panicle number m^{-2}. An increase trend in panicle number m^{-2} was observed with an increase in plant density. The highest mean number of panicles was recorded in 50 hills m^{-2} (423) and the lowest was under 16.7 hills m^{-2} (267).

Spikelet number per panicle

Spikelet number per panicle was also found significantly ($p<0.05$) different among density treatments. The spikelet number due to different densities ranges from 98 to 141. Spikelet number per panicle increased as population density decreased from 50 to 16.7 hills. The highest mean spikelet number was recorded in 16.7 hills m^{-2} (141) and followed by 22.2 hills m^{-2}, although both treatments were not significant different. However, the lowest was obtained in 50 hills m^{-2} (98) and followed by 33.3 hills m^{-2} (107) and 25 hills m^{-2} (112), respectively.

Ripening ratio

There was a significant difference in ripening ratio due to planting densities. Statistical difference was observed between treatment 25 and 50 hills m^{-2}. The lowest

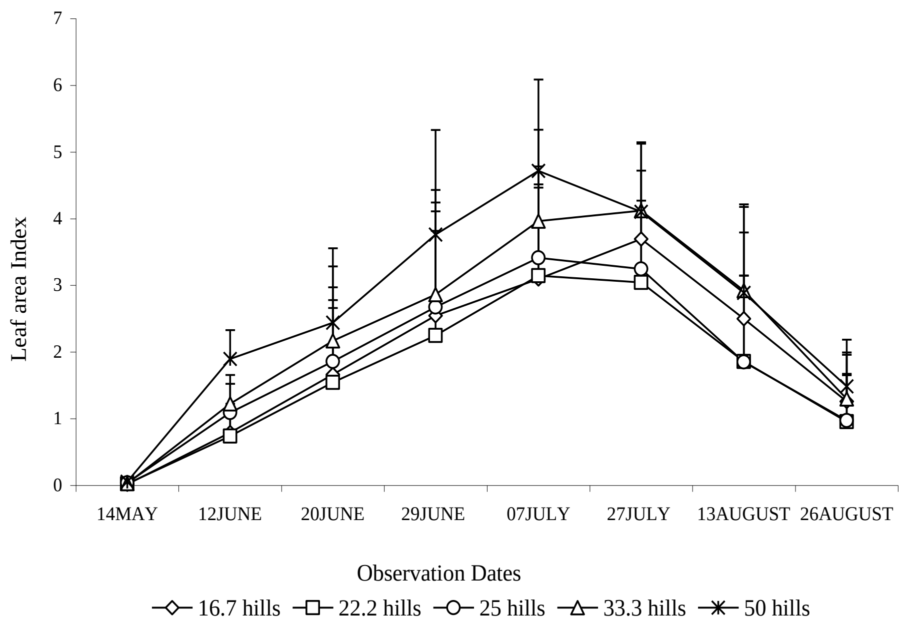

Figure 5. Effect of planting densities on leaf area index Nerica-4.

Table 2. Effect of planting densities on Yield and Yield components of Nerica-4

Planting density	Panicle number m^{-2}	Spikelet number $panicle^{-1}$	Ripening ratio (%)	1000-Grain Wt. (gm)	Paddy yield ($kg\ ha^{-1}$)	Spikelet number m^{-2} ($x\ 10^3$)
16.7 hills m^{-2}	267^b	141^a	65.07^{ab}	28.23	6,853	37.6
22.2 hills m^{-2}	276^b	132^a	61.93^{ab}	28.96	6,505	36.4
25 hills m^{-2}	303^b	112^b	68.17^a	29.37	6,795	34.0
33.3 hills m^{-2}	335^b	107^b	64.37^{ab}	28.74	6,722	35.9
50 hills m^{-2}	423^a	98^b	59.10^b	28.95	7,124	41.7
F probability (%)	0.11	0.01	1.39	42.61	89.44	32.2
CV (%)	9.13	4.85	3.75	2.38	11.15	11.4

Means in a column with the same letter are not significantly different at P<0.05 by the Turky's test (HSD).

ripening percentage was obtained in high planting density (50 hills m^{-2}). However, the highest ripening percentage was observed in 25 hills m^{-2} (68%) and followed by 16.7 hills m^{-2} (65%) and 33.3 hills m^{-2} (64%), respectively.

1000-grain weight

The non significant (p>0.05) difference in 1000-grain weight was observed due to planting density variation. In almost all treatments, the average 1000-grain weight records obtained were almost similar. The correlation analysis graph also showed a non significant relationship between 1000-grain weight and paddy yield.

Paddy yield

The effect of planting densities on paddy yield per hectare of Nerica-4 is presented in Table 2. Grain yield was not significantly (p>0.05) affected by planting densities. Even if there was no statistical significant difference, high mean average paddy yield was obtained in 50 hills m^{-2} (7,124 kg/ha) and followed by 16.7 hills m^{-2} (6,853 kg/ha), 25 hills m^{-2} (6,795 kg/ha) and 33.3 hills m^{-2} (6,722 kg/ha) respectively.
However, the lowest paddy yield was obtained in 22.2 hills m^{-2} (6,505 kg/ha).

Yield related parameters

Panicle length

Nerica-4 panicle length was significantly (p<0.05) influenced by planting densities. The highest mean average panicle length was recorded in 16.7 hills m^{-2} (24.2 cm) and followed by 22.2 hills m^{-2} (23.45 cm) and

Table 3. Effect of planting densities on yield related parameters of Nerica-4.

Planting density	Panicle Length (cm)	Stem Diameter (mm)	Straw Yield (kg ha^{-1})	Harvest Index
16.7 hills m^{-2}	24.20^{a}	0.65^{a}	7,198	0.49
22.2 hills m^{-2}	23.45^{ab}	0.58^{b}	7,829	0.46
25 hills m^{-2}	22.77^{b}	0.59^{ab}	9,178	0.43
33.3 hills m^{-2}	22.75^{b}	0.56^{b}	7,816	0.47
50 hills m^{-2}	21.40^{c}	0.46^{c}	8,241	0.47
F probability (%)	0.04	0.02	52.67	0.48
CV (%)	1.8	4.3	17.0	9.3

Means in a column with the same letter are not significantly different at P<0.05 by the Turky's test (HSD).

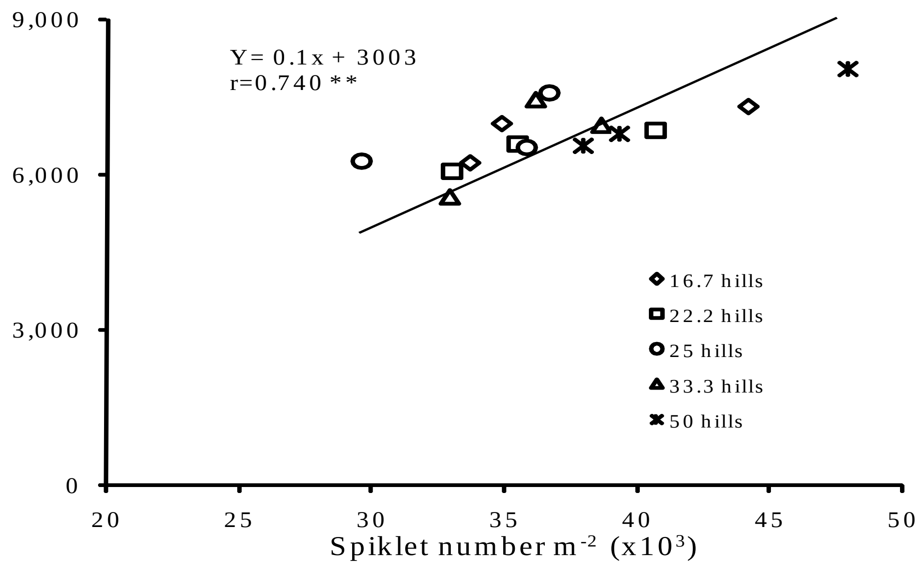

Figure 6. Relationship between spiklet nimber m^{-2} and paddy yield.

shorter panicles were observed in 50 hills m^{-2} (21.40 cm). Plots treated with sparse densities showed a longer panicle length as compared to plots treated with high densities. Generally, panicle length increases as planting density decreases and viceversa.

Stem diameter

Stem thickness due to planting density was found significant. The result revealed that thickest stem was recorded in the low density plots. The stem thickness clearly showed a decrease as the density increases. The highest mean stem diameter was recorded in 16.7 hills m^{-2} and the lowest in 50 hills m^{-2}.

Straw yield

The effect of planting density in straw yield per hectare of Nerica-4 is depicted in Table 3. Straw yield because of variation in planting density was non-significant (p>0.05). The higher mean straw yield was recorded in 25 hills m^{-2} (9,179 kg/ha) and followed by 50 hills m^{-2} (8,242 kg/ha) while the lowest was obtained in 16.7 hills m^{-2} (7,198 kg/ha). The increase in straw yield due to 22.2, 25, 33.3 and 50 hills m^{-2} planting densities over the low density treatment (16.7 hills m^{-2}) were 8.8, 27.5, 8.6 and 14.5%, respectively.

Relationship between paddy yield and yield components

The correlation coefficient between yield components and paddy yield due to density is shown Figure 6 to 7. The relationship between panicle number m^{-2} and paddy yield showed a positive correlation (0.479). Paddy yield increased with an increase in panicle number m^{-2}. In particular, paddy yield increased in high population density was much more correlated with an increase

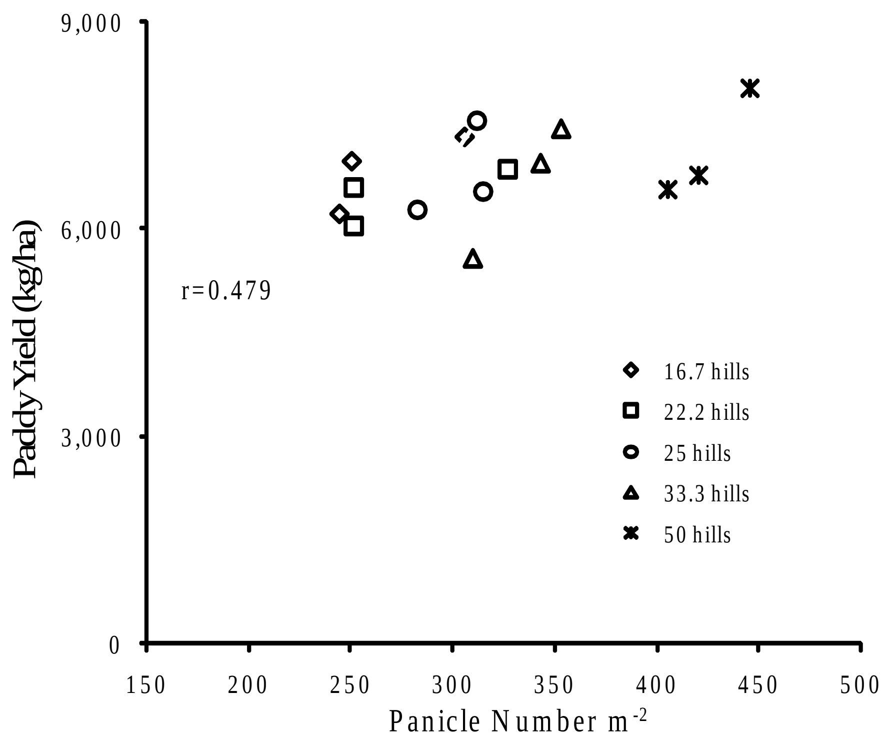

Figure 7. Relationship between panicle number m^{-2} and paddy yield.

panicle number m^{-2}. On the other hand, the correlation coefficients between yield and spikelet number per panicle, ripening ratio and 1000-grain weight showed no correlation. The correlation coefficient of spikelet number m^{-2} indicated a significant positive correlation (0.740). Any significant increase in sink size had a positive impact in an increase in paddy yield of Nerica-4.

DISCUSSION

A significant panicle number per meter square increased was noticed as an increase in density. The highest mean average panicle number was recorded in 50 hills m^{-2} and the lowest was under 16.7 hills m^{-2}. The increase in number of panicle m^{-2} over 16.7, 22.2, 25, and 33.3 hills m^{-2} were 59, 53, 40 and 26%, respectively. Sheieh (1977) also reported an increase of grain yield due to the increase in the panicle number per unit ground area. Unlike to panicle number m^{-2}, there was an increase in spikelet number per panicle with a decrease in planting densities. The highest mean average spikelet number per panicle record obtained in 16.7 hills m^{-2} might be due to proper nutrient availability and easy light penetration even to the lower leaves because of wider spacing. This could be attributed to high dry matter accumulation per hill which further contributes an increase in spikelet number per panicle. Uddin et al. (2010, 2011) indicated a significant decrease in spikelet number per panicle with an increase planting density. In this study, the ripening percentage of Nerica-4 was very low which ranges from 59% up to 68%. High temperature prevailed during reproductive stage might be the probable reason for high proportion of sterile spikelet. 1000-grain weight was not significantly affected by variation in planting densities. 1000-grain weight is a stable varietal characteristic. The size of the grain cannot grow to a size greater than that permitted by the hull (Yoshida, 1981).

Higher grain yield was obtained in 50 hills m^{-2} and followed by 16.7 hills m^{-2}, but it was not significantly different among density treatments. The paddy yield record obtained due to high planting density over 16.7, 22.2, 25 and 33.3 hills m^{-2} were 4.0, 9.5, 4.8 and 6.0% respectively. The increase in paddy yield with an increase in plant density (50 hills m^{-2}) was mainly due to high number of panicles m^{-2}. A grain yield increments of 20.6% was reported from 120 plants m^{-2} as compared to 20 plants m^{-2} (Mobasser et al., 2007). Bozorgi et al. (2011) got high grain yield in 15 cm × 15 cm treatment as compared to 20 cm × 20 cm and 25 cm × 25 cm. The experiment conducted on the effect of spacing 20 cm × 10 cm, 15 cm × 10 cm and 10 cm × 10 cm on the grain yield of early, medium and late duration tall growing indica varieties showed that spacing of 10 cm × 10 cm gave higher yield in case of early maturing varieties while the spacing of 20 cm × 10 cm gave the higher yield for medium and late maturing varieties (Chandrankar and Khan, 1981).

Nerica-4 panicle length and stem diameter was significantly ($p<0.05$) affected by planting densities. Panicle length and culm diameter decreased significantly as density increases. The lowest panicle length and culm diameter was recorded in 50 hills m^{-2} while the highest record was in 16.7 hills m^{-2}. The loss in diameter at highest planting density was 29.2%. The loss in diameter as planting density increased could be due to severe competition among plants for plant nutrients, solar radiation (Light) and space. Lower light penetration to lower leaves increases foliar shading and produces thinner stem. All these factors collectively contribute to a decrease in photosynthesis; assimilate production and its partitioning and finally results reduction in stem diameter. However, plants grown in wider spacing have more area of land around them to extract more nutrients and had more solar radiation to absorb for better photosynthetic process.

According to the results, the aothor can conclude that the paddy yield obtained due to variation in population densities was not statistical different. Number of panicles m^{-2}, spikelet number per panicle and ripening percentage were significantly affected by planting density. An increase in plant population significantly increased number of panicles m^{-2} while decreased the spikelet number per panicle. The increase of paddy yield in high planting densities was contributed more by panicle number per unit area and increasing in the spikelet number per unit area. Under low planting density plants headed a bit late, grew taller and produces higher dry matter during and after full heading stage. However, under low density plants headed earlier, grew shorter and produce lighter panicles.

CONFLICTS OF INTERESTS

The authors have not declared any conflict of interests.

ACKNOWLEDGEMENT

The author wish to convey his sincere gratitude to JICA-Japan, JICA FRG Ethiopia and Ethiopian Agricultural Research Institute for giving him the opportunity to participate in rice cultivation technique development training at Tsukuba International Center from February 26th to November 23th, 2012. The author would like express heartfelt thanks to Mr. T. Fujii and Mr. K. Miura course instructors for their undeserved guidance and assistance throughout the training course. The author is also highly appreciated to his technical advisors Dr. M. Yamada, Dr. T. Takita and Dr. K. Shohara and invited commentators Dr. S. Maruyama and Dr. J. Abe for their valuable comments, corrections and encouragement in preparation of this paper.

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