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Studies on the Effect of Sowing Techniques and Seed rate on the Growth, Yield Components and Yield of Direct Seeded Rice (*Oryza sativa* L.) under Rainfed Medium Land Situation

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A B S T R A C T

A field experiment was conducted during *Kharif* season of 2016 at Research Farm, College of Agriculture, Central Agricultural University, Imphal, Manipur. The experiment was laid out in Factorial Randomised Block Design (FRBD) with two factors: sowing techniques with two levels (broadcasting and line sowing) and seed rate with five levels (80, 90, 100, 110 and 120 kg ha^{-1}). Sowing of pregerminated seeds of rice cultivar CAU-R1 (Tamphaphou) was done by broadcasting and line sowing (20 cm spacing). Plant height (113.07 cm), plant population m^{-2} (54.33), no. of tillers m^{-2} (94.67) and no. of effective tillers m^{-2} (90.67), panicle length (28.33 cm), no. of filled grains $panicle^{-1}$ (150.33) all were highest in line sowing than broadcasting. Although plant population m^{-2} (54.33), plant height (113.07 cm) and no. of tillers m^{-2} (94.67) at harvesting were more at the seed rate of 120 kg ha^{-1}, but no. of effective tillers m^{-2} (90.67), panicle length (28.33 cm), no. of filled grains $panicle^{-1}$ (150.33), all were highest at the seed rate of 100 kg ha^{-1}. Line sowing of CAU-R1 at the seed rate of 100 kg ha^{-1} has recorded the highest grain yield (6030.11 kg ha^{-1}) and with the decrease or increase in seed rate, the grain yield was also reduced.

Introduction

Agriculture is an integral part of India's economy and society. It has about 130 million farming families; the majority of them are small and marginal farmers who practice subsistence agriculture. Rice is one of world's most favoured staple foods and more than 90% of rice is produced and consumed in Asia. Rice being an important crop in India, there is a lot to focus on enhancing rice production and productivity. Rice occupies an important place in Indian agriculture as it provides 43 % calorie requirement of 70 % of Indians and contributes to 15 % of annual GDP (Kaur and Singh, 2017).

In India, it is cultivated on an area of 44.4 million hectares in *kharif* and *rabi* /summer season out of the total 141 million hectares of land under cultivation which is maximum among all rice growing countries amounting for 29.40% of the global rice area.

Huge water inputs, labour costs and labour requirements for traditional transplanting system (TPR) have reduced profit margins (Pandey and Velasco, 1999). It leads to high losses of water through puddling, surface evaporation and percolation. Water resources, both surface and underground, are shrinking and water has become a limiting factor in rice production (Farooq *et al*., 2009a).

Although, transplanting method of establishment is reported to be the best for higher productivity of rice, puddling creates a hard pan below the plough-zone and reduces soil permeability. In recent years, there has been a shift from traditional transplanting system (TPR) to direct seeded rice (DSR) cultivation in several countries of Southeast Asia (Pandey and Velasco, 2002).

This shift was principally brought about by the expensive labour component for transplanting due to an acute farm labour shortage which also delayed rice sowing (Chan and Nor, 1993) apart from other advantages viz., requires less water, less drudgery, early crop maturity, low production cost, better soil conditions for following crops and less methane emission, provides better option to be the best fit in different cropping systems by shortening the crop duration by 7-10 days and can produce as much grain yield as that of transplanted crop.

Direct seeded rice (DSR) has received much attention because of its low input demand. In Asia, dry seeding is extensively practiced in rainfed lowlands, uplands and flood-prone areas, while wet seeding remains a common practice in irrigated areas (Azmi *et al*., 2005; de Dios *et al*., 2000; Kaur and Singh, 2017). Direct-seeded rice occupies 26% of the total rice area in South Asia (Gupta *et al*., 2006). Production and productivity of rice is influenced by various factors like type and quality of seed material, sowing techniques, timely nutrient supply, optimum plant population etc.

Moreover, seed rate exerts a strapping effect on rice grain yield, because of its aggressive influence firstly in crop growth and development and lastly on rice yields. So, there is need to search for suitable crop establishment techniques to increase the productivity and profitability of rice (Farooq *et al*., 2011).

Improper sowing method and low plant density are the most important factors of agronomic constraints for obtaining higher yield of rice (Dongarwar *et al*., 2018). Sowing techniques like broadcasting and line sowing in direct seeded rice plays an important role on the growth and production of rice due to difference in density of plants.

Optimum plant density ensures vigorous, uniform aerial and underground parts, less plant-weed competition, evenly germination, early maturity, increased photosynthesis per acre and increased water use efficiency. Seed rate has a great influence on plant density which ensures the establishment of the crop stand, number of tillers, time to maturity and yield.

The increase in plant density increases total plant weight per unit area and decreases the total weight per plant. The number of plants per unit area has an impact on plant architecture, modifies growth and development pattern and effects on the production photosynthesis (Abuzar *et al*., 2011).

The reason for the reduction in yield is due to the reduction in resources per plant. So the reduction in yield will not be compensated by increasing plant number. For this instance, the present study aimed to find out the suitable sowing techniques and seed rate of direct seeded rice on growth, yield and yield attributing characters of rice.

Materials and Methods

Experimental site

A one year field experiment was conducted during the *kharif*, 2016 in the experimental farm of the Department of Agronomy, College of Agriculture, Central Agricultural University, Imphal which is situated 24.45^0 N latitude and 93.56^0 E longitudes at an elevation of 790 m above mean sea level.

The site comes under the Eastern Himalayan Region (II) and the agro-climatic zone is under Sub-Tropical Zone (NEH-4) of Manipur. The experimental field had fairly medium levelled topography and good drainage system.

Design of experiment

The experiment was laid out in Factorial Randomised Block Design (FRBD) with two factors: Sowing techniques with two levels and Seed rate with five levels respectively. The experiment has 10 treatments and 3 replications in 3 m × 4 m plot size.

The treatment combinations are: S_1R_1 = Broadcasting + seed rate (80 kg ha^{-1}), S_1R_2= Broadcasting + seed rate (90 kg ha^{-1}), S_1R_3 = Broadcasting + seed rate (100 kg ha^{-1}), S_1R_4= Broadcasting + seed rate (110 kg ha^{-1}), S_1R_5 = Broadcasting + seed rate (120 kg ha^{-1}), S_2R_1 =Line sowing + seed rate (80 kg ha^{-1}), S_2R_2 =Line sowing + seed rate (90 kg ha^{-1}), S_2R_3=Line sowing + seed rate (100 kg ha^{-1}), S_2R_4 = Line sowing + seed rate (110 kg ha^{-1}), S_2R_5 = Line sowing + seed rate (120 kg ha^{-1}). The paddy variety 'Tamphaphou (CAU R1)' was selected for the experiment under the rainfed wetland ecosystem that matures within 135-140 days with an excellent eating quality of local preference.

The experimental field was cross ploughed once by tractor in summer. The field is kept flooded with 3 to 5 cm deep water for two to three days. Subsequent ploughing with tractor and power tiller was done to puddle the soil (Table. A, B, C).

After puddling and levelling, the field is laid out as per the experimental design. The recommended fertilizer dose of N: P_2O_5: K_2O @ 60:40:30 kg ha^{-1} was applied in all the treatments in the form of urea, single super phosphate and muriate of potash following recommended method.

Half dose of the nitrogen and full dose of phosphorus and potash applied as basal and rest of the nitrogen was top dressed in two equal splits at 30 and 60 DAS. The remaining nitrogen was applied in two equal splits one at active tillering stage (25 DAS) and the other at flower initiation stage (65 DAS).

The pre-germinated seeds were sown either by broadcasting or by line sowing at 20 cm x 10 cm spacing according to the different seed rate combinations on second fortnight of June.

The data generated from both the year was analyzed using analysis of variance (ANOVA) and the difference between treatment means was tested for their statistical significance with appropriate critical difference (CD) at 5 per cent level of probability (Gomez and Gomez, 1984).

The treatment where there is no significant difference is denoted by "NS" and degree of freedom as "df".

Table.A Soil of the experimental site

SI.No.	Particulars	Value	Interpretation	Method followed
1.	Soil pH	5.52	Strongly acidic	Glass electrode pH meter (Jackson, 1973)
2.	Soil texture Sand Silt Clay	 8% 23% 67%	Clay	Bouyoucos Hydrometer method (Bouyoucos method, 1962)
3.	Organic carbon (%)	1.15 %	High	Walkley and Black rapid titration method (Walkley and Black, 1934)
4.	Available Nitrogen (kg ha^{-1})	322	Medium	Alkaline potassium permanganate method (Jackson,1973)
5.	Available Phosphorus (kg ha^{-1})	17.59	Medium	Bray's and Kurtz's method (Jackson, 1973)
6.	Available Potassium (kg ha^{-1})	287.17	High	Flame photometric method (Jackson,1973)

Table.B Meteorological conditions during the experimental period

Month	Temperature (^oC)		Rainfall (mm)	Relative Humidity (%)		Avg. wind speed (km ha^{-1})	Avg. sunshine hours
	Maximum	Minimum		Morning	Evening		
June	31.4	22.1	205.3	89.9	78.2	4.5	4.7
July	20.5	14.9	225.6	62.0	54.5	2.7	1.4
August	31.0	22.4	119.8	88.7	73.3	4.1	4.8
September	29.4	21.9	221.5	92.2	74.3	3.2	4.6
October	28.6	19.5	198.3	92.6	71.2	3.1	5.3
November	24.9	12.3	66.2	92.6	59.9	2.8	7.2
Total	165.8	113.1	1036.7	518.0	411.4	20.4	28
Mean	27.63	18.85	172.78	86.33	68.57	3.4	4.67

Table.C Cropping history of the experimental site

Year	*Kharif*	*Rabi*
2014	Soybean	Bengal gram
2015	Rice	Bengal gram

Results and Discussion

Effect of sowing techniques and seed rate on growth parameters of direct seeded rice

Plant height

The sowing techniques has significant effect on the plant height of direct seeded rice at all the growth stages (60 DAS, 90 DAS and at harvest) except at 30 DAS. Plant height was more in line sowing (35.70 cm) than broadcasting (35.65 cm) at 30 DAS and gradually increased at 60 DAS (88.00 cm), 90 DAS (112.17 cm) and harvest (112.29 cm) in the line sowing treatment. Similarly, the seed rate has significant effect on the plant height of direct seeded rice at all the growth stages

(60 DAS, 90 DAS and at harvest) except at 30 DAS. Plant height was maximum (35.82 cm) at 30 DAS and gradually increases with increase in seed rate with a seed rate upto 120 kg ha^{-1}. The maximum plant height at 60 DAS (88.67 cm), 90 DAS (112.82 cm) and harvest (112.92 cm) with 120 kg ha^{-1} seed rate. The interaction between the sowing techniques and seed rates had no significant effect on plant height at all the growth stages of direct seeded rice. The plant height was maximum in line sowing (S_2) with a seed rate of 120 kg ha^{-1}(R_5) during harvest. The interaction between the sowing techniques and seed rates reveals the maximum plant height in the treatment S_2R_5 during harvest. However, the minimum plant height at harvest was recorded in the treatment S_1R_1 which was broadcasting at the seed rate of 80 kg ha^{-1} (Table.1).

It had been noticed that plant height was more in line sowing than broadcasting. It may be due to the reason that plants sown in line sowing had a specific distance than broadcasting and the competition between the plants were minimum and deep penetration of roots resulting in efficient nutrient uptake and good plant growth.

Similar result was reported by Mahmood *et al.*, (2013) and Ehsanullah *et al.*, (2007). Plant height was lowest at the seed rate of 80 kg ha^{-1} and gradually increased with the increase in seed rate upto 120 kg ha^{-1}. It indicates that when the plant spacing becomes closer (high seeding rate), the rice plants elongated more for want of light in narrow row spacing. Thus, the plants grow taller. This result is in consistent with those reported by Zhang *et al.*, (2006); Kaur and Singh, (2016).

Plant population m^{-2}

The plant population m^{-2} was recorded at 30 DAS and at harvest. The plant population m^{-2} had no significant effect among the different sowing techniques at 30 DAS, but at the time of harvesting it differed significantly among the two sowing techniques. There was maximum plant population m^{-2} in line sowing (S_2) *i.e* 47.93 at 30 DAS and 46.87 at harvesting compared to broadcasting method (S_2) *i.e* 47.27 at 30 DAS and 45.53 at harvesting respectively. The plant population m^{-2} had significant effect among the different sowing techniques and seed rates during both 30 DAS and harvesting stage.

Among the different seeding rates, 120 kg ha^{-1} in R_5 treatment of direct seeded rice has recorded the maximum plant population m^{-2} (54.67) and was significantly at par to 110 kg ha^{-1} (52.33), 100 kg ha^{-1} (48.17), 90 kg ha^{-1} (43.50), and 80 kg ha^{-1} (39.33) respectively at 30 DAS. During harvesting, the maximum plant population m^{-2} (53.67) has been observed in 120 kg ha^{-1} in R_5 treatment of direct seeded rice followed by 110 kg ha^{-1} (50.67), 100 kg ha^{-1} (46.67), 90 kg ha^{-1} (42.17), and 80 kg ha^{-1} (37.83) respectively. The plant population m^{-2} had non significant effect among the different sowing techniques and seed rates at 30 DAS and harvesting stage. The interaction effect of sowing techniques and seed rate have revealed the maximum plant population m^{-2} in S_2R_5 (55.33) and minimum plant population m^{-2} in S_1R_1 (39.00) at 30 DAS. During harvesting stage, maximum plant population m^{-2} in S_2R_5 (54.33) and minimum plant population m^{-2} in S_1R_1 (37.00) at harvest.

Plant population m^{-2} was non-significantly more in line sowing than broadcasting at 30 DAS. It may be due to the reason that rice seeds sown in line sowing or broadcasting experienced uneven germination and poor crop stand due to rough seedbeds, placement of seed at improper depth which resulted in lower plant population in broadcasting, poor seed covering during early growth stage but at harvesting stage, line sowing had a specific distance than broadcasting and the competition between the plants were minimum and deep penetration of roots resulting in efficient nutrient uptake and good plant growth.

Planting distance is an important factor for better production and also it gives equal opportunity to the plants for their survival and best use of other constraints supplied to the plants (Kaur and Singh, 2016). Plant population m^{-2} was significantly different among different seed rates at both 30 DAS and at harvesting. The higher plant population in direct seeding plots was due to the use of higher number of seeds m^{-2} and their increased germination percentages as compared to other treatments, wherein, lower number of seeds were planted. Similar result was reported by Baloch *et al.*, (2007).

Number of tillers m^{-2}

It has been observed that the number of tillers m^{-2} had no significant effect among the different sowing techniques at 30 DAS, but after that at 60 DAS, 90 DAS and at harvesting it differed significantly among the two sowing techniques. Number of tillers m^{-2} was more in line sowing (S_2) than broadcasting (S_1). Number of tillers m^{-2} was significantly different among different seed rates [80 kg ha^{-1} (R_1), 90 kg ha^{-1} (R_2), 100 kg ha^{-1} (R_3), 110 kg ha^{-1} (R_4), 120 kg ha^{-1} (R_5)] in all growth stages except 30 DAS. Number of tillers m^{-2} was minimum at the seed rate of 80 kg ha^{-1} and gradually increased with the increase in seed rate upto 120 kg ha^{-1}. Interaction between the sowing techniques and seed rate had no significant effect on number of tillers m^{-2}. The maximum number of tillers m^{-2} (94.67) was recorded from the treatment S_2R_5which was line sowing at the seed rate of 120 kg ha^{-1}. The lowest interaction effect (81.00) was observed from the treatment S_1R_1which was broadcasting at the seed rate of 80 kg ha^{-1}.

The tiller number increased up to 90 DAS and later on decreased with the advancement of crop age due to mortality of ineffective tillers. More number of tillers was recorded when rice was seeded with line spacing of 20 cm than broadcasting. This might be due to more availability of free space for profuse tillering in wider row spacings where in broadcasting seeds are often not properly buried in broadcast plots resulting in low germination and establishment counts (Kaur and Singh, 2016). However, tiller number increased with increasing seed rate, the maximum number of tillers m^{-2} was reported in R_5 treatment where seed rate was 120 kg ha^{-1}.Similar results were reported by Phuong *et al.*, (2005); Kaur and Singh, (2016).

Effect of sowing techniques and seed rate on yield attributes of direct seeded rice

Number of effective tillers m^{-2}

The number of effective tillers m^{-2} had significant effect among the different sowing techniques *viz*. Broadcasting (S_1) and line sowing (S_2) (Table.3).

Number of effective tillers m^{-2} was more in line sowing (85.60) than broadcasting (82.80). Number of effective tillers m^{-2} (89.17) was maximum at the seed rate of 100 kg ha^{-1}, but with the increase or decrease in seed rates it also gradually reduced. Interaction between the sowing techniques and seed rate had no significant effect on number of effective tillers m^{-2}. The maximum number of effective tillers m^{-2} (90.67) was recorded from the treatment S_2R_3 which was line sowing at the seed rate of 100 kg ha^{-1}. The lowest interaction effect (79.33) was observed from the treatment S_1R_1 which was broadcasting at the seed rate of 80 kg ha^{-1}.

Effective tillers i.e. tillers with fertile panicles are the important yield attribute, accounting around 64.5 % of the variation in rice grain yield (Walia *et al*., 2011). Number of effective tillers m^{-2} was more in line sowing than broadcasting. It may be due to the reason that seeds sown in line sowing had a specific distance than broadcasting and the competition between the plants were reduced. Also deep penetration of roots in line sowing results in efficient nutrient uptake and good plant growth.

Wider spacing or space allows the individuals plants to produce more tillers but it provides the smaller number of hills per unit area which results in low grain yield. Where in broadcasting seeds are often not properly buried in broadcast plots resulting in low germination and establishment counts. Broadcasting generally depresses seed germination and thereby affect crop establishment due to less root-soil contact to exploit the soil resources fully (Jana *et al*., 2016). Optimization of seed rate is the most important factor for the overall improvement of productivity of rice. Number of effective tillers m^{-2} was highest at the seed rate of 100 kg ha^{-1}, but with the increase or decrease in seed rates it also gradually reduced.

It may be due to restriction in space as the seed rate increased. Increasing seed rate would also increase the number of plants per unit area and results in additional unhealthy seedlings with less number of panicle due to competition and enhance the susceptibility to pests and diseases. These findings are supported by Baloch *et al.,* (2002); Jana *et al.,* (2016).

Panicle length (cm)

Panicle length (cm) differed significantly among the different sowing techniques. It was more in line sowing (26.93 cm) than broadcasting (25.80 cm). Panicle length was significantly different among different seed rates. It was highest at the seed rate of 100 kg ha^{-1} (27.67 cm) but with the increase or decrease in seed rates from 100 kg ha^{-1}, panicle length also gradually reduced. Interaction between the sowing techniques and seed rate had no significant effect on panicle length. The highest panicle length (28.33 cm) was recorded from the treatment S_2R_3 which was line sowing at the seed rate of 100 kg ha^{-1}. The lowest interaction effect (24.67 cm) was observed from the treatment S_1R_1which was broadcasting at the seed rate of 80 kg ha^{-1}.

It may be due to the reason that plants sown in line sowing had a specific distance than broadcasting and the competition between the plants were minimum and deep penetration of roots resulting in efficient nutrient uptake and good plant growth. Similar result was reported by Aslam *et al.,* (2008). It was highest at the seed rate of 100 kg ha^{-1}, but with the increase or decrease in seed rates it also gradually reduced. It may be due to restriction in space as the seed rate increased. Increasing seed rate would also increase the number of plants per unit area and results in additional unhealthy seedlings with small panicle length due to competition and enhance the susceptibility to pests and diseases. Similar result was reported by Harris and Vijayaragavan, (2015).

Number of spikelets panicle^{-1}

Number of spikelets panicle^{-1} had no significant effect among different sowing techniques. It was more in line sowing (143.00) than broadcasting (142.33). Number of spikelets panicle^{-1} had significant effect among different seed rates. It was more at the seed rate of 100 kg ha^{-1} (166.17) but with the increase or decrease in seed rates it also gradually reduced. Interaction between the sowing techniques and seed rate had no significant effect on number of spikelets panicle^{-1}. The maximum number of spikelets panicle^{-1} (167.00) was recorded from the treatment S_2R_3 which was line sowing at the seed rate of 100 kg ha^{-1}. The lowest interaction effect (140.00) was observed from the treatment S_1R_5 which was broadcasting at the seed rate of 120 kg ha^{-1}.

Maximum number of spikelets panicle^{-1} in line sowing may be due to the reason that plants sown in line sowing had a specific distance than broadcasting and the competition between the plants were minimum and deep penetration of roots resulting in efficient nutrient uptake and good plant growth. Similar result was reported by Mahmood *et al.,* (2013).

Maximum number of spikelets panicle^{-1} with seed rate @ 100 kg ha^{-1} suggests that marked reduction in number of spikelet panicle^{-1} occurs only beyond an optimum plant density, *i.e.* 100 kg ha^{-1} in this experiment. When seed rate is increased beyond an optimum point, it increases the leaf area and vegetative parts per unit area, thus increasing the respiration which in turn could lead to a reduction of number of grains. Similar result was reported by Harris and Vijayaragavan (2015).

Number of filled grains panicle^{-1}

Number of filled grains panicle^{-1} had no significant effect among different sowing techniques. It was more in line sowing (135.73) than broadcasting (134.33). Number of filled grains panicle^{-1} had significant effect among different seed rates. It was highest at the seed rate of 100 kg ha^{-1} (148.17) but with the increase or decrease in seed rates it also gradually reduced (Table.5). Interaction between the sowing techniques and seed rate had no significant effect on number of filled grains panicle^{-1}. The maximum number of filled grains panicle^{-1} (150.33) was recorded from the treatment S_2R_3which was line sowing at the seed rate of 100 kg ha^{-1}. The lowest interaction effect (124.67) was observed from the treatment S_1R_5 which was broadcasting at the seed rate of 120 kg ha^{-1}.

Maximum number of filled grains panicle^{-1} in line sowing may be due to the reason that plants sown in line sowing had a specific distance than broadcasting and the competition between the plants were minimum and deep penetration of roots resulting in efficient nutrient uptake and good plant growth. Conversely, lower light interception due to higher vegetative biomass and uneven space and aeration resulted in minimum number of filled grains per panicle in soaked seed broadcast. Similar result was reported by Aslam *et al.,* (2008); Mahmood *et al.,* (2013). It was also revealed that as seed rate increased, the number of filled grains panicle^{-1} remarkably reduced. When seed rate is increased beyond an optimum point, it increases the photosynthetic and vegetative parts per unit area, thus increasing the respiration which in turn could lead to a reduction of filled grains. High percentage of filled grains was obtained in lower plant density. This is in agreement with the findings of Baloch *et al.,* (2002) and Ehsanullah *et al.,* (2007).

This indicates that compared to panicle density, the effect of filled grains per panicle is the most important factor in contributing to yield which is positive in this study.

Test weight (g)

Sowing techniques had no significant effect on test weight. Test weight was little bit more in line sowing (29.50 g) than broadcasting (29.43 g). Seed rates had no significant effect on test weight. Test weight (29.83 g) was highest in optimum plant density that is at the seed rate of 100 kg ha^{-1}. Interaction between the sowing techniques and seed rate had no significant effect on test weight. The highest test weight (30.00 g) was recorded from the treatment S_2R_3 which was line sowing at the seed rate of 100 kg ha^{-1} and the lowest interaction effect (29.00 g) was observed from the treatment S_1R_5 which was broadcasting at the seed rate of 120 kg ha^{-1}.

Both the sowing techniques has at par value of test weight. This might be due to production of less number of tillers per unit area, which facilitated translocation of solutes throughout the grain developmental stages and eventually activated the florets to absorb nutrients to their fullest extent and develop heavy kernels in presoaked broadcasting technique (Baloch *et al*., 2007). This investigation also showed that increasing seed rate lesser and beyond 100 kg ha^{-1} recorded less test weight because more plant density will increase the mutual shading and respiration and results in the reduction of number of panicles $plant^{-1}$, grains $panicle^{-1}$, percentage of filled grains and uneven starch filling in the grains. Also rise in plant density increases the number of panicles per unit area did not compensate for the reduction in above yield parameters, thus resulting in a decrease in yield. Similar type of result was reported by Tahir *et al.,* (2007); Harris and Vijayaragavan (2015).

Effect of sowing techniques and seed rate on yield of direct seeded rice

Grain yield

Grain yield differed significantly among different sowing techniques. It was more in line sowing (5682.84 kg ha^{-1}) than broadcasting (5430.62 kg ha^{-1}) (Table.6). Grain yield had significant effect among different seed rates. It was recorded highest at the seed rate of 100 kg ha^{-1} which was 5868.00 kg ha^{-1} but with the increase or decrease in seed rates it also gradually decreased. Lowest grain yield (5284.72 kg ha^{-1}) was found in the treatment with seed rate of 120 kg ha^{-1}.

Interaction between the sowing techniques and seed rate had significant effect on grain yield. The highest grain yield (6030.11 kg ha^{-1}) was recorded from the treatment S_2R_3 which was line sowing at the seed rate of 100 kg ha^{-1}. The lowest interaction effect (5163.89 kg ha^{-1}) was observed from the treatment S_1R_5 which was broadcasting at the seed rate of 120 kg ha^{-1}.

Grain yield is a function of various growth and yield parameters like effective tillers, panicle length etc. It is the most effective parameter to compare different treatments. The higher paddy yield recorded in line sowing was attributed to the good crop conditions due to easier intercultural practices, better root growth and proliferation, opportunity to extract water and nutrients both from larger soil profile area, which in turn must have improved synthesis and translocation of metabolites to various reproductive structures of rice plant and better distribution of it into grain would always results in higher grain yield. Similar results were reported by Jana *et al.*, (2016). Optimum seed rate helps efficient utilization of natural resources (soil, light, water, air etc.) as the competition between the plants were minimum which resulted in higher number of tillers and panicles per unit area and spikelets per panicle compared to higher seed rate resulting in dense population. Similar results were reported by Aslam *et al.,* (2008); Javaid *et al.*, (2012).

Straw yield

Straw yield had no significant effect among different sowing techniques. It was more in line sowing (9802.27 kg ha^{-1}) than broadcasting (9619.20 kg ha^{-1}). Straw yield had no significant effect among different seed rates. Straw yield was highest (9926.00 kg ha^{-1}) at the seed rate of 100 kg ha^{-1} but with the increase or decrease in seed rates it also gradually decreased. Interaction between the sowing techniques and seed rate had no significant effect on straw yield.

The highest straw yield (9926.00kg ha^{-1}) was recorded from the treatment S_2R_3 which was line sowing at the seed rate of 100 kg ha^{-1}. The lowest interaction effect (9466.00 kg ha^{-1}) was observed from the treatment S_1R_1 which was broadcasting at the seed rate of 80 kg ha^{-1}.

In broadcasting, closer spacing hampers intercultural operations and increases competition among the rice plants for nutrients, air, light and water which results in weaker plants, reduced panicle weight and mutual shading thus favours more straw yield than grain yield. Optimum plant spacing ensures the plant to grow properly with their aerial and under-ground parts by utilizing more solar radiation and nutrients.

Higher leaf area were produced in lower population levels (wider spacing) which have the capacity to capture more sunlight because of less mutual shading effect among the leaves and less competition for nutrients in wider spacing. The result is coincided with the results of Faisul *et al.*, (2013); Jana *et al.*, (2016). Increase in straw yield can be ensured by maintaining appropriate plant population and the suitable plant density is an effective factor on yield increases. The plants at low seed rate have sufficient space and this enables to utilize more nutrients, water and solar radiation for better photosynthesis. Hence, the individual plants have better vegetative growth. This is in agreement with the studies reported by Baloch *et al.*, (2002).

Harvest index

Harvest index differed significantly among different sowing techniques. It was more in line sowing (36.69 %) than broadcasting (36.07 %). Harvest index differed significantly among different seed rates. It was highest (37.37 %) at the seed rate of 100 kg ha^{-1}, but with the increase or decrease in seed rates it also gradually decreased. The lowest harvest index was obtained at the seed rate of 120 kg ha^{-1} (35.08 %) (Table.7).

Interaction between the sowing techniques and seed rate had no significant effect on harvest index. The highest harvest index (37.79 %) was recorded from the treatment S_2R_3 which was line sowing at the seed rate of 100 kg ha^{-1}. The lowest interaction effect (34.82 %) was observed from the treatment S_1R_5 which was broadcasting at the seed rate of 120 kg ha^{-1}.

Table.1 Effect of sowing methods and seed rate on plant height (cm) of direct seeded rice

	30 days						**60 days**					
	R_1	**R_2**	**R_3**	**R_4**	**R_5**	**Mean**	**R_1**	**R_2**	**R_3**	**R_4**	**R_5**	**Mean**
S_1	35.5	35.5	35.7	35.7	35.8	35.6	86.3	87.3	87.6	88.0	88.3	87.5
S_2	35.5	35.5	35.7	35.8	35.8	35.7	87.3	87.6	87.6	88.3	89.0	88.0
Mean	35.5	35.5	35.7	35.7	35.8		86.8	87.5	87.6	88.2	88.6	
	S.Em (±)			**CD (P = 0.05)**			**S.Em (±)**			**CD (P = 0.05)**		
S	0.11			NS			0.13			0.40		
R	0.18			NS			0.21			0.63		
SXR	0.25			NS			0.30			NS		
	90 days						**At harvest**					
	R_1	**R_2**	**R_3**	**R_4**	**R_5**	**Mean**	**R_1**	**R_2**	**R_3**	**R_4**	**R_5**	**Mean**
S_1	110.6	110.8	111.6	111.8	112.7	111.5	111.0	111.2	111.7	111.9	112.7	111.7
S_2	111.1	111.7	112.2	112.8	112.9	112.2	111.2	111.8	112.4	112.9	113.1	112.3
Mean	110.8	111.3	111.9	112.3	112.8		111.1	111.5	112.1	112.4	112.9	
	S.Em (±)			**CD (P = 0.05)**			**S.Em (±)**			**CD (P = 0.05)**		
S	0.13			0.39			0.10			0.30		
R	0.21			0.61			0.16			0.47		
SXR	0.29			NS			0.22			NS		

Table.2 Effect of sowing methods and seed rate on plant population of direct seeded rice

	30 days						At harvest					
	R_1	R_2	R_3	R_4	R_5	Mean	R_1	R_2	R_3	R_4	R_5	Mean
S_1	39.00	43.33	48.00	52.00	54.00	47.27	37.00	41.67	46.00	50.00	53.00	45.53
S_2	39.67	43.67	48.33	52.67	55.33	47.93	38.67	42.67	47.33	51.33	54.33	46.87
Mean	39.33	43.50	48.17	52.33	54.67		37.83	42.17	46.67	50.67	53.67	
	S.Em (±)			CD (P = 0.05)			S.Em (±)			CD (P = 0.05)		
S	0.35			NS			0.27			0.81		
R	0.56			1.66			0.43			1.28		
SXR	0.79			NS			0.61			NS		

Table.3 Effect of sowing methods and seed rate on number of tillers m^{-2} of direct seeded rice

	30 days						60 days					
	R_1	R_2	R_3	R_4	R_5	Mean	R_1	R_2	R_3	R_4	R_5	Mean
S_1	34.67	35.00	35.33	35.67	36.00	35.33	77.33	82.33	88.67	91.67	93.67	86.73
S_2	35.00	36.00	35.67	36.00	36.33	35.80	79.33	84.33	91.00	93.33	94.00	88.40
Mean	34.83	35.50	35.50	35.83	36.17		78.33	83.33	89.83	92.50	93.83	
	S.Em (±)			CD (P = 0.05)			S.Em (±)			CD (P = 0.05)		
S	0.20			NS			0.55			1.64		
R	0.32			NS			0.87			2.59		
SXR	0.46			NS			1.23			NS		
	90 days						At harvest					
	R_1	R_2	R_3	R_4	R_5	Mean	R_1	R_2	R_3	R_4	R_5	Mean
S_1	81.00	85.67	89.67	92.00	93.67	88.40	80.00	85.67	89.67	92.00	93.67	88.20
S_2	84.00	87.67	91.33	94.33	94.67	90.40	83.00	86.00	91.67	93.67	94.67	89.80
Mean	82.50	86.67	90.50	93.17	94.17		81.50	85.83	90.67	92.83	94.17	
	S.Em (±)			CD (P = 0.05)			S.Em (±)			CD (P = 0.05)		
S	0.46			1.38			0.48			1.43		
R	0.73			2.18			0.76			2.25		
SXR	1.04			NS			1.07			NS		

Table.4 Effect of sowing methods and seed rate on number of effective tillers m^{-2} and panicle length of direct seeded rice

	Number of effective tillers m^{-2}						Panicle length (cm)					
	R_1	R_2	R_3	R_4	R_5	Mean	R_1	R_2	R_3	R_4	R_5	Mean
S_1	79.33	82.33	87.67	83.00	81.67	82.80	24.6	25.3	27.0	26.6	25.3	25.8
S_2	80.33	83.67	90.67	87.67	85.67	85.60	26.3	26.6	28.3	27.3	26.0	26.9
Mean	79.83	83.00	89.17	85.33	83.67		25.5	26.0	27.6	27.0	25.6	
	S.Em (±)			CD (P = 0.05)			S.Em (±)			CD (P = 0.05)		
S	0.45			1.34			0.26			0.78		
R	0.71			2.12			0.41			1.23		
SXR	1.01			NS			0.58			NS		

Table.5 Effect of sowing methods and seed rate on number of spikelets panicle^{-1} and filled grains panicle^{-1} of direct seeded rice

	Number of spikelets panicle^{-1}						Filled grains panicle^{-1}					
	R_1	R_2	R_3	R_4	R_5	Mean	R_1	R_2	R_3	R_4	R_5	Mean
S_1	142.3	151.6	165.3	141.0	140.0	142.3	126.6	137.3	146.0	137.0	124.6	134.3
S_2	143.0	155.3	167.0	142.6	142.3	143.0	127.6	138.0	150.3	137.6	125.0	135.7
Mean	142.6	153.5	166.2	141.8	141.2	142.6	127.2	137.6	148.2	137.3	124.8	
	S.Em (±)			CD (P = 0.05)			S.Em (±)			CD (P = 0.05)		
S	0.76			NS			1.05			NS		
R	1.21			3.59			1.66			4.94		
SXR	1.71			NS			2.35			NS		

Table.6 Effect of sowing methods and seed rate on grain yield and straw yield of rice of direct seeded rice

	Grain yield (kg ha^{-1})						Straw yield (kg ha^{-1})					
	R_1	R_2	R_3	R_4	R_5	Mean	R_1	R_2	R_3	R_4	R_5	Mean
S_1	5208	5639	5706	5436	5164	5208	9466	9597	9733	9633	9667	9619
S_2	5578	5706	6030	5695	5406	5578	9633	9700	9926	9863	9889	9802
Mean	5393	5673	5868	5565	5285		9550	9648	9830	9748	9778	
	S.Em (±)			CD (P = 0.05)			S.Em (±)			CD (P = 0.05)		
S	20.75			61.62			52.29			NS		
R	32.81			97.43			82.67			NS		
SXR	46.39			137.78			116.92			NS		

Table.7 Effect of sowing methods and seed rate on test weight and harvest index of rice of direct seeded rice

	Test weight (g)						Harvest index (%)					
	R_1	R_2	R_3	R_4	R_5	Mean	R_1	R_2	R_3	R_4	R_5	Mean
S_1	29.33	29.67	29.67	29.33	29.00	29.40	35.51	37.01	36.96	36.08	34.82	36.07
S_2	29.33	29.33	30.00	29.67	29.33	29.53	36.67	37.04	37.79	36.60	35.34	36.69
Mean	29.33	29.50	29.83	29.50	29.17		36.09	37.02	37.37	36.34	35.08	
	S.Em (±)			CD (P = 0.05)			S.Em (±)			CD (P = 0.05)		
S	0.13			NS			0.17			0.49		
R	0.21			NS			0.26			0.78		
SXR	0.30			NS			0.78			NS		

One of the ways to increase the yield is to increase harvest index. Sink formation and ripening are the two physiological processes that explain the improvement in harvest index. Higher harvest index due to satisfying the basic requirement of nutrient which is highly related in higher economic return to the crop as well as more translocation of photosynthates from source to sink. Similar result was reported by Mahmood *et al.*, (2013).

From the above study, it can be concluded that line sowing is more ecologically and economically sustainable as it ensures better germination, reduces seed requirement and facilitates intercultural operation, increases grain yield as compared to broadcasting method of sowing. Also standardisation of seed rate (100 kg ha^{-1}) helps in lowering cultivation cost and gaining optimum yield.

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