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Yield Component Compensation as Affected by Seeding Rates in Dry Direct Seeded Rice

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Sustainability of the transplanted and flooded rice system is threatened by water and labor availability in many Asian countries including the Philippines. Dry direct seeding instead of transplanting is evolving as a viable crop establishment option to deal with labor and water shortages. Two experiments from July 2020 to June 2021 were conducted to determine the effect of different seeding rates [20 kg ha^{-1} (SR20), 40 kg ha^{-1} (SR40), 60 kg ha^{-1} (SR60), and 120 kg ha^{-1} (SR120)] on the growth, grain yield, and yield components of 2 rice varieties that were established through direct seeding in dry tilled soil and subsequently grown under flooded conditions. Seeding rates of SR40, SR60, and SR120 produced comparable and not significantly different grain yields. However, these seeding rates produced significantly higher grain yields than SR20 (20 kg ha^{-1}). The lower grain yield in SR20 was due to lower panicle density which caused a reduction in sink size. Strong compensation between the number of panicles and the number of grains per panicle was observed in different seeding rates in both varieties. Plants grown at the high seeding rate (120 kg ha^{-1}) had a higher number of panicles but with lower filled grains per panicle. On the other hand, plants grown at the low seeding rate (20 kg ha^{-1}) had more filled grains per panicle with a lower number of panicles per m^2. Yield component compensation to maintain desirable sink size was effective at 40 and 60 kg ha^{-1} seeding rates, although not enough at 20 kg ha^{-1}. Moreover, a longer duration of tiller production was observed at the low seeding rate (SR20) which resulted in a higher number of late emergent tillers with poor grain production. The seed rate of 120 kg ha^{-1} in this study did not result in yield reduction due to an excessive number of tillers that eventually reduced the number of grains per panicle as observed in other studies. Compensation was between panicle number and grain number per panicle. SR40 and SR60 had similar yield levels with SR120 due to compensation among yield components, these seeding rates would be more attractive to farmers due to lower seed costs.

Keywords: dry direct seeding, crop establishment, yield components, compensation effect, sink size

Abbreviations: DAS—days after seeding, Fl—days to flowering, GY—grain yield, HI—harvest index, Mat—days to maturity, PAR—photosynthetically active radiation, PI—panicle initiation, T_{max}—average maximum temperature, T_{min}—average minimum temperature

INTRODUCTION

Rice is the major staple crop in the Philippines. Irrigated rice accounts for 70% of the total area planted for rice (PSA 2021), and transplanting is the main method of crop establishment which requires puddled land preparation. Direct seeding instead of transplanting is one of the innovative solutions to increase efficiency in irrigated rice systems and is a viable alternative establishment method to deal with labor and water shortages (Xu et al. 2019). Under direct seeding, the use of water, labor, and seeds is maximized during crop establishment. Land preparation is done when the soil moisture status is at field capacity. In contrast, a huge volume of water is needed for puddled land preparation, accounting for 25% to 37% of the rice's seasonal water input in clay soil (Cabangon et al. 2004; Bouman, Humphreys et al. 2007). This high volume of water is used to saturate and soak the field for at least 1 wk with ponded water of about 5 – 10 cm water depth before soil tillage. Both puddling and transplanting require a lot of water and even labor to manage crop establishment operations. In the 1980s, rice farmers were pushed to switch from the traditional transplanting to wet direct seeding by broadcasting seeds into puddled soil because of the high labor cost associated with crop establishment. De Datta (1986) reported that at least 30% of the irrigated rice area in the dry season shifted to seed broadcasting into puddled soil. There was a rapid change from transplanting to broadcasting in Central Luzon and even in certain areas in Bicol (Moody and Cordova 1985). A dramatic shift was reported in Nueva Ecija—from 10% of broadcasting in 1979 to 27% in 1986 of farmers practicing transplanting and 100% of farmers with combination practices (transplanting and broadcasting) shifting to broadcasting into puddled soil (Erguiza et al. 1990). The shortage of labor supply required during transplanting served as the driving switch from transplanting to wet broadcasting. This shift was also observed not only in the Philippines in the 1980s but also in the neighboring rice-growing countries like Thailand (De Datta and Nantasomsaran 1991). At the start of the 21st century, direct-seeded rice occupied 12% of the total rice planted in Asia (Pandey and Velasco 2002).

Seed broadcasting into puddled soil, however, would still utilize a high volume of water during land preparation similar to the requirement of the puddled-transplanting method. While the availability of water supply was not a major concern in the 1980s, water shortage for agricultural use in the late 1990s threatened the traditional way of puddled land preparation. Water-saving technologies were developed like the aerobic rice culture (Bouman, Lampayan et al. 2007) where dry direct seeding was used as an establishment method to address both labor and water issues. The common impression for dry direct seeding is that it is a version of upland rice or aerobic cultivation through alternate wetting and drying under rainfed ecosystems. On the contrary, dry direct seeding can be an option for rice establishment methods in irrigated areas to save water during the land preparation phase. The rest of the growing season will be flooded to control weeds. The biggest challenge in upland and aerobic rice culture is the potential biotic threat caused by weeds which is controlled by flooding during the rest of the growing season.

Reported studies on the effect of plant density were mostly established in the traditional transplanting and flooded cultures. Plant density is known to affect crop performance because of plant competition to access resources needed for growth and development. High plant densities in rice cause a decrease in the rate of leaf appearance (Clerget et al. 2016) and cause the phyllochron to be extended under temperate environments (Martinez-Eixarch et al. 2013). When plant densities of 5 – 100 plants m^{-2} were used, a higher grain yield was noted in favor of a greater number of plants per area (Hayashi et al. 2006; San-Oh et al. 2008; Nakano et al. 2012). In addition, Lampayan et al. (2019) reported that transplanted seedlings of 25 – 75 m^{-2} densities produced similar grain yields in flooded fields.

Seeding rates in DSR are highly variable. High seed rates under dry direct seeding were more advantageous to use than lower seed rates because of earlier canopy closure, thereby controlling weeds in fields where the soil moisture status during the whole growing season was not continuously flooded (Mahajan and Chauhan 2016). Studies on seeding rates using dry direct seeding in dry tilled soil that is flooded during the remaining time of the season are lacking in the Philippines. It is therefore relevant to conduct studies on this subject in response to the continuing concerns on the scarcity of inputs like water and labor for sustained rice production in the country. Thus, this study was conducted to determine the effect of seeding rates on the growth, grain yield, and yield components of 2 rice varieties established through direct seeding in dry tilled soil and subsequently grown under flooded conditions.

MATERIALS AND METHODS

Site Description

Two experiments were conducted at the research farm of the International Rice Research Institute (IRRI), adjacent to the University of the Philippines, Los Baños, Laguna, Philippines (14°11′N, 121°15′E, 21 m above mean sea level) from July 2020 to June 2021. The topsoil has a clay loam texture with 3.54 g soil organic matter kg^{-1}, 0.15 g total N kg^{-1}; with pH ($CaCl_2$) of 6.4, cation exchange capacity (CEC) of 31.77 meq $100g^{-1}$, and particle size distribution of 38% clay, 41% silt, and 21% sand.

Experimental Design and Crop Management

The experiments were laid out using a split-plot randomized block design with 4 replications. The main plot was variety: NSIC Rc222, commonly used by farmers because of its high-yielding ability with good adaptations to both irrigated and rainfed environment; and NSIC Rc420, an irrigated lowland variety tolerant to drought and resistant to sheath blight. Four different seeding rates were tested: 20 kg ha^{-1} (SR20), 40 kg ha^{-1} (SR40), 60 kg ha^{-1} (SR60), and 120 kg ha^{-1} (SR120). The size of each experimental plot was 20 m^2.

For both experiments, the dry land preparation method (plowing, harrowing) was used to prepare the experimental field. Seeds corresponding to the different seeding rates were manually drilled along the rows spaced 20 cm apart. The area was irrigated after seeding to wet the soil evenly for germination and seedling emergence. Soil moisture was maintained at saturation to field capacity for 2 wk in all plots, then submerged in 3 – 5 cm of water until 2 wk before harvest.

A total of 120 kg N ha^{-1} was applied in 3 splits during 2020 late wet season (WS) specifically: 40 kg N ha^{-1} a week after seedling emergence, 40 kg at tillering, and 40 kg at panicle initiation using complete (14-14-14) and Urea (46-0-0) fertilizers. Phosphorus (40 kg P_2O_5 ha^{-1}) and potassium (40 kg K_2O ha^{-1}) were applied a week after seedling emergence in all plots. In the 2021 early WS, 60 kg N, 60 kg P_2O_5, and 60 kg K_2O ha^{-1} using complete fertilizer were applied 1 wk after seedling emergence, and 2 splits of 40 kg N ha^{-1} were applied at tillering and panicle initiation stages in all the plots.

Weeds were controlled by the application of pre-emergence herbicide at 5 d after seeding (DAS), followed by post-emergence herbicide, and spot weeding to control weeds. Insect pests were controlled using insecticides to avoid plant damage when required.

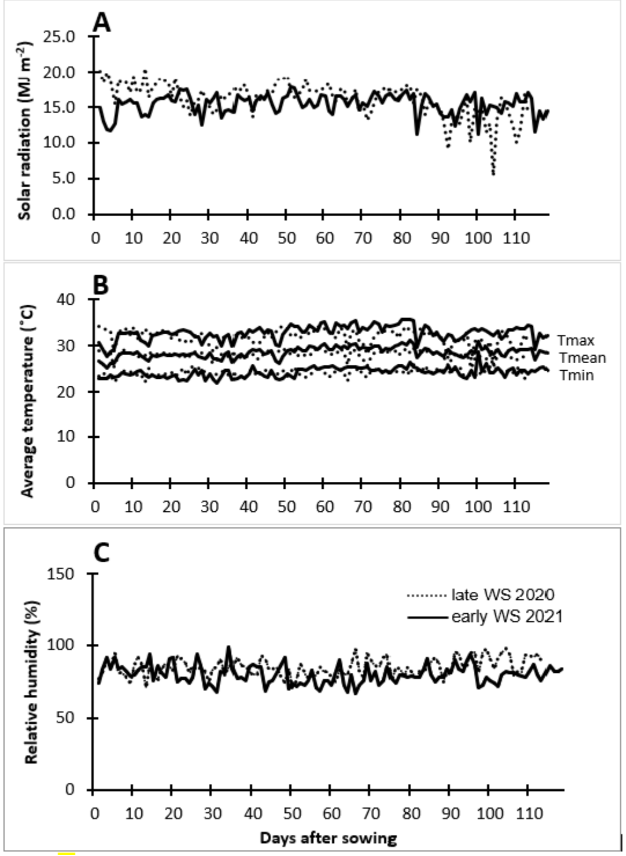

Fig. 1s. Average daily solar radiation (A), average daily temperature (B), and average relative humidity (C) during the late WS 2020 and early WS 2021.

Measurements

Weather data (minimum temperature, maximum temperature, solar radiation, and relative humidity) were collected from the National Agromet Station (NAS) of the University of the Philippines Los Baños. The climatic description during the conduct of the experimental trials was presented in Table 1 and Fig. 1s. The average minimum temperature (T_{min}) on the different phenological phases was almost similar in both late WS 2020 and early WS 2021 trials. The average maximum temperature (T_{max}) was slightly higher during the reproductive and ripening phases in early WS 2021. Average daily radiation was slightly higher during the vegetative and reproductive stages with 17.1 MJ m^{-2} and 16.7 MJ m^{-2}, respectively in late WS 2020 than during the ripening phase with 13.7 MJ m^{-2}. In 2021, average daily radiation was almost similar among the different growth phases. Radiation conditions of both late WS 2020 and early WS 2021 trials were considered as representative of the actual growing environments of the site, wherein the total cumulative solar radiation was 1705 MJ m^{-2} and 1702 MJ m^{-2}, respectively. The average daily relative humidity (RH) was high, indicating that vapor pressure deficit (VPD) was appreciably low.

Panicle initiation was determined by visually observing the appearance of the white feathery cone stage dissected from the sampled main tillers. Flowering was determined in each plot when 50% of the spikelets per panicle of the main tiller from 50% of the observed plants had exerted their anthers. The crop maturity was determined when 90% to 95% of the spikelets of the whole plot had turned from green to yellow color.

Seedling emergence was determined by counting seedlings from a randomly selected 1 m row (equivalent

Table 1. Duration of the different growth phases, minimum and maximum temperature, average daily radiation, cumulative radiation, and relative humidity (RH) during the vegetative, reproductive, and ripening phases.

Year	Months	Growth Phases	No. of Days	Ave T_{min}	Ave T_{max}	Ave Daily Radiation (mJ m^{-2})	Cumulative Solar Radiation (mJ m^{-2})	Ave Daily RH (%)
2020	July-Aug	Vegetative	50	24	32	17.1	773	83
Late WS	Sept	Reproductive	30	24	31	16.7	502	81
	Oct	Ripening	31	24	30	13.5	430	86
2021	Mar-Apr	Vegetative	51	24	32	15.4	721	81
Early WS	May	Reproductive	32	25	34	16.0	496	78
	June	Ripening	31	25	33	15.0	485	81

to 0.2 m^2) 14 DAS. Shoot biomass and tiller number were collected during tillering, panicle initiation, flowering, and physiological maturity from 2 representatives of 0.5 m rows (0.2 m^2) in each plot in both experiments. At physiological maturity, plant samples were collected from 2 representatives of 0.5 m rows (0.2 m^2) in each plot. The collected panicles were counted and detached from the stem and threshed by hand; filled and unfilled (empty) grains were separated by flotation in tap water; and the number of filled grains was counted. The total weight of filled and unfilled grains and the weight of 1000 filled and unfilled grains were measured after oven-drying at 72°C for 72 h. The number of filled and unfilled grains was estimated through the ratio of the total weight to the 1000-grain weight while the fertility rate was computed as the ratio of filled grains to the total number of grains. Harvest index (HI) was computed as filled grain dry matter divided by shoot dry matter. Sink size was calculated as the product of panicle number and number of grains per panicle. Grain yield (GY) was determined by harvesting a 5 m^2 (10 rows × 2.5 m) sampling area in the center of each plot calculated at 14% moisture content.

Data Analysis

Analysis of variance (ANOVA) was done by using the general linear model in STAR v. 2.0.1 software (http://bbi.irri.org), implemented in the R software package. Mean separation tests were performed using Fisher's least-significant-difference test (LSD).

RESULTS

Climate and Phenological Stages

Phenological information on the number of days to panicle initiation (PI), number of days to flowering (Fl), and number of days to maturity (Mat) of the two varieties did not change with the experimental seasons as presented in Table 2. The number of days to reach panicle initiation was 50 and 51 after emergence for late 2020 WS and early WS 2021, while it took 80 and 83 d to reach 50% Fl, respectively. The Mat was 111 d in late WS 2020 and 113 d in early WS 2021.

Table 2. Phenological information (number of days to panicle initiation (PI), flowering, and maturity) of NSIC RC 222 and NSIC RC420 in the late WS 2020 and early WS 2021.

Year	Variety	Number of Days		
		PI	Flowering	Maturity
2020	NSIC Rc222	52	83	113
Late WS	NSIC Rc420	47	77	108
	Average	50	80	111
2021	NSIC Rc222	53	85	116
Early WS	NSIC Rc420	49	80	113
	Average	51	83	114

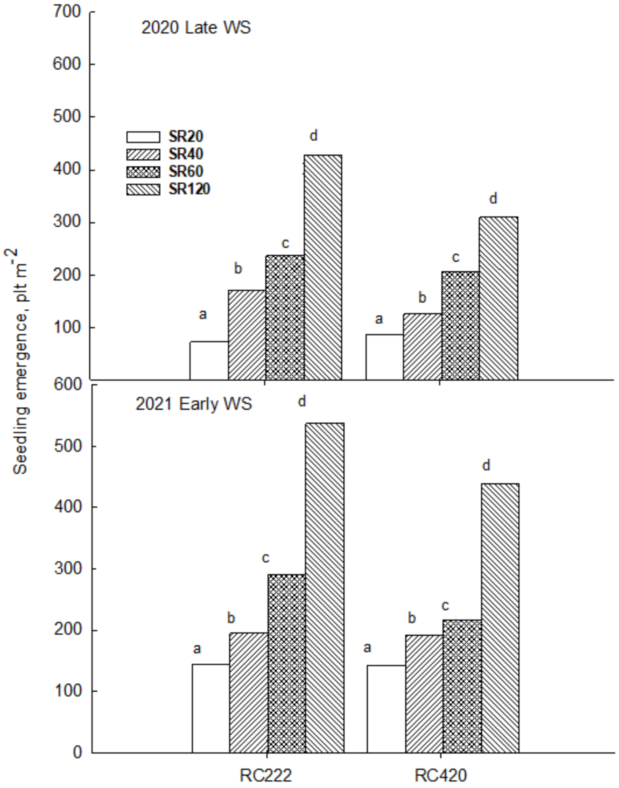

Fig. 1. Number of seedlings as affected by seeding rates of NSIC RC 222 (RC 222) and NSIC RC 420 (RC 420) during the late WS 2020 and early WS 2021.

Seedling Emergence, Tillering and Biomass

The number of emerged seedlings was significantly affected by seeding rates in both late WS and early WS trials (Fig. 1). The number of emerged seedlings significantly increased with higher seeding rates. The number of seedlings per m^2 was highest in SR120 during the late WS 2020 and early WS 2021 in both varieties, with values ranging from 310 to 537 plants m^{-2}. This was followed by SR60 with 207 – 290 plants m^{-2} and SR40 from 127 to 195 plants m^{-2}. SR20 had the lowest emergence ranging 73 to 145 plants m^{-2} (Fig. 2). The greater number of plants in higher seeding rates resulted in more tillers.

Maximum tillering stage was observed earlier in higher seeding rates and more pronounced with NSIC Rc420 (Fig. 2). Moreover, the tiller production of NSIC Rc222 was higher. The maximum number of tillers of NSIC Rc222 was 1020 and 1067 m^{-2} in SR120 followed closely by SR60 of 1042 and 912 tillers m^{-2} in late WS 2020 and early WS 2021, respectively. The maximum number of tillers of SR40 NSIC Rc222 was 807 and 828 m^{-2} in late WS 2020 and early WS 2021, respectively. The lowest number of tillers at the maximum tillering stage was in SR20 with values of 700 and 791 m^{-2} for NSIC Rc222 in late 2020 WS and early 2021 WS, respectively. The maximum

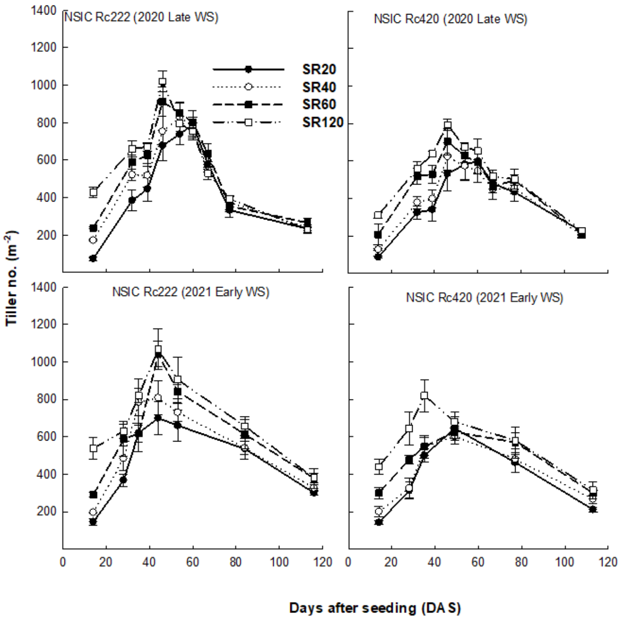

Fig. 2. Tiller number per m^2 with days after seeding as affected by seeding rates of NSIC RC222 and NSIC RC420 during the late WS 2020 and early WS 2021.

number of tillers of NSIC Rc420 was lower than NSIC Rc222. However, a similar tillering trend such as in NSIC Rc222 was noted in NSIC Rc420 on the effect of seed rates. SR120 had the highest number of maximum tillers of 680 and 793 tillers m^{-2} in contrast to SR20 with only 645 and 598 tillers m^{-2} in late WS 2020 and early WS 2021, respectively. After the maximum tillering stage, however, the number of tillers in both varieties did not differ significantly until maturity across seeding rates (Fig. 2).

The dynamics of biomass accumulation during the growing season were presented in Fig. 3. Total biomass increased with seeding rate in both varieties, in the following sequence: SR120 > SR60 > SR40 > SR20. The difference in biomass was more noticeable during the reproductive and maturity phases which was apparent in both NSIC Rc222 and NSIC Rc420.

Yield Components and Grain Yield

The effect of seeding rates on grain yield was presented in Table 3. In late WS 2020, grain yield was not significantly different among SR120 (5.35 t ha^{-1}), SR60 (5.25 t ha^{-1}), and SR40 (4.85 t ha^{-1}), although these seeding rates (40 - 120 kg ha^{-1}) had significantly higher grain yield than the seeding rate at 20 kg ha^{-1} [SR20 (3.99 t ha^{-1})]. In early WS 2021, grain yield did not differ among SR120 (5.71 t ha^{-1}), SR60 (5.23 t ha^{-1}) and SR40 (4.79 t ha^{-1}). However, the grain yield of SR20 (4.31 t ha^{-1}) was significantly lower than SR120 and SR60 but did not differ from SR40. Higher seeding rates resulted in higher biomass especially in early WS 2021, wherein SR120 and SR60 > SR40 > SR20. No significant effect of seeding rates on HI was observed in both late WS 2020 and early WS 2021 with values ranging from 0.39 to 0.42 in 2020 and from 0.36 to 0.38 in 2021. The number of panicle m^{-2} was highest with SR120 followed by SR60 and SR40, and lowest in SR20 in 2020. In 2021, no significant difference in the number of panicle m^{-2} was observed between SR120 and SR60, but these two seeding rates were higher than SR40. Moreover, SR20 had a significantly lower number of panicles compared to SR40. In contrast, the number of filled grains per panicle was lowest in SR120 in both the 2020 and 2021 trials, indicating a high compensatory mechanism between the number of panicles and the number of grains per panicle. Grain size or 1000 filled grain weight and fertility rate appeared to be unaffected by seeding rates.

Comparison between varieties showed that NSIC Rc222 had a significantly higher yield than NSIC Rc420, with 5.07 t ha^{-1} and 4.76 t ha^{-1} yields in 2020 and 5.09 t ha^{-1} and 4.72 t ha^{-1} in 2021, respectively (Table 3). No interaction between seeding rates and varieties was observed in both 2020 and 2021 trials on grain yield and yield components. Varietal response to seeding rates were consistent within 2020 and 2021 trials. Biomass and HI did not differ between varieties (Table 3). The number of panicles per m^2 was not significantly different between NSIC Rc222 (299) and NSIC Rc420 (304) in 2020 trial, but significantly higher in NSIC Rc222 (383) compared to NSIC Rc420 (318 m^{-2}) in 2021 trial (Table 3). Filled grain number per panicle was 79 in NSIC Rc222 which was

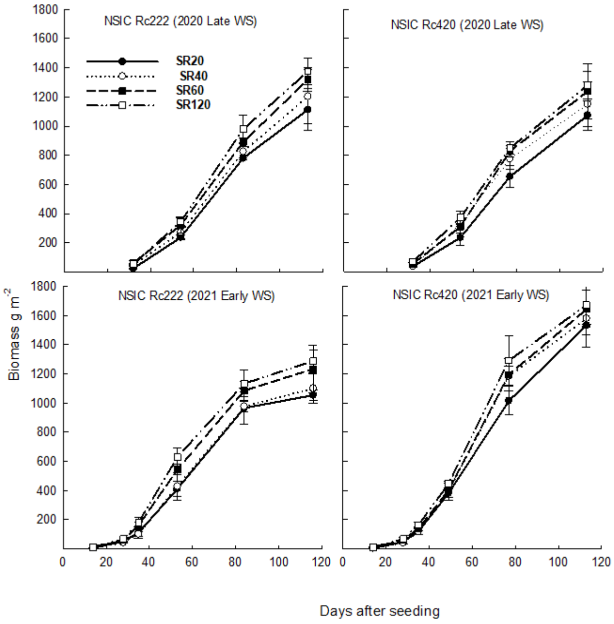

Fig. 3. Biomass with days after seeding as affected by seeding rates of NSIC RC 222 and NSIC RC 420 during the late WS 2020 and early WS 2021.

Table 3. Grain yield and yield components per factors from late WS 2020 and early WS 2021.

Year	Variety	Grain Yield (t ha-1)	Biomass at PM	Harvest Index	No. of Panicle (m^2)	Sink Size	No. of Filled Grain (pan^{-1})	1000FigrWt (g)	Fert Rate (%)
2020	Rc222	5.07^{a}	12.16^{a}	0.42^{a}	299^{a}	23733^{a}	79^{a}	21.36^{b}	67^{a}
Late WS	Rc420	4.76^{b}	12.04^{a}	0.39^{a}	304^{a}	20297^{b}	67^{b}	23.58^{a}	69^{a}
	Seed Rates								
	SR20	3.99^{b}	9.76^{c}	0.41^{a}	232^{c}	17931^{b}	77^{ab}	22.19^{a}	69^{a}
	SR40	4.85^{a}	11.88^{b}	0.41^{a}	309^{b}	22162^{a}	72^{bc}	22.06^{a}	67^{a}
	SR60	5.25^{a}	12.53^{ab}	0.42^{a}	284^{b}	23222^{a}	82^{a}	22.70^{a}	68^{a}
	SR120	5.35^{a}	13.71^{a}	0.39^{a}	377^{a}	23955^{a}	64^{c}	22.51^{a}	65^{a}
2021	Rc222	5.09^{a}	13.32^{a}	0.38^{a}	383^{a}	21681^{a}	57^{a}	23.46^{b}	55^{b}
Early WS	Rc420	4.72^{b}	13.07^{a}	0.35^{a}	318^{b}	19052^{b}	60^{a}	24.84^{a}	65^{a}
	Seed Rates								
	SR20	4.31^{b}	11.55^{c}	0.36^{a}	274^{c}	18014^{b}	66^{a}	24.00^{a}	59^{a}
	SR40	4.79^{ab}	12.70^{b}	0.38^{a}	334^{b}	19791^{a}	59^{b}	24.09^{a}	61^{a}
	SR60	5.23^{a}	14.12^{a}	0.37^{a}	380^{a}	21653^{a}	57^{b}	24.20^{a}	60^{a}
	SR120	5.17^{a}	14.10^{a}	0.36^{a}	399^{a}	21326^{a}	53^{b}	24.21^{a}	61^{a}

Means followed by same letter within seeding rate and within variety per year were not significantly.

significantly higher than NSIC Rc420 (67), but not observed in the 2021 trial. Sink size (product of the number of panicles per m^2 and number of filled grains per panicle) was significantly higher in NSIC Rc222. Grain size, measured as the 1000 filled grain weight, was significantly higher in NSIC Rc420 compared to NSIC Rc222. The fertility rate was higher in NSIC Rc420, although a significant difference was observed only in the 2021 trial. The higher grain yield in NSIC Rc222 was due to the higher sink size formed during the reproductive phase.

The relationship between grain yield and tiller number at different crop stages was presented in Fig. 4. Significant and higher *r* values were observed during the tillering phase (0.70 and 0.83) in contrast to a weaker correlation at panicle initiation (0.60) and an insignificant correlation at the flowering stage. Regression analysis revealed that the coefficient of determination (R^2) presented in Fig. 5 showed that the tiller number during maximum tillering can explain 82% of the sink size.

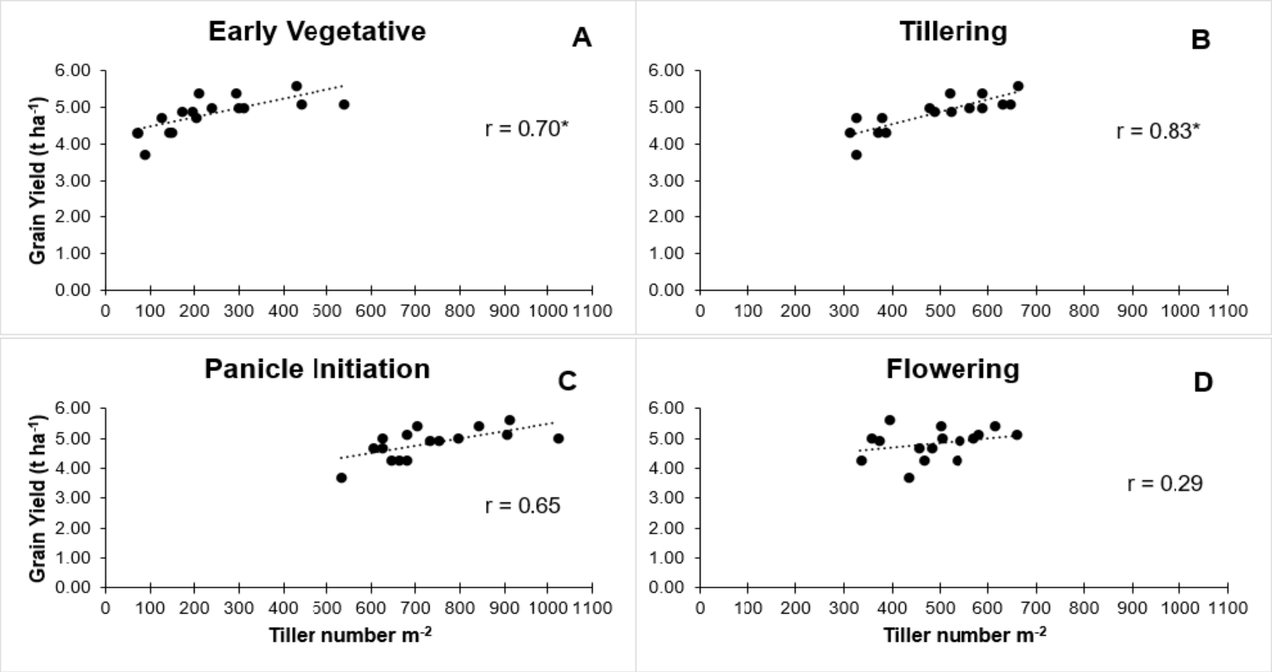

Fig. 4. Relationship between tiller number and grain yield at early vegetative (A), tillering (B), panicle initiation (C), and flowering (D) at different seeding rates of NSIC RC 222 and NSIC RC 420.

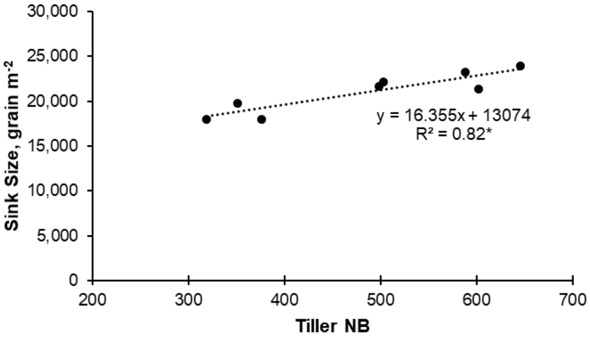

Fig. 5. Relationship of Tiller number during tillering stage and sink size.

DISCUSSION

Seeding at the rates of 40, 60, and 120 kg ha^{-1} (SR40, SR60, and SR120) produced comparable and not significantly different grain yields. However, these seeding rates produced grain yield that was significantly higher than the yield of 20 kg ha^{-1} (SR20) seeding rate. The lower yield in SR20 is attributed to the lower panicle density, hence the lower sink size. Strong compensation effect between number of panicles and number of grains per panicle was observed at the different seeding rates (40 – 120 kg ha^{-1}) in both varieties. Plants grown at high seeding rate (40 – 120 kg ha^{-1}) had a higher number of panicles but had a lower number of filled grains per panicle. Plants grown at the low seeding rate (20 kg ha^{-1}) had more filled grains per panicle but had a lower number of panicles. Yield component compensation was effective in maintaining the sink size, particularly in SR60 and SR40; however, it did not work when the seeding rate was too low (SR20). Due to the high compensatory mechanism between the number of panicles and the number of grains per panicle, seeding rates of 40 and 60 kg ha^{-1} produced sink sizes that were comparable to the 120 kg ha^{-1} seeding rate. Thus, grain yields in these seeding rates (40 and 60 kg ha^{-1}) did not differ significantly from the seeding rate at 120 kg ha^{-1}.

Another reason for the lower yield at the lower seeding rate (20 kg ha^{-1}) was the longer duration of tiller production that resulted in a higher number of late emergent tillers with implications of poor grain production or of becoming unproductive tillers. Mohapatra and Kariali (2008) reported that late emergent tillers have a short growth duration that results in poor grain production. In addition, Wang et al. (2016) noted that there is an unequal distribution of photosynthetically active radiation (PAR) in favor of the early emergent tillers that blocked the uppermost light source and shaded the late emerging tillers. Tillering capacity in rice is greatly influenced by planting distance (Clerget et al. 2016) or seeding rates (Gravois and Helms 1996). Similar to this study, lower grain yield of low seed rates was also reported by Gravois and Helms (1996) due to lesser crop stands with higher secondary and tertiary tillers compared to a higher seeding rate. The higher seeding rate in this study—120 kg ha^{-1}—had more vigorous tillers, mostly main and primary tillers, in contrast to the 20 kg ha^{-1} seed rate that had more late emergent tillers. A wide tillering window will result in heterogenous tiller ranks with variable leaf numbers and asynchronous grain filling duration. Late emergent tillers become either less productive or unproductive at maturity (Mohapatra and Kariali (2008). Primary tillers produce better grains compared to late emergent tillers (Vergara et al. 1990). Late emergent tillers produced a lesser number of spikelets per panicle and a lower grain filling rate (Wang et al. 2017). The reason for this is the smaller number of vascular bundles in the late emergent tillers (Kim and Vergara 1991) that could limit the supply of assimilates and hormones from the leaves to the panicles, which will then limit the growth and development of the spikelets. Optimal tillering allows simultaneous flowering, maturity, and uniform panicle size (Kush 2000). All of this is made possible by proper seeding rates, which are very important for high grain yields.

During the vegetative phase, the number of tillers per m^2 has the greatest influence among the different plant traits on grain yield. This has also been reported in previous studies wherein tiller number has a positive association with plant biomass and grain yield (Deng et al. 2015; Clerget et al. 2016). Moreover, leaf area during the vegetative phase is highly dependent on the number of tillers and blade growth rate is influential to biomass accumulation, contributing to higher yield (Lafarge and Bueno 2009). Maximum number of tillers was achieved earlier with 120 kg ha^{-1} which was more pronounced in NSIC Rc420. NSIC Rc222 has a higher tillering capacity and longer tiller production; hence, tiller cessation was observed later. Correlation coefficients revealed that grain yield was significantly associated with the number of tillers per m^2 during the vegetative phase, and this association was not observed at the later part of the growing season. Regression analysis showed that 82% of the sink size was attributed to tillering characteristics (Fig. 5). This relationship between sink size and number of tillers per m^2 is a strong indicator of the performance of the crop at different seeding rates, affecting sink size (as a function of tillering) during the vegetative phase, which was also reported by Bueno and Lafarge (2017). To some extent, the yield potential of a rice cultivar may be characterized by tillering capacity. It can even show that this tillering trait may serve as a major indicator of yield potential even at an early growth stage, which could be relevant to rice breeders. The number of tillers per hill determines the number of panicles, which is a key component of grain yield (Yoshida 1981). However, rice plants producing more tillers in a wide tillering window can show a greater inconsistency in mobilizing assimilates and nutrients among tillers, resulting in variations in grain development and yield among different types of tillers (Yoshida 1981).

Other studies reported that high seeding rates can result in yield losses due to an excessive number of tillers, which eventually reduces grain number per panicle (Kabir et al. 2008). However, the highest seeding rate used in this study (120 kg ha^{-1}) did not exhibit this condition and did not show further negative effects on yield due to excessive tillers, which could promote increased proportion of ineffective tillers and the creation of favorable conditions for diseases, which was observed in other studies (Kabir et al. 2008). Seeding rate at 120 kg ha^{-1} can still be used within the conditions of the study, except that lower seeding rates of 60 kg and 40 kg ha^{-1} which resulted in similar grain yield due to compensatory effect among yield components would be more attractive to farmers in consideration to seed cost.

CONCLUSION

There was a significant effect of seeding rates on the growth, grain yield, and yield components from the 2 conducted trials in late 2020 wet season and early 2021 wet season. A significantly lower grain yield was observed in the seeding rate at 20 kg ha^{-1} in comparison to the yields of 40, 60, and 120 kg ha^{-1} that ranged from 4.79 to 5.35 t ha^{-1}. The main reason for the lower yield in the seeding rate at 20 kg ha^{-1} was the lower panicle density which reduced sink size. A strong compensation between the number of panicles per m^2 and the number of grains per panicle was observed in different seeding rates in both varieties. This compensatory effect of yield components on maintaining good grain yield was effective in the 40 and 60 kg ha^{-1} seeding rates, producing grain yields that did not differ from the seeding rate at 120 kg ha^{-1}. However, the compensatory effect was not enough when the seeding rate was very low (20 kg ha^{-1}) due to a significant reduction in sink size. Another reason is the long duration of the tillering period at the seeding rate of 20 kg ha^{-1}, producing more late emergent tillers which are inferior in producing grains due to the shorter growth duration, a lesser amount of photosynthetically active radiation received, and a smaller number of vascular bundles, all of which could contribute to the lower grain production or even to the higher number of unproductive tillers. Tillering characteristics appeared to be the primary driver for the sink size, regulating the leaf area production at the vegetative stage, the number of panicles during the reproductive phase, and poor grain filling due to a low supply of assimilates and hormones caused by poor vascularization. These findings were important in further dissecting the response of tillering on seeding rates for improving the yield of dry direct seeded rice and its interaction with other cultural practices such as fertilizer management towards the maximization of sink size for higher grain yield.

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