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AGRONOMIC TRAITS AND YIELD COMPONENTS ASSOCIATED WITH BROADCASTED AND TRANSPLANTED HIGH-YIELDING RICE GENOTYPES

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A B S T R A C T

The study was done to identify agronomic traits and yield components associated with high-yielding rice genotypes grown under transplanted and broadcasted methods using the seed rate of 50 kg/ha (BC50) and 25 kg/ha (BC25) and transplanting (TP) in an irrigated area during the dry season. Used as tests genotypes were two hybrids (Bigante and SL8), two inbreds (PSB Rc82, IR72) and a new plant type (IR72967-12-2-3). Results showed that grain yield were consistently higher under BC25 than under TP, ranging from 0.5 to 2.5 t/ha among genotypes. Harvest index accounted for 21.3% of grain yield increase under BC25 and higher harvest index was obtained between hybrid genotypes, particularly SL8. SL8 produced fewer panicles in the three crop establishment methods but had the highest average number of filled grains per panicle. Positively associated with grain yield, filled grains per panicle accounted for 91.27% of the variation in yield as shown in the stepwise regression analysis. Total dry matter accounted for 78.6% yield increase and was also positively associated with grain yield. Grain yield under SL8 and Bigante was higher among the genotypes due to their higher efficiency in partitioning dry matter as measured through harvest index and sink strength index.

Keywords: Bigante, SL8, hybrid rice, total dry mater, harvest index, sink strength index, tillering efficiency.

INTRODUCTION

Rice is the major staple food in Asia. By 2030, it is estimated that the world demand for rice will be about 533 million tonnes of milled rice (FAO, 2001a). In view of the increasing demand, there is a continuing quest to increase yield amidst declining resources base (land, water) and escalating prices of inputs (fertilizer, fuel, pesticides). In recent years, however, the rate of increase in yield went down to around 1% per annum (Nguyen, 2001a) and the small increase in area devoted to rice production will not be sufficient to meet the growing demands. Learning from the experiences in China as they have considerably increased their rice output over the past decades, there is a need to increase yield by using hybrid genotypes. Hybrid rice offers 15-20% increase in yields relative to semi-dwarf, inbred varieties, which are what farmers plant today.

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Presently, rice varieties are established mainly through transplanting. Many studies have reported that grain yield of wet seeded rice (WSR) is higher than transplanted rice (TPR) (De Dattaet al 1988; IRRI 1988, 1991). Direct seeding is increasingly replacing transplanting in puddled soil (De Datta, 1986). Generally, farmers in developing countries adopt direct seeding because of farm labor migration to non-farm jobs, which has led to labor shortage, and the consequent higher wages for manual transplanting (Ho 1995, Pandey 1995, Pingali 1994). Direct seeding is fast becoming attractive among farmers to save on labor costs. Also, farmers resort to wet direct seeding whenever transplanting is delayed. With improved water control, direct seeding can be more conducive to mechanization (Yoong and Hui, 1982).

The transplanting method of crop establishment causes transplanting shock, leading to delayed tillering by 15 days (Dingkuhn et al 1990b). Moreover, late transplanting delayed tiller emergence by 15 days for rice genotypes in relation to early transplanting (Pasuquin et al 2004). Early transplanting appears to be a relevant practice to improve yield in irrigated rice. However, the high cost of manual transplanting and uneven plant population are major constraints in transplanting. Transplanted seedlings have delayed crop establishment and reduced tillering and leaf areas.

In contrast, direct seeded rice had higher crop growth rates during the vegetative stage than transplanted rice, exhibited faster leaf area development and greater dry matter accumulation which led to higher yields of rice genotypes. Broadcasting promotes quicker leaf area development, dry matter and N uptake than transplanting until panicle initiation (PI) stage and even slower during grain filling (Peng et al 1996). Direct seeding shortens the growth duration by a week (Schnier et al 1990). That high biomass production translating into higher grain yield depends on numerous factors which include cultural practices, climate and genotype (Dingkuhn et al 1990a). For instance, canopy CO_2 assimilation and crop growth rate of broadcast-seeded were depressed due to lower leaf N content and greater mutual shading in broadcast-seeded rice (Dingkuhn et al 1990a&b, 1991, 1992a&b, Schnier et al 1990b). But tiller number was higher in direct seeding, hence grain yield.

In farmers' fields, yields under direct seeding are lower than transplanting. This can be attributed to uneven establishment, difficulties in weed control and other constraints like crop lodging. Land leveling and standing water can reduce the weed burden that depresses yields in the direct-seeded rice. Planting adapted hybrid genotypes in broadcasting method can also increase grain yield. Hence, the study was conducted to identify agronomic traits and yield components associated with high-yielding rice genotypes grown under transplanting and broadcasting methods using the seed rate of 50 kg/haand 25 kg/ha in an irrigated area during the dry season.

METHODOLOGY

The study was conducted during the dry season (DS) of 2005 at the experimental farm of Philippine Rice Research Institute (PhilRice) in Maligaya, Science City of Muñoz, NuevaEcija, Philippines. The PhilRiceAgrometeorological station is located at coordinates 15°45' N: 120°56' E and 48 m asl. The experiment was laid out following a split plot in randomized complete block design, replicated 4 times. The randomization and layout of the experiment is presented in Figure 1. Crop establishment methods (TP, BC50, and BC25) occupied the main-plot while genotypes (G1, G2, G3, G4, and G5) on the sub-plot. Each plot measured 5m x 8m equivalent to 40 m^2 area. Tests genotypes included 2 hybrids (SL8 and Bigante), one new plant type (IR72967-12-2-3), and 2 elite inbreds (IR72 and PSB Rc82). IR72 was used as the check genotype. Where the field trial was conducted, the soil was classified as UsticEpiaquerts (Maligaya clay) with 1.33 g/cm^3 bulk density, 6.13 pH and 1.32% organic C.

Pre-germinated seeds (24-h soaking and 24-h incubation) were manually broadcasted on a wet seedbed for growing seedlings that were used in transplanting. Simultaneously, 25 kg/ha (BC25) and 50 kg/ha (BC50) were broadcasted in the main plots, two days after land leveling. Nine-day old seedlings were pulled out from the seedbed and maintained overnight in the wet seedbed in packs. They were transplanted the following day at 20 cm x 10 cm hill spacing with 2 seedlings/hill (100 plants/m^2). The basal fertilizer consisted of 40 kg N/ha, 50 kgP_2O_5/ha, 50 kg K_2O/ha, and 25 kgZn/ha applied and incorporated in the soil during the third harrowing in the broadcasted plots and two days before transplanting in the transplanted plot. Topdressing N fertilizers were based on the chlorophyll meter (SPAD) readings. Readings were done twice a week in all the plots starting at early tillering stage (21 days after sowing) until heading stage. Nitrogen was applied when SPAD reached 36 and below. The total N fertilizer (basal and topdressing) applied was 180 kg/ha for both BC25and TP, and 200 kg/ha for BC50. Standing water was maintained at 3-5 cm in all the plots from early vegetative stage and drained two weeks before harvest. Data gathered from the vegetative, reproductive and maturity phases are shown in Table 1.

At vegetative phase, maximum tillering stage (50 days after broadcasting), the number of tillers was taken from a 0.5-m^2 crop cut.At maturity phase, physiological maturity stage, grain yield was taken from the same 5-m^2 crop cut. Oven-drying of threshed grain samples at 70°C for 48 hours was done to obtain 14% moisture content (MC) of the grains. Yield components [number of productive tillers (panicle number) per unit of ground area, number of filled grain per panicle and 1000-filled grain dry weight] were taken from the 3 locations (0.12 m^2 per location) in each broadcasted plot. This area (0.12 m^2) corresponded to 6 hills in the transplanted plot. The same samples: panicle dry weight was determined then filled and unfilled grain numbers per panicle were numbered; the dead tillers were separated from the productive tillers then, numbered and; the dry weight of 200 representative filled grains was converted to 1000-filled grain dry weight.

The data on agronomic traits of the rice genotypes were determined from the same samples derived from yield components and they were consisted of the following parameters: total dry matter, tillering efficiency, specific stem length, percent filled grain, duration of grain filling, harvest index, sink strength index, and crop duration.

Total dry matter weight was determined by taking the sum of stem dry weight + leaf sheath dry weight, leaf dry weight and panicle dry weight. Where, panicle dry weight composed of filled and unfilled grains, and rachis. Tillering efficiency was computed as the total number of tillers at maximum tillering stage minus the number of dead tillers at maturity stage and divided by the total number of tillers at maximum tillering stage. Specific stem length is the ratio of stem length of tillers to their stem dry weight (including leaf sheath dry weight). Percent (%) filled grain was calculated as the number of filled grains per panicle multiplied by a factor of 100 over the total number of filled grains per panicle. Grain filling duration was from the 80% flowering date to maturity. Harvest index was calculated by dividing the total filled grain yield (dry weight) by its total dry matter weight (the whole plant dry weight except root dry weight due to some difficulty in obtaining its value). Sink strength index was calculated as the specific stem length multiplied by panicle dry weight. This value was introduced as a way to compare the ability of the plant to partition efficiently its dry matter to the economic part of the plant (i.e., grains) at maturity and it had more efficiency than the value of harvest index. Crop duration (including the period of growth in the nursery in the case of transplanting) was counted from the first day of broadcasting the seeds to maturity. Data on agronomic traits, yield components, and grain yield of the five rice genotypes were analyzed using the Statistical Analysis System (SAS) software. Treatment mean comparisons were done using the Tukey-Kramer's test. This is a multiple comparison test which requires a single value such as the Least Significant Difference (LSD) to compare the treatment means. Moreover, it is stricter than Duncan's Multiple Range Test (DMRT). Relationships among all data parameters were established through correlation analysis. Stepwise Multiple Regression was also used to determine the relationships of grain yields with important agronomic traits and yield components.

Table 1. The data gathered at vegetative, reproductive and maturity stages of rice genotypes.

Vegetative Stage	**Vegetative/Reproductive to Maturity Stage**	**Maturity Stage**		
Tiller at maximum tillering stage (no/m²)	**Tillering efficiency (dimensionless)**	Gran yield at 14% moisture content (t/ha)	Productive tiller (no/m²)	Filled grain (no/panicle)
		1000-filled grain dry weight (g)	Panicle dry weight (g)	Unfilled grain (no/panicle)
	Duration of grain filling from 80% flowering to maturity (day)	Dead tiller (no/m²)	Total dry matter weight (g/m²)	Stem dry weight + leaf sheath dry weight (g)
		Leaf dry weight (g)	Specific stem length (cm/g)	Percent (%) filled grain
		Harvest index (dimensionless)	Sink strength index (cm)	Crop duration (day)

RESULTS

Mean grain yield was highest from broadcasting at 25 kg seeds/ha (BC25) compared to transplanting (TP) and broadcasting at 50 kg/ha (BC50). The differences in grain yields among crop establishment methods between BC25 and TP were significant at 1.32 t/ha (Table 2). The two hybrids (SL8 and Bigante) had higher grain yields than the check genotype, IR72. Crop establishment methods influenced grain yields of rice genotype; the performances of the two hybrids produced significantly higher or comparable grain yields to that of IR72 under both BC25 and BC50 methods. However, the SL8 hybrid produced the highest yield overall under BC25, 10.58 t/ha. PSB Rc82 produced the lowest yield under BC25 (8.08 t/ha) and BC50 (7.42 t/ha) at least 1 t/ha lower than the other genotype in this study. This is a noteworthy finding, as PSB Rc82 is a popular genotype for direct seeding in the Philippines. The performances of IR72 and new plant type (NPT) were intermediate between those of the hybrids and PSB Rc82.

Crop duration and grain filling duration were somehow not affected by crop establishment method (Tables 3 and 4). In particular, transplanting 10-day old seedlings did not extend crop duration in comparison to direct seeding establishment. Bigante was characterized by the longest crop duration, 112 days under the conditions of this study, and PSB Rc82 by the shortest, 99 days, while the other three genotypes had similar crop duration of about 107 days. The longer duration of Bigante over IR72 and SL8 was due to the longer duration of the grain-filling phase (Table 4). The duration of grain filling of PSB Rc82 was, however, long with regard to its whole crop duration, whereas that of NPT was the shortest one.

Total dry matter weights per unit area at maturity were appreciably higher under BC25 than under transplanting even though they had similar plant densities (Table 5). The values of SL8 and Bigante were higher than that of IR72, while the values of NPT and PSB Rc82 were the lowest. Total dry matter weight of each genotype decreased with increasing plant density under broadcasting except for Bigante. The two hybrids produced and accumulated higher dry matters under BC25 and BC50 than under TP method. Hence, the production and accumulation of total dry matter of rice genotypes were affected by the crop establishment method.

Harvest index and grain weight (1000-filled grain dry weight) of rice genotypes did not vary among crop establishment methods even though the value of harvest index under BC25 was slightly higher than those of BC50 and TP (Table 6). Yield components were strongly affected by the crop establishment method. The number of panicles per unit area increased significantly from transplanting to broadcasting (BC25 and BC50), with respective values of 469, 528 and 586 (Table 6). Considering the measured rates of seed germination and seedling emergence under broadcasting, the plant densities numbered in the fields under BC25 and BC50 were 77 and 139 plants/m^2, respectively. SL8 had significantly higher harvest index with 0.45 while IR72, NPT and PSB Rc82 ranged between 0.40 and 0.41 (Table 7). Basic yield components were strongly different among genotypes. SL8 produced a low panicle number at 414/m^2 with the heaviest grain weight while IR72 and PSB Rc82 were both high at 624/m^2 but with lighter grain weights (Table 7).

The filled grain number per panicle was higher under BC25 and TP than that of BC50 (Table 8). This observation was valid for crop establishment methods at the lower plant densities; BC25 produced higher panicle number per unit area at maturity.Hybrid rice (79), SL8 and Bigante (75) produced significantly the highest number of filled grains per panicle whereas PSB Rc82 had the lowest (48) (Table 8). Moreover, the two hybrids had significantly higher numbers of filled grains per panicle regardless of the crop establishment method.

Tillering efficiency (survival efficiency) was lower for SL8 and Bigante (0.39 and 0.38) and IR72 (0.44) while NPT (0.56) and PSB Rc82 (0.59) were more efficient (Table 9). SL8 and Bigante had the highest mortality number of tillers. Tillering efficiency was inversely related to grain yield while it was not influenced by crop establishment method (Tables 2 and 9).

Percent filled grains (fertility rates) were not significantly different among crop establishment methods. The values appreciably varied among genotypes. The SL8 and PSB Rc82 had the highest value, both at 74% (Table 10). Fertility rate of rice genotypes was not affected by crop establishment method.

The sink strength index (SSI) was the highest under BC25 (Table 11). The average value of 110.8 cm for SL8 was significantly higher than of the 86.3 cm for IR72; NPT (78.9 cm) and PSB Rc82 (83.6 cm) regardless of the crop establishment method.

Table 2. Grain yield (t/ha).

Crop Establishment Method (CE)	**Genotype (G)**					**Mean**
	IR72	**SL8**	**Bigante**	**NPT‡**	**PSB Rc82**	
Transplanting (TP)	8.22cde≠	8.09de	8.52bcde	7.46e	7.49e	7.96c*
Broadcasting at 25 kg/ha (BC25)	9.15abcd	10.58 a	9.43abcd	9.18abcd	8.08de	9.28a
Broadcasting at 50 kg/ha (BC50)	8.39cde	10.10ab	9.72abc	8.32cde	7.42e	8.79b
Mean	8.59bc$^{\delta}$	9.59a	9.22ab	8.32cd	7.66d	-

‡NPT = new plant type

≠in the table of CE X G means with the same letter is not significantly different at 0.05 probability level (Tukey-Kramer).

*in the column of CE means with the same letter is not significantly different at 0.05 probability level (Tukey-Kramer).

δ in the row of G means with the same letter is not significantly different at 0.05 probability level (Tukey-Kramer).

Table 3. Crop duration (day).

Crop Establishment Method (CE)	Genotype (G)					Mean
	IR72	SL8	Bigante	NPT‡	PSB Rc82	
Transplanting (TP)	108bc≠	107c	113a	111ab	99d	108a*
Broadcasting at 25 kg/ha (BC25)	107c	107c	113a	107c	99d	106b
Broadcasting at 50 kg/ha (BC50)	107c	107c	111ab	107c	99d	106b
Mean	107bδ	107b	112a	108b	99c	-

‡NPT = new plant type

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δ in the row of G means with the same letter is not significantly different at 0.05 probability level (Tukey-Kramer).

Table 4. Duration (day) of grain filling from 80% flowering to maturity.

Crop Establishment Method (CE)	Genotype (G)					Mean
	IR72	SL8	Bigante	NPT‡	PSB Rc82	
Transplanting (TP)	23c≠	22cd	25bc	23c	23c	23a*
Broadcasting at 25 kg/ha (BC25)	23c	23c	29a	19d	23c	23a
Broadcasting at 50 kg/ha (BC50)	23c	23c	27ab	19d	23c	23a
Mean	23bδ	23b	27a	20c	23b	-

‡NPT = new plant type

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δ in the row of G means with the same letter is not significantly different at 0.05 probability level (Tukey-Kramer).

Table 5. Total dry matter weight (g) per square meter at maturity.

Crop Establishment Method (CE)	Genotype (G)					Mean
	IR72	SL8	Bigante	NPT‡	PSB Rc82	
Transplanting (TP)	1712abc≠	1672abc	1785abc	1691abc	1616bc	1695b*
Broadcasting at 25 kg/ha (BC25)	1960abc	2020ab	1900abc	1928abc	1682abc	1898a
Broadcasting at 50 kg/ha (BC50)	1827abc	1925abc	2060a	1845abc	1564c	1844ab
Mean	1833bcδ	1872ab	1915a	1821bc	1621c	-

‡NPT = new plant type

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δ in the row of G means with the same letter is not significantly different at 0.05 probability level (Tukey-Kramer).

Table 6. Harvest index, panicle number per square meter, 1000-filled grain dry weight.

Crop establishment method (CE)	Harvest index	Panicle (no/m^2)	1000-filled grain dry weight (g)
Transplanting (TP)	0.41a	469c	24.4a
Broadcasting at 25 kg/ha (BC25)	0.43a	528b	24.4a
Broadcasting at 50 kg/ha (BC50)	0.42a	586a	24.1a

In the column, means with the same letter are not significantly different at 0.05 probability level (Tukey-Kramer).

Table 7. Harvest index, panicle number per square meter, 1000-filled grain dry weight.

Genotype (G)	Harvest index	Panicle (no/m^2)	1000-filled grain dry weight (g)
IR72	0.41b	624a	22.5c
SL8	0.45a	414c	26.7a
Bigante	0.43ab	498b	21.6d
New plant type (NPT)	0.40b	478b	26.7a
PSB Rc82	0.41b	624a	24.0b

In the column, means with the same letter are not significantly different at 0.05 probability level (Tukey-Kramer).

Table 8. Filled grain number per panicle.

crop Establishment Method (CE)	Genotype (G)					Mean
	IR72	SL8	Bigante	NPT‡	PSB Rc82	
Transplanting (TP)	56de≠	84ab	86a	53de	50de	63a*
Broadcasting at 25 kg/ha (BC25)	60cde	78abc	78abc	63cde	50de	64a
Broadcasting at 50 kg/ha (BC50)	48de	78abc	66bcd	52de	45e	56b
Mean	54b$^{\delta}$	79a	75a	56b	48b	-

‡NPT = new plant type
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δ in the row of G means with the same letter is not significantly different at 0.05 probability level (Tukey-Kramer).

Table 9. Tillering efficiency.

Crop Establishment Method (CE)	Genotype (G)					Mean
	IR72	SL8	Bigante	NPT‡	PSB Rc82	
Transplanting (TP)	0.50abcd≠	0.38d	0.40cd	0.51abcd	0.62ab	0.48a*
Broadcasting at 25 kg/ha (BC25)	0.46abcd	0.45bcd	0.37d	0.60ab	0.64a	0.50a
Broadcasting at 50 kg/ha (BC50)	0.37d	0.34d	0.37d	0.57abc	0.51abcd	0.43a
Mean	0.44b$^{\delta}$	0.39b	0.38b	0.56a	0.59a	-

‡NPT = new plant type
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δ in the row of G means with the same letter is not significantly different at 0.05 probability level (Tukey-Kramer).

Table 10. Percent (%) filled grain.

Crop Establishment Method (CE)	Genotype (G)					Mean
	IR72	SL8	Bigante	NPT‡	PSB Rc82	
Transplanting (TP)	66abc≠	76ab	65bc	62c	78a	69a*
Broadcasting at 25 kg/ha (BC25)	69abc	74abc	70abc	67abc	71abc	70a
Broadcasting at 50 kg/ha (BC50)	69abc	72abc	67abc	65abc	73abc	69a
Mean	68b$^{\delta}$	74a	67b	65b	74a	-

‡NPT = new plant type
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δ in the row of G means with the same letter is not significantly different at 0.05 probability level (Tukey-Kramer).

Table 11. Sink strength index (cm).

Crop Establishment Method (CE)	Genotype (G)					Mean
	IR72	SL8	Bigante	NPT‡	PSB Rc82	
Transplanting (TP)	87.4abcd≠	112.28ab	114.6a	76.2d	77.4d	93.6b*
Broadcasting at 25 kg/ha (BC25)	92.7abcd	114.5a	112.7ab	86.0bcd	93.9abcd	99.9a
Broadcasting at 50 kg/ha (BC50)	78.9cd	105.6abc	99.3abcd	74.5d	79.6cd	87.6c
Mean	86.3bc$^{\delta}$	110.8a	108.9ab	78.9d	83.6cd	

‡NPT = new plant type

≠in the table of CE X G means with the same letter is not significantly different at 0.05 probability level (Tukey-Kramer).

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DISCUSSION

Grain yield was consistently higher under BC25 than under TP by 0.5 to 2.5 t/ha among genotypes. Plants were grown under the same conditions such as seeds sown on the same day, plant density similar, fertilizer applied at the same time and in the same quantity and based on plants' needs. Plant growth was not affected in the nursery and by transplanting because of low seedling age at transplanting (Pasuquin et al 2008) and supported by the simultaneous maturity. This was also observed for genotypes characterized by different ways of producing grains; some producing many panicles at maturity (624/m^2) but bearing low number of filled grains per panicle (48) and others producing a low number of panicles (414/m^2) but bearing a high number of filled grains (79), with the filled grain weight varying from 21 to 26 g with regard to the genotype. The increase in grain yield was higher with genotypes producing a low number of panicles (productive tillers) with many filled grains. The number of filled grains per panicle is the most important yield component rather than the number of productive tillers that determine grain yield, especially for rice crop established under BC50 or higher plant densities. The stepwise regression analysis showed that filled grain number per panicle accounted for the 91.27% of the variation in yield and subsequent correlation analysis indicated that it was positively associated with grain yield at r = 0.95 (where, r is a correlation coefficient). This is not in consonance with the findings of Gravois &McNew (1993) which stated that the panicle number (productive tillers) per unit area is generally the most important yield component, accounting for 87% of the variation in yield while grain weight accounted for only 3% (Fageria 2001).

For all genotypes, the number of panicles increased from TP to BC25. The value of total dry matter per unit area significantly increased and was brought about by the higher light interception in the densely covered areas of the broadcast-seeded plot. **U**nder transplanting, the free spaces in between hills led to lower leaf area coverage leading to lower light interception. PSB Rc82 is a popular variety for direct seeding (broadcasting) in the Philippines and had the lowest grain yield under broadcasting; lowest increase in grain yield from transplanting to broadcasting method. Stepwise regression analysis indicated that total dry matter weight was the important agronomic trait which influenced grain yield of rice genotypes under BC25 with 78.6% yield increase. BC25 had significantly higher total dry matter weight and was positively associated with grain yield (r = 0.88). This means that the higher total dry matter weight contributes to more translocation of assimilates from the leaves, leaf sheaths and stems to the panicles during the grain filling period, resulting in higher grain yield under the low seeding rate of 25 kg/ha.

Grain yield was also higher under BC25 than BC50 regardless of the genotype. The main difference between broadcasted densities (25 and 50 kg/ha) was compensated by the number of productive tillers and number of filled grains per panicle; genotypes under higher density produced higher number of productive tillers and lower number of filled grains per panicle while fertility rate and grain weight did not differ.

SL8 produced significantly the highest grain yields. It is a genotype that can adapt to broadcasting method as well as transplanting in irrigated areas. BC25 and BC50 contributed to a higher grain yield of SL8 than TP. SL8 under BC25 had yield higher by 30.78% (2.49 t/ha) than that of TP.

The hybrid rice Bigante was the only genotype that exhibited an increase in grain yield from BC25 to BC50. This was primarily due to the higher number of panicles produced, which contributed to higher yield. The decrease in grain yield with the increase in plant density was attributed to the decrease in tillering efficiency. However, hybrid rice had a low number of tillers. Choi & Kwon (1985) explained that genotypes with fewer tillers have bigger tillers, which results in a higher sink: source ratio, spikelet number, percent filled grain and sink capacity. A low tiller number genotype ensures a higher number of vascular bundles to facilitate the production of heavy tillers and a higher number of high density grains (Choi & Kwon 1985, Hayashi 1976).

Bigante, however, was the only genotype that increased in both grain yield and dry matter weight while maintaining its tilleringefficiency. Hence, the increase in its total dry matter weight was a result for higher grain yield. It was also the shortest genotype during the vegetative phase, with the smallest leaf area per individual plant. Seemingly the high plant density for small genotypes such as Bigante was required to achieve high tiller production and high leaf area coverage, and subsequently high yield. The lower yield reported under high density compared to low density for most genotypes may have been the result of the lower tillering efficiency leading to higher wastage of dry matter.

Hybrid rice genotypes had higher efficiency in partitioning dry matter as supported by their higher measured values of harvest and sink strength indexes. Consequently, they had higher grain yields. Stepwise regression analysis indicated that the harvest index of rice genotypes accounts for 21.3% grain yield increase under BC25. Sinclair (1998) stated that harvest index has been an important trait associated with the dramatic increases in crop yields during the twentieth century. Harvest index reflects the partitioning of photosynthates (assimilates) between the grain and the vegetative plant and emphasizes the importance of carbon allocation for grain production.

In this study, the sink strength index was introduced as an improved index of partitioning efficiency that is independent of blade senescence but accounts for the variability of stem length to the difference of harvest index. The variability of genotypes in their ability to partition dry matter, and the superiority of hybrid rice, was better characterized with the sink strength index. In contrast, the accumulation of total dry matter did not support the superiority of hybrid rice as strongly as the efficiency of dry matter partitioning. High sink strength index of rice genotypes under BC50was positively associated with number of filled grains per panicle ($r = 0.92$) and grain yield ($r = 0.90$).

SL8 and Bigante were significantly higher in both sink strength and harvest indices. Lafarge et al (2006) cited that the yield advantage of hybrid rice over conventional inbred rice in tropical favorable environments is up to 15%. This is commonly attributed to higher dry matter production due to higher seedling vigor leading to faster growth rate and higher harvest index. SL8 hybrid rice had high efficiency of assimilate partitioning to the grains, resulting in heavy grains as indicated by a high sink strength index. NPT had a low harvest index and sink strength index leading to a low number of filled grains per panicle. PSB Rc82 had low efficiency of assimilate partitioning to the grain, resulting in a light grain weight indicated by low sink strength index. IR72 had a low harvest index and sink strength index resulting in having a light grain weight. Moreover, the low dry matter accumulation of PSB Rc82 associated with its short crop duration was mainly due to its performance being lowered by 1 t/ha compared to that of IR72. The higher efficiency in dry matter partitioning of the most productive genotypes was associated with a low number of productive tillers and high number of filled grains per panicle while the low-yielding genotypes were characterized by a high number of productive tillers and low number of filled grains per panicle.

The tillering efficiency was significantly lower for the high-yielding genotypes such as hybrid rice than the low-yielding genotype PSB Rc82. The increase in tillering efficiency was one of the key targets for selecting new plant types and increasing yield potential. In the present study, NPT, which had an Indica background, was indeed characterized by a high tillering efficiency as expected, similar to that of PSB Rc82. Despite its high tillering efficiency, NPT expressed the lowest efficiency in dry matter partitioning (lowest harvest index and sink strength index) and consequently low grain yield. However, the grain yield of this new plant type was similar to that of IR72 and significantly lower than that of hybrid rice.

The sink size could be expressed by percentage of filled grain which varied among genotypes and was quite high with regard to the ratio of fertile spikelet that varied from 0.65 to 0.74 regardless of the genotype's performance. Based on the percentage of filled grain, the sink size was clearly not a limit for grain filling for each of these genotypes due to the more number of spikelets that were unfilled being recognized by a value of percentage of filled grain. Hence, sink size was neither a relevant trait for high performance. Thus, the grain size did not appear as a key trait since some high- and low-yielding genotypes were bearing heavy grains while some were bearing light grains.

CONCLUSION AND RECOMMENDATIONS

SL8 produced the highest grain yield, harvest index, number of filled grains per panicle, 1000-filled grain dry weight, % filled grain dry weight, and thicker stems. Bigante obtained the second while IR72 obtained the third; PSB Rc82 and NPT were not able to produce better grain yield than the check genotype. Yield components were strongly affected by the crop establishment method and were strongly different among genotypes. The average number of panicles per unit area increased significantly from TP to BC25 and to BC50. SL8 produced low panicle number when averaged for the three establishment methods but with the highest average number of filled grains per panicle. The increase in grain yield was higher with genotypes producing low panicles with many filled grains. Grain yields were consistently higher under BC25 than under TP among rice genotypes. BC25 is the most recommended method since seeds of hybrid rice are costly and farmers usually want to save. BC25 could also provide great opportunities to farmers in lowering labor requirements and production costs (Table 12). The net benefit derived from BC25 is 34% higher than that under TP.

Table.12. Simple costs and returns (production economics) of irrigated rice production under broadcasting and transplanting methods of crop establishment based on recent year 2013.

Costs	Cost/unit	Unit number	Broadcasting		Transplanting
			25 kg/ha (BC25)	**50 kg/ha (BC50)**	**2 seedlings/hill (TP)**
1. Taxes (0.5% of asset value of the land): asset value = 30,000/ha	Php150/ha/year (1 year = 2 cropping)	1 cropping (dry season)/ha	75	75	75
2. Seed price for broadcasting					
2.1 Hybrid seed (Bigante& SL8)	Php120/kg	*	3,000	6,000	3,000
3. Pump rental (5% of gross yield)	Php650/sack of hulled rice for grain dry weight at 14% MC	***	6,032	5,714	5,174
4. Diesel for irrigation	4hrs/time/day x 16 times/ha x 6.5liter diesel/4hrs/time x Php50/liter diesel	104 liters diesel/ha	5,200	5,200	5,200
5. Laborer for irrigation	Php150/man-day	8 man-days/ha	1,200	1,200	1,200
6. Land preparation (hand tractor)	-	-	-	-	-
6.1 Nursery bed (25 m^2)	-	-	-	-	-
6.1.1 Laborers for irrigation	Php150/nusery bed/time	2 times/nursery	0	0	300
6.2 Main fields	-	-	-	-	-
6.2.1 Plowing (inclusive of meal)	Php1,750/ha	1 time/ha	1,750	1,750	1,750
6.2.2 Harrowing and land leveling (inclusive of meal)	Php1,750/ha	1 time/ha	1,750	1,750	1,750
7. Laborers (pulling the seedlings)	Php150/man-day	6 man-days/ha	0	0	900
8. Laborers for broadcasting	Php150/man-day	2 man-days/ha	300	300	0
9. Fertilizer cost	-	-	-	-	-
9.1 Solophos super phosphate (0-18-0)	Php667/sack ¶	50 kg P_2O_5/ha	3,706	3,706	3,706
9.2 Muriate of potash (0-0-60)	Php1290/sack ¶	50 kg K_2O/ha	2,150	2,150	2,150
9.3 Zinc sulfate (ZnSo4), 98% Zn	Php1934/sack ¶	25 kg Zn/ha	987	987	987

9.4 Urea [$CO(NH_2)_2$] (45-0-0)	Php1067/sack ¶	180/200kg N/ha	8,536	9,484	8,536
10. Fertilizer application	-	-	-	-	-
10.1 Basal fertilizer application	Php150/man-day	2 man-days	300	300	300
10.2 First N topdressing	Php150/man-day	2 man-days	300	300	300
10.3 Second N topdressing	Php150/man-day	2 man-days	300	300	300
10.4 Third N topdressing	Php150/man-day	2 man-days	300	300	300
11. Transplanting	Php150/man-day	20 man-days/ha	0	0	3000
12. Chemical cost	-	-	-	-	-
12.1 Herbicide (weed killer)	Php540/liter of chemical	1 liter of chemical/ha	540	540	540
13. Chemical application	-	-	-	-	-
13.1 Herbicide spraying	Php150/man-day	3 man-days/ha	450	450	450
14. Hand weeding at vegetative stage	Php150/man-day	5 man-days/ha	750	750	750
15. Hand weeding at reproductive stage	Php150/man-day	5 man-days/ha	750	750	750
16. Harvesting (inclusive of bundling but exclusive of meal)	Php150/man-day	20 man-days/ha	3,000	3,000	3,000
17. Threshing (6% of the gross yield)	Php650/sack of hulled rice # for grain dry weight at 14%MC	***	7,238	6,856	6,209
18. Packaging (sack cost)	Php7/sack	**	1,299	1,231	1,114
19. Transportation of the grain from farm to house	Php15/sack of hulled rice #	**	2,784	2,637	2,388
20. Seed drying (sun-dry)	-	-	-	-	-
20.1 First grain drying	Php10/sack of hulled rice #	**	1,856	1,758	1,592
20.2 Second grain drying	Php10/sack of hulled rice #	**	1,856	1,758	1,592
Gross cost/ha basis	-	-	56,410	59,245	57,313
Gross income/ha basis	-	-	-	-	-
1. Grain yield	-	-	-	-	-
1.1 Dry weight (14%MC) after harvest	Php16.5/kg	***	136,277	129,081	116,893
Net income (benefit)/ha basis	-	-	79,867	69,836	59,579
Benefit/Cost ratio	-	-	1.42	1.18	1.04
Assumption :	-	-	-	-	-

*** Gross yield at 14%MC: 9.28, 8.79 and 7.96 t/ha for BC25, BC50 and TP, respectively. ** 186 sacks/ha for BC25; 176 sacks/ha for BC50 and; 159 sacks/ha for TP. * 25 kg seeds/ha for BC25 and TP; 50 kg seeds/ha for BC50. # 1 sack of hulled rice is equivalent to 50 kg. ¶ 1 sack of fertilizer is equivalent to 50 kg. Php is a Philippine peso. Where; the Php 40.62 is equivalent to 1 USD on 24 January 2013 (http://www.xe.com/ucc/convert/?Amount=1&From=USD&To=PHP).

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