
Growth Dynamics and Yield of Rice Genotypes Grown in Transplanted and Direct-Seeded Fields

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Abstract This study was conducted during the dry season 2005 at the experimental farm of the Philippine Rice Research Institute (PhilRice) in Maligaya, Science City of Muñoz, Nueva Ecija, Philippines to assess the growth dynamics of rice genotypes consisting of two hybrids (SL-8 and BIGANTE), two inbreds (PSBRc82 and IR72) and 1 new plant type (IR72967-12-2-3) when grown in transplanted and in direct seeded fields at recommended (50 kg ha^{-1}) and low seed density (25 kg ha^{-1}) and to identify morphological plant characteristics that contribute to higher grain yield. Direct-seeded rice had higher crop growth rates during vegetative stage than transplanted rice, exhibits leaf area development and greater dry matter accumulation. Transplanted seedlings exhibited transplanting shock which delayed crop establishment and reduced tillering and leaf areas. This led to higher yields of all genotypes under broadcast seeding. Of the two seeding densities, significantly higher yield was obtained in low seeding (SB25) than in broadcast seeding at 50 kg ha^{-1} and transplanting. At low seed density of 25 kg/ha , the hybrids had faster and better growth rate during the vegetative stage. Of the two hybrids, SL-8 had more erect leaves, higher canopy, longer stem length, and greater leaf area in direct seeded field at 25 kg/ha . At 84 days after sowing, SL-8 and BIGANTE have achieved optimum LAI 8.55 and 7.2, respectively. Although this was not significantly different with BIGANTE, SL-8 had the highest grain yield at 10.58 t/ha . The better performance of hybrids under direct seeding and at low seeding density suggests that these hybrids can be established in this method other than the usual transplanting in irrigated areas.

Introduction

Farmers in developing countries increasingly adopt direct seeding because of farm labor migration to non-farm jobs which lead to labor shortage, and the consequent high wages for manual transplanting (Ho 1995; Pandey 1995; Pinggali 1994). Direct seeding eliminates labor demands for seedbed preparation, seedling care, pulling of seedlings, and transplanting shock (IRRI 1987). With improved water control, direct seeding can be more conducive to

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mechanization (Yoong and Hui, 1982). The yield of rice under direct seeding is reported to be generally lower than transplanting. Reasons for this low yield include uneven distribution of seeds, poor seedling emergence and high competition of weeds. Competition against weeds could be solved by high seed density or by the use of high tillering genotype that could cover the soil surface more rapidly. Direct-seeded rice exhibited higher crop growth rates and tillering ability during vegetative stages than transplanted rice, even when planting density and geometry were equal. Dry matter accumulation until flowering was significantly higher in direct-seeded rice. Whether the higher dry matter accumulation can translate into higher grain yield depends on numerous factors which include cultural practices, climate and genotype (Dingkuhn *et al.*, 1990a). During vegetative growth stage, rice crop established by broadcasting have more rapid leaf area development, dry matter accumulation, and N uptake than transplanted rice, but growth rates and N uptake decrease after panicle initiation, particularly during the grain filling period. Canopy CO₂ assimilation and crop growth rates of broadcast-seeded rice were depressed due to lower leaf N content and greater mutual shading in the broadcast-seeded canopy (Dingkuhn *et al.*, 1990a,b, 1991, 1992a,b; Schnier *et al.*, 1990b).

Studying the influence of contrasting crop management, like seed density and seedling establishment techniques associated with real time N management on the performance of different genotypes is important for improving direct seeding. Hence, this study was conducted to assess the growth dynamics of rice genotypes grown in transplanted and direct-seeded fields at recommended, 50 kg seeds/ha⁻¹ and low seed density, 25 kg seeds/ha⁻¹ and to identify morphological plant characteristics that contribute to higher grain yield of rice genotypes grown under transplanting and direct seeding.

Materials and methods

Place of the Study and Rice Genotypes

The experiment was conducted during the dry season (DS) of January to May 2005. The soil taxonomy was Ustic Epiaquerts (Maligaya clay) with pH 6.13. The experiment was laid out following a split plot in randomized complete block design (RCBD), replicated 4 times. Crop establishment methods (TP =Transplanting, SB50=Broadcast seeding at 50 kg seeds ha⁻¹, and SB25= Broadcast seeding at 25 kg seeds ha⁻¹) occupied the main-plot while genotypes (I1=IR72, I3=PSBRc82, N4=IR72967-12-2-3, H3=SL8, and H9=BIGANTE) on the sub-plot treatments. Five rice genotypes consisting of two inbred (IR72 and PSBRc82), two hybrids (SL-8 and BIGANTE), and one

new plant type (IR72967-12-2-3) were used and IR72 was used as check genotype.

Crop Establishment Methods and Field Experiment Management

In direct-seeded plots, basal fertilizer was applied during the third harrowing at 50 kg ha⁻¹ for P and K, 25 kg ha⁻¹ for Zn, and 40 kg ha⁻¹ for N. In transplanted plots, the same rate of the same fertilizer was applied two days before transplanting. Land leveling was done two days before direct seeding and transplanting while the surface soil was still wet.

Pre-germinated rice seeds (24-h soaking and 24-h incubation) at the seed rate of 25 kg ha⁻¹ for each variety were sown on a well-puddled soil (2 days after leveling) in each seedbed for transplanting without basal fertilizer. On the same day, pre-germinated rice seeds were also broadcast at the rate of 50 kg ha⁻¹ (SB50) and 25 kg ha⁻¹ (SB25) in the direct-seeded plots. Nine-day old seedlings were pulled from the seedbed and were transplanted the following day in spacing of 20cm x 10cm at two seedlings hill⁻¹ or 100 plants m⁻².

The irrigation water was applied during the early stage and was drained out of the field as the day of irrigation to control golden apple snail. It was maintained at the water level of 3-5 centimeters at 14 days after sowing (DAS). Water in rice field was drained two or three weeks before harvesting to facilitate grain filling, maturity, and lodging reduction. Its N fertilizer rates (30 kg ha⁻¹) were applied depending on SPAD readings (threshold value of 36) for both transplanted and direct-seeded plots for topdressing. SPAD readings were done to adjust nitrogen application. All the plots were measured almost twice a week by SPAD starting at 21 DAS before the first top dressing N fertilizer application from early tillering stage to heading stage. The indicator of the regular SPAD readings is above the number 36. This is assumed that there is still enough nitrogen present in the leaves; therefore, nitrogen application is not required. The first topdressing of N fertilizer was at the rate of 30 kg N/ha. The second topdressing was 30 kg N/ha. Third topdressing was 60 kg N/ha for SB50 plots and 40 kg N/ha for SB25 and TP plots. The last topdressing was 40 kg N/ha. The total amount of N fertilizer applied was 200-210 kg/ha.

Data Gathering For Growth Dynamics and Morphological Characteristics of Rice Plants

Two measurements were made at about 2 week intervals on a relatively large number of rice plants that were required for growth analysis: leaf area and dry weight of all plant parts (leaves, stems, and panicles). Tiller number, and leaf area index (LAI) and shoot dry weight (ShDW) are parameters for growth dynamics which were obtained from the vegetative stage, reproductive and maturity stages. The formulas of both LAI and ShDW are as follows; (1) Shoot dry weight (g) = Stem dry weight (g) + Leaf dry weight (g) + Panicle dry weight (g), and (2) Leaf area index = Leaf area (m²)/ Ground area (m²). The following parameters for morphological characteristics of rice plants are as canopy height (cm), stem length (cm) and Blade Angle (°).

Plant Sampling and Measuring Procedure

Seedling samples were taken from the seedbed 10 days after sowing. For each genotype, two sets of sample (10 seedlings/set) were pulled out in the seedbed and brought to the laboratory and then the numbers of tillers were counted. Leaves were separated from their stems and green leaf area was then measured using a calibrated LICOR planimeter. After that the mean values of green leaf areas of each genotype were divided by two and were recorded as transplanted rice leaf area. All the leaves (dead and green leaves) and stems of each genotype were placed separately in the paper bags and then were put inside the oven at 70 °C for 48 hours afterwards to measure dry weights as a part of growth dynamic values. On the same day, randomized plant samples were taken from the area of 0.5 m² starting 10 DAS in direct-seeded plots. Next randomized plant samples were taken in each plot in both direct-seeded and transplanted plots at 15-16, 29-30, 36-37, 50-51, 64-65, 80% flowering day, and at harvest. The plant samples of the two inbreds (IR72 and PSBRc82) and new plant type genotypes were first taken at the same day and the following day the two hybrid genotypes (SL-8 and BEGANTE) were done. Roots were removed and total tiller number was then calculated. A sub-sample of 0.12 m² was randomly chosen from the area of 0.5 m². In transplanted plots, 0.5 m² corresponded to 15 hills and 0.12 m² to 6 hills. Until flowering, total tiller number was counted and leaf areas of green leaves were measured. Green leaves, dead leaves and stems were oven-dried before measuring dry weight.

Five hills in each transplanted plot were tagged. Parameters that were monitored for morphological characteristics of rice plants included canopy height, stem length, and blade angle. Canopy height was measured using a ruler

from the soil to the highest tip of the plant without stretching it. Stem length was measured from the soil to the highest collar of the plant. Blade angle (leaf angle) with the stem was read on the main tiller with the blade attached on the second highest collar using a protractor. These parameters were measured at 21, 28, 34, 42, 49, 55, 64 days after sowing (DAS) and at 80% flowering day.

At maturity, Harvest Index (HI) was calculated from the total filled grain dry weight and divided it by the total shoot dry weight.

Rice plants from an area of 2.5m x 2m (5 m²) were harvested for grain yield. The samples were threshed to get the whole grains of each plot and were dried. The grains were sun dried for two to three days. The moisture content of the grains was stabilized at 14 %. Subsequently, the total dry grain weight (kg) per 5 m² was converted into ton per hectare (t/ha) basis.

Data on grain yields of five rice genotypes was analyzed using the Statistic Analysis System (SAS) program. Treatment Means comparisons were done using the Duncan's Multiple Range Test (DMRT).

Results and discussion

Growth Dynamics

Tiller number. The tiller formation of the five genotypes is shown in Fig. 1. Tiller number per square meter of IR72 (I1) genotype increased faster than the other genotypes from 15 to 50 DAS or 5 to 40 days after transplanting (DAT) under transplanting (Fig. 1a). At 50 DAS or 40 DAT, it had the highest tiller number while the lowest was in the new plant type (N4) under the same transplanting method. After 40 DAT, the tiller number among the five genotypes started to decrease. At harvest, PSBRc82 (I3) and IR72 (I1) had the highest number of productive tiller at 559 and 541 tillers/m², respectively. The two hybrids (SL-8 (H3) and BIGANTE (H9)) and the new plant type

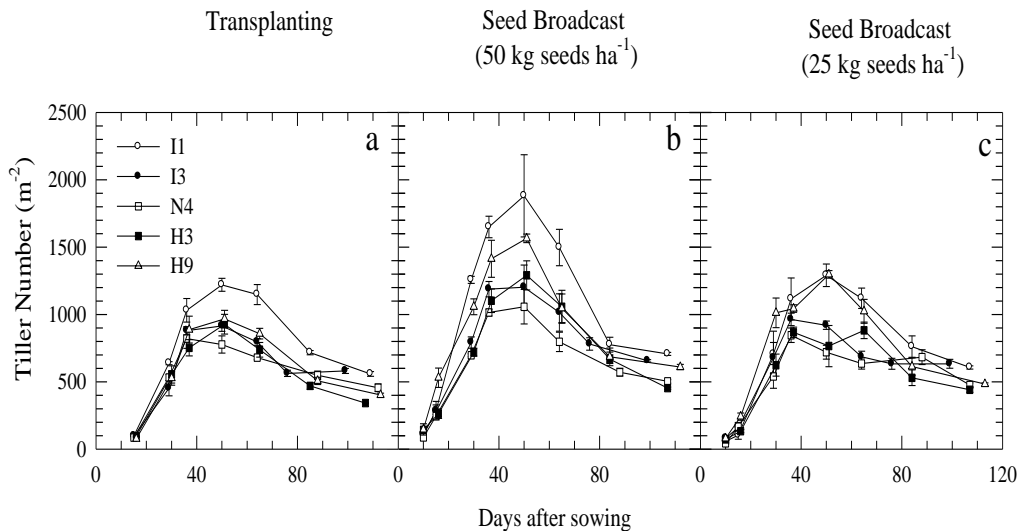


Figure 1. Tiller number of five rice genotypes under three crop establishment methods.

(N4) had lower productive tiller number at harvest. However, the higher tiller number of the two inbreds (I3 and I1) did not lead to higher shoot dry matter than the hybrid genotype BIGANTE (H9) as illustrated in Fig. 3. This is because BIGANTE (H9) had bigger and taller stem than the two inbreds (I3 and I1). Choi and Kwon (1985) reported that bigger tillers usually result in higher leaf area per tiller, hence greater shoot biomass.

The tiller number in BIGANTE was highest compared to the other genotypes during early vegetative stage in direct-seeded field at 50 kg seeds/ha (Fig. 1b). IR72 (I1) had higher tiller number compared to the other genotypes after early vegetative stage. At 50-51 DAS, IR72 (I1), BIGANTE (H9), SL-8 (H3), PSBRc82 (I3) and the new plant type (N4) had 1880, 1565, 1290, 1202 and 1057 tillers/m², respectively. The two inbreds had higher tiller number than BIGANTE while the new plant type and SL-8 had the lowest tiller number at harvest. Although IR72 had the highest tiller number 50 DAS, not all tillers were productive at harvest in direct seeding at 50 kg seeds/ha. After maximum tillering, several IR72 tillers died.

At low seed density (SB25), there was an increase in tiller number of BIGANTE (H9) from early vegetative stage up to 30 DAS. The lowest tillers were found in the new plant type (N4) in direct-seeded field (Fig. 1c). All the genotypes reached the maximum tiller number at 51 DAS but BIGANTE had the highest tillers at 1297 tillers/m². After 51 DAS, the tiller number of the five genotypes senesced until harvest. The two inbreds (I1 and I3) had higher

productive tillers than the three remaining genotypes at harvest under SB25 condition.

Leaf area index (LAI). LAI of all the genotypes were measured at early vegetative stage and their measurements were stopped by 80% flowering day as presented in Fig.2. The leaf area index of BIGANTE (H9) and SL-8 (H3) increased rapidly during the vegetative stage than the other three genotypes under the transplanting condition (Fig. 2a). At 50 DAS or 40 DAT, BIGANTE and the new plant type had higher LAI than PSBRc82 (I3) but I3 had similar LAI to SL-8 while the lowest LAI occurred in IR72 (I1) in the transplanted field. At 64 DAS or 54 DAT, the two hybrids and the new plant type (N4) had higher LAI than the two inbreds. IR72 had the lowest. However, 54 DAT, all of the genotypes had lower LAI until 80% flowering day. This reduction indicated leaf senescence. Slower leaf senescence occurred in both BIGANTE and the new plant type while the other three genotypes had faster leaf senescence. Slower leaf senescence generally lead to higher photosynthesis due to the remaining larger green leaf area to intercept light for photosynthesis and to produce more assimilates. Shin and Kwon (1985) reported that the green leaf area 30 days after heading is positively correlated with grain weight. Both BIGANTE and the new plant type had higher LAI with a value of 6 at 88 DAS or 78 DAT while PSBRc82 had only 4 at 76 DAS or 66 DAT (80% flowering day).

In direct-seeded field at the recommended seed density rate of 50 kg/ha, BIGANTE had higher LAI from early vegetative stage up to 50 DAS (Fig. 2b). Leaf expansion in BIGANTE was rapid, which indicated that it had better growth rate during the vegetative stage compared to the other genotypes. 50 DAS until 64 DAS, SL-8 (H3) had higher LAI than the other genotypes. Leaf expansion was faster compared to the other genotypes. The slowest leaf expansion was in PSBRc82 (I3) during this period. However, LAI for all genotypes decreased at 64 DAS due to leaf senescence.

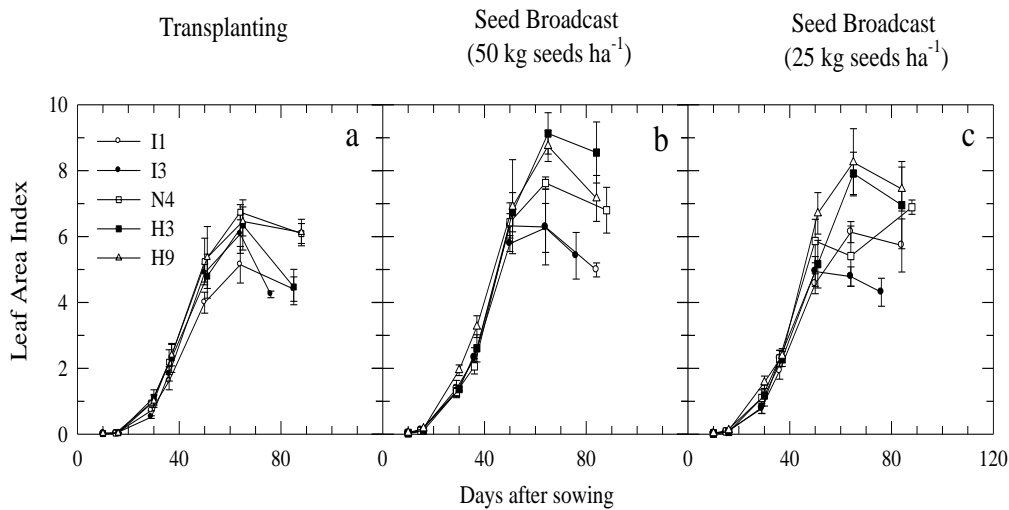


Figure 2. Leaf area index of five genotypes under three crop establishment methods.

SL-8 had the highest LAI with 8.55 at 84 DAS while the LAI for BIGANTE was only 7.2 on the same day. The new plant type (N4) had intermediate LAI (6.8) at 88 DAS while the two inbreds (PSBRc82 and IR72) had lower LAI than the three other genotypes. Higher LAI generally means higher light interception due to the leaf area's ratio to the ground area occupied by the crop. The lower LAI of two inbreds meant low light interception, leading to lower dry matter production than the hybrids (SL-8 and BIGANTE) in direct-seeded field at the recommended seed density of 50 kg/ha. Gardner et al. (1985) reported that an LAI of 3-5 is necessary for maximum dry matter production of most cultivated crops. Crops belonging to the grasses families have erectophile (upright) leaf orientation. They require an LAI of 8 -10 under favorable conditions to maximize light interception. The five rice genotypes had erectophile leaf orientation rice belong to the grasses. The hybrids (BIGANTE and SL-8) had achieved the optimum LAI while the inbreds and new plant type had LAI lower than the 8-10 LAI optimum for erectophile.

Under low direct seeding rate (SB25), BIGANTE had higher LAI than the other genotypes during early vegetative to 50 DAS (Fig. 2c). BIGANTE had faster leaf expansion (faster growth). Meanwhile, the two inbreds had lower LAI than others on the same period, which was due to smaller leaf size. From 50 to 84 DAS, BIGANTE had higher LAI compared to the others while PSBRc82 had the lowest LAI. The two hybrids had higher LAI than the new plant type and inbreds (IR72 and PSBRc82 genotypes) from early vegetative stage to 80 % flowering day.

Shoot dry weight. SL-8 (H3) genotype had the highest shoot dry weight (dry matter) from early vegetative stage to 50 DAS or 40 DAT while the lowest was in IR72 under transplanting (Fig. 3a). 70 DAS or 60 DAT, BIGANTE (H9) increased significantly in shoot dry weight over the other genotypes until harvest. Shoot dry weight per square meter for BIGANTE was 1,786 grams at harvest (113 DAS or 103 DAT). The highest shoot dry weights for the other genotypes were achieved earlier.

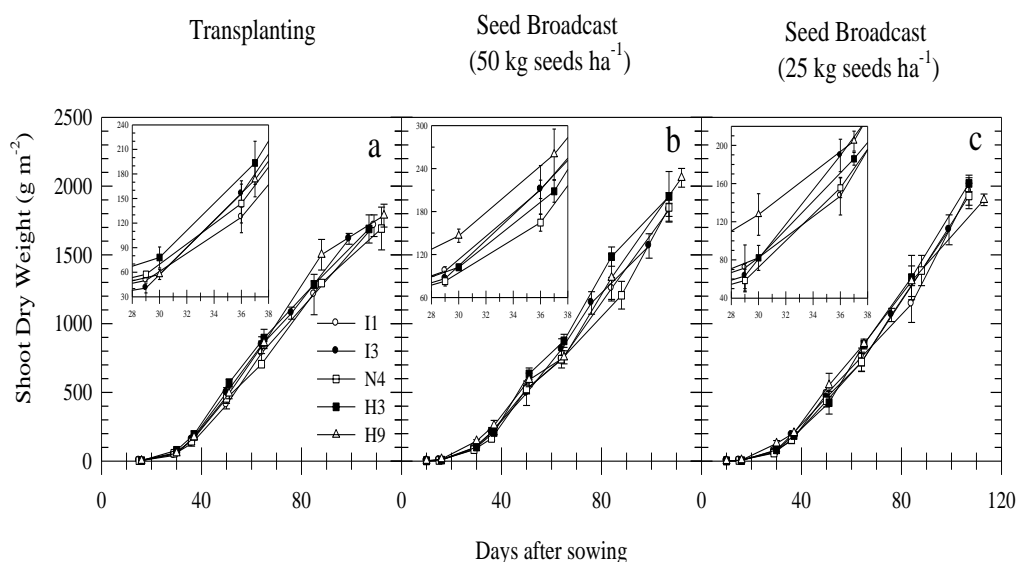


Figure 3. Shoot dry weight of five rice genotypes under three crop establishment methods.

IR72 (I1) with 1,712 grams at 109 DAS or 99 DAT, the new plant type (N4) with 1,691 grams at 111 DAS or 101 DAT, SL-8 with 1,672 grams at 107 DAS or 97 DAT, and PSBRc82 (I3) with 1,616 grams at 99 DAS or 89 DAT, at harvest. The higher shoot dry weight for BIGANTE was due to higher growth rate compared with the other genotypes. This is due to better performance of genetic characteristics in the given transplanting condition compared to other genotypes under the same condition. BIGANTE (H9) genotype had the highest dry matter among the five rice genotypes in the transplanted field. Jiang et al. (1988), Akita (1989), and Amano et al. (1993) further stated that high yield was achieved by increasing shoot dry weight production.

Shoot dry weight at vegetative stage until 50 DAS of BIGANTE (H9) was higher compared to the other genotypes (Fig. 2b) in direct-seeded field at the recommended seed density (SB50). This is due to higher tiller number during the vegetative stage. BIGANTE also had faster growth during this period leading to higher shoot dry weight. After 50 DAS until harvest, shoot dry

weight of SL-8 (H3) increased rapidly compared to the other genotypes in SB50. This was due to the leaf expansion was faster, thus the more larger leaf area the more light interception for photosynthesis to produce more assimilates for plant growth. However, shoot dry weight of SL-8 was slightly lower than BIGANTE at harvest. This is due to the shorter crop duration and low tiller number of SL-8 than BIGANTE in direct seeding (SB50). The lowest shoot dry weight was observed in PSBRc82 (I3), a short duration genotype (Fig. 3b). Short duration variety has lower dry matter (shoot dry weight) than the longer crop duration as shown in previous studies. Vergara et al. (1964) reported that traditional varieties with longer growth duration than high yielding varieties (HYVs) accumulate more carbohydrates in the culm before the reproductive stage. These accumulated carbohydrates are remobilized in the production of larger panicles and heavier grains. However, the two hybrids (SL-8 and BIGANTE) had higher shoot dry weight and longer growth duration than the two inbreds (PSBRc82 and IR72) in direct-seeded field at the recommended seed density. Thus, there were more accumulation of assimilates in the stem and leaves of BIGANTE (H9) and SL-8 (H3) genotypes during the vegetative and reproductive stages.

The shoot dry weight of BIGANTE (H9) was higher than the other genotypes from early to late vegetative stage while the four genotypes were similar in direct-seeded field at low seed density (SB25) in Fig. 3c. But SL-8 (H3) had higher shoot dry weight than BIGANTE from early reproductive (50 DAS) stage up to harvest. During harvest, the highest shoot dry weight was in SL-8 at 2,060 g/m² followed by BIGANTE, IR72 and the new plant type. The lowest shoot dry weight occurred in PSBRc82 (I3) with 1682 g/m². High shoot dry weight of SL-8 could be attributed to higher LAI during the reproductive stage from 51 – 84 DAS. It is favorable to have more light interception to the leaves in the canopy, which contributes to high shoot dry weight (dry matter) in direct-seeded field at low seed density (SB25).

At harvest, shoot dry weight of 1898 g m⁻² in broadcast seeding at SB25 was highest among the three crop establishment methods while the lowest shoot dry weight of 1695 g m⁻² occurred in the transplanting method. Shoot dry weight at 1844 g m⁻² in direct seeding (SB50) was visibly higher than the transplanting method. Thus, these indicate that the contribution of shoot dry weight production to genetic gains in grain yield potential varied among the crop establishment methods. Dingkuhn *et al.* (1990a,b,c) and Schnier *et al.* (1990a,b) studies using semi-dwarf IR cultivars showed that direct-seeded flooded rice culture results in crop growth dynamics which significantly varied from the transplanted rice. IRRI (1987), Dingkuhn *et al.* (1990) and Schnier *et al.* (1990a) confirmed that growth dynamics and partitioning patterns of

irrigated rice depend on cultural practices, particularly on planting method. Rice crop established by broadcasting have more rapid leaf area development, dry matter accumulation than transplanting during vegetative growth stage but slower growth rate after panicle initiation, particularly during the grain filling period.

Morphological Characteristics of Rice Plants

The measurement of all parameters was done only in the transplanted field because plants were sown in a fixed distance between each other (20 cm between rows, 10 cm between plants). Due to these, transplanted rice plants facilitated measurement of these parameters than direct-seeded rice plants as presented in Fig. 4. Knowing that direct-seeded rice grow better as mentioned above, the morphological characteristics of the rice genotypes under transplanting conditions were used to explain their characteristics in direct seeded fields.

Canopy height Except for IR72 (I1), four of the five genotypes had rapid increase in canopy height from early vegetative stage up to 42 DAS or 32 DAT (Fig. 4a). From 42 until 64 DAS or 32 to 54 DAT), the four genotypes had canopy height increase differently from each other with IR72 having the lowest canopy height. But the five genotypes increased in canopy height differently from 64 DAS (54 DAT) up to the 80 % flowering day; BIGANTE (H9) had the highest canopy height at 109.5 cm (90 DAS or 80 DAT), while SL-8 (H3) at 103.5 cm (83 DAS or 73 DAT), and the new plant type (N4) at 94.5 cm (90 DAS or 80 DAT). PSBRc82 (I3) had a canopy height of 89.6 cm (79 DAS or 69 DAT) while IR72 had the lowest canopy height at 82.8 cm (83 DAS or 73 DAT).

The higher canopy height of the two hybrids (H3 and H9) than the three remaining genotypes led to more favorable light penetration and better air circulation lending to higher CO₂ concentration inside the canopy (Kuroda *et al.* 1989). This was due to the wider space between the leaves of the hybrids. It should be recalled that the hybrids had achieved optimum LAI of 8.55 for SL-8 and 7.2 for BIGANTE. This higher LAI and canopy height led to higher shoot dry matter accumulation in the hybrids, particularly for BIGANTE. IR72 had the lowest canopy height and short crop duration which was unfavorable for light penetration to the lower leaf canopies resulted in lower shoot dry weight accumulation.

Transplanted Field

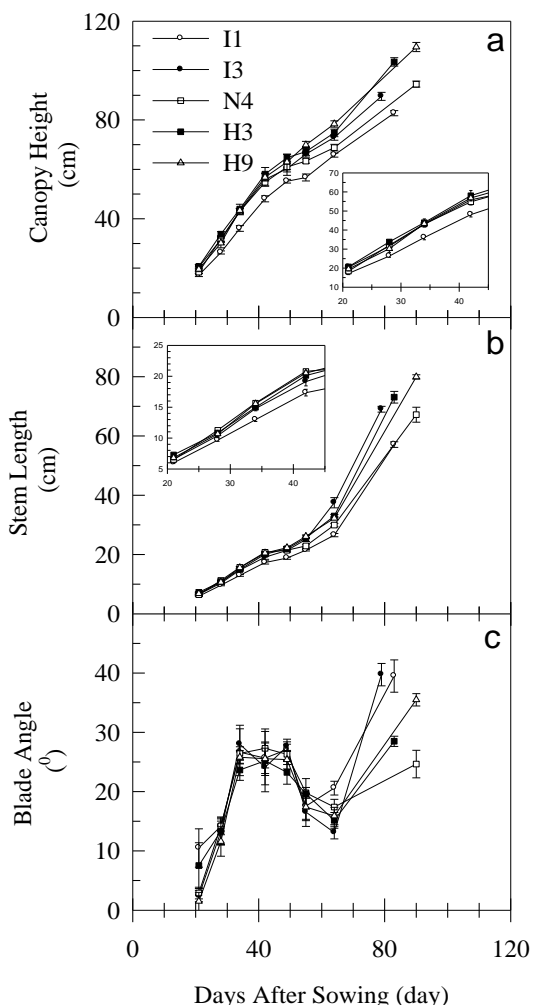


Figure 4. Morphological characteristics of rice plants in transplanted field

Stem length Stem lengths of the five genotypes varied at 64 DAS or 54 DAT up to 80% flowering day. H9 during the flowering stage (90 DAS or 80 DAT) had the highest stem length at 80 cm (Fig. 4b). Meanwhile, H3, I3, N4 and I1 had stem length of 73, 69, 67, and 57 cm, respectively. SL-8 (H3) and

BIGANTE (H9) had significantly higher stem length among the genotypes. It is apparent that the expression of genetic attribute on the stems of these hybrids and their wider space between leaves in the canopy allowed greater light penetration and higher CO₂ concentration in the lower leaf canopies resulted in higher photosynthetic rate. On the other hand, IR72 (I1) had the shortest stem with narrow space between leaves leading to mutual shading among leaves in the lower canopies which in depressed photosynthesis.

Blade angle In early vegetative stage until 28 DAS or 18 DAT, leaf blades of IR72 (I1) and SL-8 (H3) were less erect than the remaining genotypes (Fig. 4c). Less erect leaves during the early vegetative stage is good to cover the area so less light penetrate to the ground. This resulted in lower growth of weeds to compete with the crop. A high proportion of the crops studied for leaf angle are the planophile type (Trenbath and Angus 1975). This could be due to previous selection for competition to weed development in crop stands. Most weeds are severely hampered in growth due to shading. These in turn weed competition for water, nutrients, and light as a result of heavy shading covering weeds during vegetative development of SL-8. It was found out that from 34–49 DAS (or 24-39 DAT), the blade angle among the five genotypes was constant. From 64 DAS or 54 DAT to 80% flowering day, the two inbreds had less erect leaves compared to the two hybrids (H3 and H9) and the new plant type (N4). Less erect leaves of 60.5° from horizontal were both observed for I1 and I3, which were unfavorable for light distribution to the entire lower leaf canopies with short stem. Types of leaf angle have been defined by de Wit (1965). These idealized patterns range from planophile, with most leaves nearly horizontal (<35° from horizontal), to erectophile, with most leaves nearly vertical (>60° from horizontal). The angle of leaves affects radiation interception and distribution in the canopy. On the other hand, the two hybrids (H3 and H9) had more erect leaves at 71.5° and 64.5° from horizontal and also had higher stem length and canopy height than the other genotypes. The more erect leaves and high stem indicates that there are more space between the leaves in the canopy, hence light could penetrate to the lower canopies, to produce high assimilate, including high assimilate partitioning to the panicle. Chandler (1969) reported that erect leaves provide better light distribution.

Grain Yield and Harvest Index

Grain yield was significantly different in the three crop establishment methods (Table 1). Highest yield was achieved in SB25 at 9.28 t/ha followed SB50 at 8.79 t/ha. The lowest yield was achieved in TP at 7.96 t/ha. Grain yield was 16.58% or 1.32 t ha⁻¹ higher in SB25 compared with TP. There were

significant differences in grain yield among the five rice genotypes. The two hybrids (SL-8 and BIGANTE) had significantly higher grain yield at 9.59 and 9.22 t/ha, respectively than the two inbreds (IR72, PSBRc82) and the new plant type (N4). Among the two inbreds, PSBRc82 had the lowest grain yield at 7.66 t/ha. At 8.59 t/ha, inbred IR72 (I1) had comparable yield with hybrid BIGANTE (H9).

Grain yields of rice genotype were significantly influenced by crop establishment methods (TP, SB50 and SB25). SL-8 genotype yielded the highest under direct seeding methods at the recommended (SB50) and low seed density (SB25). The shift of planting method from transplanting to direct seeding methods resulted in an increase in grain yield of SL-8. Yield increases were 24.85 % (2.01 t/ha) and 30.78% (2.49 t/ha) for SL-8 in direct seeded fields at recommended and low seed density, respectively. Also, BIGANTE had higher grain yield in direct seeded fields at recommended and low seed density compared to the transplanted field. The new plant type (N4) yielded high in SB25 and lowest in TP. The difference was 1.72 t ha⁻¹ or 23.06%. The Inbred genotypes had similar yielding pattern with the new plant type under SB25. Except for the new plant type, IR72 yielded the highest under SB25.

Table 1. Grain yield (t ha⁻¹) of rice genotypes as influenced by crop establishment methods.

GENOTYPE	CROP ESTABLISHMENT METHOD			MEAN
	Transplanting (TP)	Broadcast Seeding at 50 kg/ha (SB50)	Broadcast Seeding at 25 kg/ha (SB25)	
IR72 (I1)	8.22cde	8.39cde	9.15abcd	8.59bc
PSBRc82 (I3)	7.49e	7.42e	8.08de	7.66d
IR72967-12-2-3 (N4)	7.46e	8.32cde	9.18abcd	8.32cd
SL-8 (H3)	8.09de	10.10ab	10.58a	9.59a
BIGANTE (H9)	8.52bcde	9.72abc	9.43abcd	9.22ab
Mean	7.96c	8.79b	9.28a	

Means with the same letter are not significantly different at 0.05 probability level (DMRT).

The higher yield of rice genotypes in the direct-seeded field at SB25 was contributed by morphological rice plant characteristics. Higher grain yield of SL-8 genotype (10.58 t ha^{-1}) was due to higher LAI and slower leaf senescence, longer stem, and more erect leaves during vegetative and reproductive stages. These plant characters contributed to better light interception and higher assimilate production in this genotype under SB25. Likewise, its lower productive tiller number due to its genetic expression led to bigger tillers which resulted in more assimilate accumulation in the stems and assimilates partitioning for grains at maturity. Consequently, there was higher filled grain weight per panicle and higher filled grain number per panicle for SL-8 (hybrid rice). SL-8 is a low tillering genotype while IR72 is high tillering but grain yield of SL-8 was higher. The lower productive tiller of SL-8 did not affect its grain yield compared to IR72. This is because SL-8 had bigger tillers, which results in a higher sink: source ratio, spikelet number, leaf area per tiller and sink capacity. Hayashi (1976) described a low-tiller number genotype as having a higher number of vascular bundles that facilitate the production of heavy tillers and a higher number of high density grains (Choi and Kwon 1985). The high grain index is usually higher in primary tiller than in secondary or tertiary tiller (Ahn 1986; Kim 1988). The number of vascular bundles is positively related to culm thickness, tiller order, and number of grains per panicle (Hayashi 1980). Secondary tillers have less number of vascular bundles than primary tillers; tertiary tillers have fewer vascular bundles (Hayashi 1976). But the number of vascular bundles that developed is also influenced by N nutrition (Lee et al. 1985). Therefore, these physiological and morphological characteristics contributed to meet the requirements of highest grain yield for SL-8 hybrid rice compared to the other genotypes in transplanted and direct-seeded fields at the recommended (SB50) and low seed density (SB25). While yields were higher in SL-8, the differences were not statistically different with that of BIGANTE.

Harvest index indicates the efficiency of assimilate partition to the parts of economic yield of the rice plants (i.e. panicle). Higher harvest index indicates better assimilate transport to the panicle. There was significant difference in harvest index (HI) among the five rice genotypes regardless of crop establishment method used based on mean values (Table 2). The results indicate that SL-8 (hybrid rice) had the highest harvest index (HI) with a value of 0.45. The second highest harvest index with value of 0.43 was in BIGANTE (hybrid rice). The high harvest index (HI) and bigger stem had more vascular bundles (phloem and xylem) that provided more assimilates to the panicle for the two hybrids.

Table 2. Harvest index (HI)

GENOTYPE	CROP ESTABLISHMENT METHOD			MEAN
	Transplanting (TP)	Broadcast Seeding at 50 kg/ha (SB50)	Broadcast Seeding at 25 kg/ha (SB25)	
IR72 (I1)	0.42a	0.40a	0.41a	0.41b
PSBRc82 (I3)	0.41a	0.42a	0.43a	0.41b
IR72967-12-2-3 (N4)	0.39a	0.39a	0.42a	0.40b
SL-8 (H3)	0.43a	0.47a	0.46a	0.45a
BIGANTE (H9)	0.42a	0.42a	0.44a	0.43ab
Mean	0.41a	0.42a	0.43a	

Means with the same letter are not significantly different at 0.05 probability level (DMRT).

Lower harvest index (HI) was observed in the three genotypes (IR72, PSBRc82, and the new plant type). However, their harvest indexes were not significantly different from each other. Studies of historical cultivars often show that genetic improvement in yield potential results to an increase in harvest index (Lawes, 1977; Austin *et al.*, 1980; Riggs *et al.*, 1981), which indicates that the two hybrids (SL-8 and BIGANTE) had higher harvest index than the two inbreds (IR72 and PSBRc82) and the new plant type. Better assimilate partitioning from the source (leaf and non-laminar organ i.e., leaf sheath, stem, flag leaf) to the panicle (sink) occurred in the two hybrids compared with the two inbreds and the new plant type.

Higher harvest index (HI) in the two hybrids was related to their higher grain yields while lower harvest index (HI) in the two inbreds and the new plant type was likewise related to lower grain yields.

There were no significant differences in harvest index (HI) among the three crop establishment methods and no significant interactions in HI between genotypes and the crop establishment method used.

Relationships of Grain Yield with Plant Parameters

Through stepwise multiple regression analysis, the plant parameters most significantly influence yield were determined. In the three crop establishment method, there were 2 common plant parameters (shoot dry weight and harvest index (HI)) that significantly determined grain yield. The equations were as follows:

$$\begin{aligned} \text{Grain yield}_{(TP)} &= - 7.44 + 0.0045(\text{shoot dry weight} \\ &\text{per square} \\ &\text{meter}) + 18.83(\text{harvest index}) \\ &\quad (1) \end{aligned}$$

$$R^2 = 0.99^{**}$$

$$\begin{aligned} \text{Grain yield}_{(SB25)} &= - 9.93 + 0.0051(\text{shoot dry weight} \\ &\text{per square} \\ &\text{meter}) + 22.29(\text{harvest index}) \\ &\quad (2) \end{aligned}$$

$$R^2 = 0.99^{**}$$

$$\begin{aligned} \text{Grain yield}_{(SB50)} &= - 9.72 + 0.0056(\text{shoot dry weight} \\ &\text{per square meter}) + 20.21(\text{harvest} \\ &\text{index}) \\ &\quad (3) \end{aligned}$$

$$R^2 = 0.99^{**}$$

Grain yield in the transplanting crop establishment method can be explained by the shoot dry weight per meter square and harvest index with 99 % accuracy as shown in the multiple regression equation (1). The positive coefficient values indicate that by increasing harvest index (HI) and shoot dry weight, grain yield also increases. Shoot dry weight is the combination of panicle dry weight, leaf dry weight and stem dry weight. The higher leaf dry weight indicates that more leaves are photosynthetically productive. Later on, assimilates move to the stems. Higher stem dry weight implied more space to accumulate carbohydrates and more green stem areas (non-laminar) to intercept light for photosynthesis producing assimilates for grain filling. Hence, as shoot dry weight increases, grain yield also increases.

Likewise, an increase in harvest index indicates higher efficiency of assimilates transported to the panicle. Consequently, higher grain yield were obtained for these rice genotypes. It was mentioned earlier that an increase in both shoot dry weight and harvest index is directly related to obtaining higher grain yields.

The same result was obtained for direct seeding both at 25 kg/ha (SB25) and 50 kg/ha (SB50). Shoot dry weight per square meter and harvest index

explain 99 % of the grain yield of the five rice genotypes as shown in equation (2) and (3). The positive coefficient values indicate that when harvest index and shoot dry weight increase, grain yield also increases.

Summary and Conclusion

Direct seeding in rice is increasingly replacing transplanting in puddled soil, even though transplanting is still the most common crop establishment method in irrigated areas. It is important to check which plant characteristics are affected by crop establishment methods and how different genotypes are performing particularly at low seed density. This study was conducted to assess the growth dynamics of rice genotypes grown in transplanted and direct-seeded fields at recommended (50 kg/ha) and low seed density (25 kg/ha) and to identify morphological plant characteristics that contribute to higher grain yield. Five rice genotypes were utilized consisting of two inbreds (IR72 and PSBRc82), two hybrids (SL-8 and BIGANTE), and a new plant type (IR72967-12-2-3), during the dry season (DS) of January to May 2005 at the experimental farm of the Philippine Rice Research Institute (PhilRice) in Maligaya, Science City of Muñoz, Nueva Ecija, Philippines. The experiment was laid out in a split plot in randomized complete block design (RCBD) with crop establishment methods on the main plot and rice genotypes on the sub-plot.

Rice genotypes had % higher yield in direct seeded (9.03 t/ha) than in transplanted fields (7.96 t/ha). Direct-seeded rice had higher crop growth rates during vegetative stage than transplanted rice. They rapidly developed larger leaf areas and accumulated more dry matter. Transplanted seedlings exhibited transplanting shock which delayed their establishment and reduced their tillering and leaf area. Broadcast seeding at 25 kg/ha produced higher grain yield than broadcast seeding at 50 kg/ha and transplanting. The hybrids (SL-8 and BIGANTE) had longest canopy height, more erect leaves, longest stem length, largest leaf area, highest harvest index (HI) and greatest shoot dry weight at physiological maturity. They had more erect leaves, longer stem and taller canopies resulting to greater light penetration inside the canopies due to more space between leaves. All of these morphological and physiological attributes of the hybrids contributed to their higher grain yield than the three remaining genotypes.

SL-8 had the highest shoot dry weight from early vegetative stage to 51 DAS whereas BIGANTE (hybrid rice) had better growth rate after 70 DAS until harvest due to higher shoot dry weight. This higher shoot dry weight of the two hybrids was found strongly associated with higher grain yield through multiple regression analysis. In broadcast seeding at 50 kg/ha, BIGANTE had

faster growth rate than the other genotypes during early vegetative stage until 50 DAS accumulating more carbohydrates for grain filling. After 51 DAS until harvest, SL-8 had faster and better growth rate as indicated by higher shoot dry weight. These results suggest that the current hybrids can be established through direct seeding and at low seed density (25 kg/ha). The prevailing practice is to establish hybrids through transplanting.

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