
Leaf elongation rate, agronomic traits and grain yield of three transplanted rice genotypes

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This study was conducted to determine if leaf elongation rate (LER) is related to some agronomic traits and grain yield of three transplanted rice genotypes, two inbreds (IR64 and IR72) and one hybrid (SL-8). Faster day and night LERs were observed in the two inbreds more than the hybrid. Night LER was positively correlated with grain yield. Conversely, leaf blade length was negatively correlated with grain yield. The two inbreds had significantly shorter leaf blade length than that of the hybrid. Duration of leaf elongation was negatively correlated with filled grain number. Shorter duration of leaf elongation increased carbohydrate accumulation in the culm during the vegetative stage, and high accumulated carbohydrates partitioned to the grains resulted to higher percent filled grain in IR64 inbred. High root dry matter of IR72 and SL-8 caused lower grain yields. Root dry matter was negatively correlated to percent filled grain. Number of productive tillers had strong positive correlation with grain yield. IR64 had higher grain yield than SL-8 and IR72 due to higher number of productive tillers, high shoot dry matter, high harvest index, higher shoot:root ratio, greater percent filled grain, and high grain density. IR64 had also the highest night LER.

Key words: Yield components, agronomic traits, leaf elongation rate, night leaf elongation rate, day leaf elongation rate, crop duration, duration of leaf elongation, harvest index, shoot: root ratio

Introduction

Diurnal (day) leaf elongation of rice (*Oryza Sativa* L.) under well-watered conditions was characterized by a high daytime rate and a lower nighttime rate with a transient decrease at the night-to-day transition and a transient increase at the day-to-night transition. Leaf elongation rate (LER) of well-watered control plants in the growth chamber was greater during the day than at night even though bulk leaf turgor potential that was less during the day (Cutler *et al.*, 1980). At the transition to night conditions, elongation rate and

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turgor pressure (Ψ_p) rapidly increased after which the rate declined to a relatively steady and lower rate, even though Ψ_p remained high. Similar diurnal patterns of leaf elongation have been observed in maize (Watr, 1974), sorghum (Johnson, 1976), and wheat (Christ, 1978).

Using sucrose-phosphate synthase (SPS) kinetic in rice to determine the relationship between SPS activity and LER, Rowland-Bamford and Boote (1988) simplified the measurement of LER as rice blades are like those of other monocots in that it grows from a basal meristem. The SPS is the key enzyme in controlling sucrose (the major compound transported) synthesis in the leaves (Huber and Israel, 1982). Although enhanced CO_2 assimilation rates of expanded leaves at elevated CO_2 concentrations is likely to be the first step in providing the extra carbohydrate for accelerated LER early in ontogeny. It is ultimately the production and transport of sucrose to the growing leaf blade that is crucial in controlling LER (Nelson and Mac Adam, 1989). Since phloem transport of sucrose does not appear to limit blade growth, sucrose synthesis is likely to be a key step in determining LER, especially early in ontogeny when the growing blade is the major sink for carbohydrate in the shoot (Bachmann *et al.*, 1994). The early advantage gained by faster leaf area production at high CO_2 results in greatly increased grain yield in crops such as rice and wheat (Conroy *et al.*, 1994; Seneweera *et al.*, 1994). Dingkuhn *et al.* (1990a) cited that the translation of high dry matter accumulation into higher grain yield depends on numerous factors that include cultural practices, climate and genotype. This study was conducted to determine if LER is related to some agronomic traits and grain yield of the three transplanted rice genotypes: IR64, IR72 and SL8. These genotypes were selected because they are generally favored by local farmers for their high yields, have good eating quality and they performed well in irrigated area.

Materials and Methods

Time and Place of the Study

The study was conducted during the dry season of January to May of 2007 at the pot experiment station of International Rice Research Institute (IRRI), Los Baños, Laguna, Philippines. It is geographically situated at latitude of $14^\circ 13'$ N and longitude of $121^\circ 15'$ E at an elevation of 23 m above mean sea level. The pot experiment was conducted under tropical climate. The climate data obtained from the IRRI climate unit during the study indicated that radiation ranged from 13.2 to 20.2 MJ m^{-2} . Day temperature ranged from 29.0 to 34 $^\circ\text{C}$, while night temperature ranged from 22.5 to 24.8 $^\circ\text{C}$. Evaporation

varied from 2.6 to 6.9 mm, and precipitation ranged from 0.30 to 6.20 mm. Relative humidity was from 81% to 84% and wind speed ranged from 1.2 to 2.7 m s⁻¹.

Rice Genotypes

Three irrigated rice genotypes consisting of two inbreds (IR64 and IR72) and one hybrid (SL-8) were used in the study. Rice genotypes were arranged in a randomized complete block design (RCBD), replicated four times. The same sizes of ten-day-old seedlings were pulled out from the seedling trays and transplanted in pots with a dimension of 8 inches high x 8 inches diameter. Each pot contained four (4) kg of soils with five (5) seedlings (one seedling per hill). After transplanting, all the pots were placed in open space for air exposure up to harvest. At heading stage to maturity, rice plants were covered with fishnets to protect them from bird-damage.

Before transplanting, basal fertilizers were applied at the rate of 2.20 g P pot⁻¹; 0.34 g K pot⁻¹; and 0.08 g Zn pot⁻¹. After transplanting, only nitrogen (N) fertilizer was used for topdressing. The same rate of application of 0.30 g N pot⁻¹ (Urea) was done 10 days after transplanting, before maximum tillering, and at panicle initiation (PI). At flowering stage, 0.23 g N pot⁻¹ was applied. Standing water was maintained from the transplanting date until harvest.

Plant Sampling and Maturing Procedure

At tillering stage, the 9th leaf on the culm of each genotype was used for day and night LER from the first day of the leaf appearance until the last day of the leaf elongation. Day and night LER was measured at 30-37 days after sowing (DAS) or 20-27 days after transplanting (DAT) for the IR64 inbred genotype, 31-41DAS or 21-31 DAT for the SL-8 hybrid genotype, and 32-39 DAS or 22-29 DAS for the IR72 inbred genotype. A ruler was used to measure leaf elongation in a unit of centimeter (cm). Measurement of LER was done twice a day at 12-hour intervals, from 6:00 am to 6:00 pm and again from 6:00 pm to 6:00 am. Measurement of night leaf elongation was at 6:00 a.m.; day leaf elongation was at 6:00 p.m. Leaf elongation rate was computed as $LER = (LE2 - LE1) / (T2 - T1)$ where: LER = leaf elongation rate (mm hr⁻¹); LE1 = leaf elongation at a given time 1 (mm); LE2 = leaf elongation at a given time 2 (mm); T1 = 0 hr; and T2 = 12 hr. The average of day LERs from the first day of leaf appearance until the last day of leaf elongation was calculated and reported as day LER in a unit of millimeter per hour (mm hr⁻¹). Likewise, the average night LER was reported as night LER in the same unit. Leaf blade

length was measured on the following day after leaf elongation have ceased in a unit of centimeter (cm). Duration of leaf elongation refers to the period from the first day of leaf appearance until the last day of leaf elongation in a unit of day. Leaf blade length and duration of leaf elongation were classified as agronomic trait at tillering stage.

At maturity, data on the agronomic traits that include crop duration, harvest index, shoot dry matter, root dry matter, shoot:root ratio and percent (%) filled grain were taken. Yield components including productive tiller number per hill, number of filled and unfilled grains per hill, 1000-filled grain dry weight were likewise obtained. Five hills per pot and four pots per genotype were harvested using scissors to cut the panicles from the productive tiller. Roots from each pot were also cut from the stem using scissors and were washed with water to remove the soil. In each pot, all the roots, panicles, stems and leaves were put separately in paper bags and dried in the oven for 48 hours at 70°C temperature. The panicles from each pot were threshed to get the whole grains. The moisture content of the grains was stabilized at 14 percent. Total grains were weighed and computed for the grain yield in a unit of gram per hill (g hill^{-1}).

Crop duration refers to the life cycle of the crop from sowing date to harvesting, in a unit of day. Harvest index (HI) was computed by dividing the total filled grain dry weight by the sum of the panicle dry weight, the stem dry weight and the leaf dry weight. Shoot dry matter is the sum of the panicle dry weight, the stem dry weight and the leaf dry weight in a unit of gram per hill (g hill^{-1}). Root dry matter was recorded in a unit of gram per hill (g hill^{-1}). Shoot:root (S:R) ratio was calculated by dividing the shoot dry matter by the root dry matter. The number of productive tillers in each pot was counted and recorded in a unit of number per hill (no hill^{-1}). Filled grain and unfilled grain number in each pot were counted and recorded in a unit of number per hill (no hill^{-1}). Percent (%) filled grain was calculated by dividing the total number of filled grain per panicle by the total number of filled and unfilled grain per panicle and then multiplying the result by 100. The representative of two hundred filled grains were weighted and scaled to 1,000-filled grain dry weight in a unit of gram (g).

Data on day and night leaf elongation rates, agronomic traits and yield components of three transplanted rice genotypes were analyzed using randomized complete block design (RCBD). Mean comparisons were done through Least Significant Difference (LSD). Relationships of grain yield with all other plant variables were determined using correlation analysis. All analyses were done using the statistical analysis system (SAS).

Results and Discussion

Day and Night Leaf Elongation Rates, Duration of Leaf Elongation and Leaf Blade Length of Rice Genotypes

At tillering stage, day LERs of the two inbred (IR64 and IR72) genotypes were significantly higher than the SL-8 hybrid genotype (Table 1). On the other hand, the night LER of IR64 at 1.62 mm hr⁻¹ was found to be significantly higher than SL-8 (1.46 mm hr⁻¹) but not significantly different from IR72 inbred (1.59 mm hr⁻¹). Christ (1978) cited that effects of low night temperature limited the carbohydrate required for leaf expansion. The faster day and night LERs of the two inbred (IR64 and IR72) indicated that the leaves produced higher amount of carbohydrates in both days and night periods than the SL-8 hybrid genotype. Further, as both inbreds are also high tillering genotypes, higher amount of carbohydrates produced led to faster production of tillers per hill (plant). High production of tillers mean more number of leaves per hill, hence more leaves to intercept light for photosynthesis. (Conroy *et al.*, 1994; Seneweera *et al.*, 1994) reported the advantage gained by faster leaf area production at high CO₂ results in greatly increased grain yield in rice.

Table 1. Day and night leaf elongation rate on the culm, duration of leaf elongation and leaf blade length of rice genotypes grown under transplanting with 1 seedling per hill.

Genotype	Day leaf elongation rate (mm hr ⁻¹)	Night leaf elongation rate (mm hr ⁻¹)	Leaf blade length (cm)	Duration of leaf elongation (day)
IR64	2.09a	1.62a	28.94b	6.50b
SL-8	1.75b	1.46b	36.59a	9.50a
IR72	2.20a	1.59ab	30.70b	6.75b
CV (%)	7.96	5.89	5.76	7.28

Note: In a column, means followed by a common letter are not significantly different at $P < .05$ based on LSD.

Day LERs of all three genotypes were greater than night LERs throughout the observation periods (Table 1). The transition from day to night resulted in a reduction of LER in IR64 by 22.49 percent (0.47 mm hr⁻¹), in IR72 by 27.73 percent (0.61 mm hr⁻¹), and in SL-8 by 16.57 percent (0.29 mm hr⁻¹). This implies that the higher reduction of LER during transition from day to night in the two inbreds provided high carbohydrate accumulation at nighttime. Watrs (1974) and Hsiao *et al.* (1976) reported that when elongation occurred, day elongation was equal to or greater than that at night, despite

greater bulk leaf and turgor pressure (Ψ_p) at night. Cutler *et al.* (1980) cited that leaf elongation rate of well-watered control plants in the growth chamber was greater during the day than at night even though bulk leaf turgor potential was less during the day. As blade growth is not limited by the phloem transport of sucrose (Bachmann *et al.*, 1994), sucrose synthesis is likely to be crucial in determining LER, especially early in ontogeny when the growing blade function as the major sink for carbohydrate in the shoot.

In this study, leaf blade length of the two inbred (IR64 and IR72) genotypes from the first day of appearance until the last day of leaf elongation were found to be not significantly different, although their leaf blade lengths were shorter than that of the SL-8 hybrid. Correlation analysis showed that leaf blade length of rice genotypes had strong negative correlation ($r = -1.00$) with grain yield (Table 3). The longer leaf blade length of SL-8 was due to high carbohydrate utilization for growth, thus, lowering carbohydrate accumulation in the culm during the tillering stage. This resulted in the delay for the production of the new tiller, which led to lower number of tillers per hill at the tillering stage. This in turn resulted to low productive tiller per hill which also led to lower grain yield at maturity. Likewise, leaf blade length had strong negative correlation with night LER ($r = -0.99$). This implies that an increase in night LER is likely to produce larger cells and/or increase the number of cells in the leaf resulting to a thicker leaf. The two inbreds (IR64 and IR72) had higher night LER than the SL-8 hybrid thus IR64 and IR72 genotypes had thicker leaves than the SL-8 hybrid. The two inbreds had significantly shorter leaf blade lengths than SL-8 hybrid. The duration of leaf elongations of the two inbreds were found to be significantly shorter than the hybrid. Thus, the shorter duration of leaf elongation and faster LER in IR64 and IR72 could contribute to higher dry matter production which could then be translated into higher grain yield (Dingkuhn *et al.*, 1990a).

Grain Yield, Yield Components and Agronomic Traits of Rice Genotypes

Grain yields of rice genotypes varied from 14.35 to 17.22 g hill⁻¹ (Table 2). Although no significant difference in grain yield was noted among the three genotypes, grain yield of IR64 inbred was higher by 20% (2.87g hill⁻¹) than that of SL-8 hybrid. Likewise, IR64 was higher by 3.99% (0.66 g hill⁻¹) than

that of IR72 inbred. Correlation analysis showed that high grain yield was positively correlated with high night LER ($r = 0.99$, Table 3). This means that higher night LER was translated into higher grain yield. A higher night LER is likely to cause thicker leaf in rice. Yoshida (1972) reported that thicker leaves in rice have higher photosynthetic rate per unit leaf area. In this case, the two inbreds, IR64 and IR72, have thicker leaves than the SL-8 hybrid, which means that carbohydrates were synthesized resulting to higher grain yields. Of the two inbreds, the night LER of the IR64 was slightly higher than IR72. Thus, IR64 inbred had higher grain yield than IR72 inbred.

Longer crop duration was significantly observed in IR72 (126 days), followed by SL-8 (119 days), while the IR64 (114 days) was the shortest (Table 2). Vergara *et al.* (1964) mentioned that traditional rice varieties with longer growth durations accumulate more carbohydrates in the culm before reaching the reproductive stage than high-yielding varieties (HYVs). Carbohydrates from the culm can contribute to the grain weight by as much as 26% (Cock and Yoshida, 1972). In this case, IR72 which had the longest crop duration would have high carbohydrates production which it could utilize in the production of more productive tiller per hill which could then lead higher shoot dry matter weight (22.03 g) as shown in Table 2. However, IR72 had low carbohydrate translocation to the grains as compared to the IR64, a short crop duration genotype, as observed in their grain yields at maturity. IR64 had also higher harvest index (HI = 0.46) than that of IR72 at HI = 0.41.

Harvest index (HI) is an indicator of the efficiency of carbohydrate partitioning to the grains. Higher HI means greater amount of carbohydrate was translocated to the grains (sink). HI values obtained in this study for SL-8 and IR72 transplanted at 1 seedling per hill were similar to those obtained by Wiangsamut *et al.* (2006) for the same genotypes (SL-8 and IR72) but under different transplanting method of 2 seedlings per hill. However, the lower HI in IR72 inbred than that of IR64 was due to high carbohydrates translocated to the root for root growth (Table 2). This suggested that, in the IR72 inbred, there was sink competition between root and grain to capture carbohydrates for growth.

Root dry matter was not significantly different between the SL-8 hybrid and IR72 inbred, although both had statistically greater root dry matter than that of IR64 inbred (Table 2). Root dry matter hill⁻¹ in SL-8 hybrid was 48.84 percent or 1.26 g greater than root dry matter in IR64. While root dry matter hill⁻¹ in IR72 was 68.99 percent or 1.78 g greater than that in IR64. White (1937) cited that root growth is determined by residue of carbohydrate available after the shoot had used its requirements. Correlation analysis indicated that high root dry matter per hill was correlated with low percent

filled grain ($r = -0.99$, Table 3). Greater root dry matter in SL-8 and IR72 than that of IR64 was observed at maturity. This indicated that there was a high sink competition between root and grain for the carbohydrates in SL-8 and IR72 during the grain filling period. In this case, sink competition meant that more carbohydrates were partitioned to the roots than to grains. Hence, IR64 obtained higher grain yield than SL-8 and IR72.

The IR64 inbred had significantly greater shoot:root (S:R) ratio than both IR72 inbred and SL-8 hybrid (Table 2). Luquet *et al.* (2005) reported that a decrease in S:R ratio results from modifications of carbohydrate partitioning. Hence, in the case of IR64, it was evident that more carbohydrates were utilized for shoot growth than root growth. The S:R ratio of IR64 was 61.26 percent higher than SL-8 hybrid and 56.68 percent higher than IR72. Grain yield of IR64 was 20 percent higher than SL-8 hybrid and 3.99 percent higher than IR72 inbred, suggesting that more carbohydrates partitioned to the grains of the IR64 inbred. Thus, slightly higher shoot dry matter and slightly lower grain yield in IR72 than IR64 indicated that there was a high carbohydrate accumulation in the leaves and stems of IR72 inbred rather than in the grains. This was also supported by the lower harvest index, lower percent filled grain and higher unfilled grain of IR72 inbred than that of IR64 inbred.

The production of number of productive tillers in IR64 inbred (14 hill^{-1}) was significantly higher than SL-8 hybrid (7 hill^{-1}) and IR72 inbred (12 hill^{-1}) (Table 2). Hayashi (1976) stated that a low-tiller-number ideotype would ensure a higher number of vascular bundles to facilitate the production of heavy tillers and a higher number of high density grain (Choi and Kwon, 1985). While SL-8 hybrid produced heavier grain than IR64 and IR72, it is still produced lower yield because of its low number of productive tillers per hill as compared to the two inbred genotypes. High productive tiller number was found to be closely correlated with shorter leaf blade length. This suggests that during the tillering stage, longer leaf blade length resulting from high carbohydrate utilization led to low carbohydrate residue. In turn, low carbohydrate residue delayed tillering which led to lower tiller number produced. In the case of SL-8 hybrid, this eventually resulted to low productive tiller number at maturity. Correlation analysis indicated that productive tiller number per hill had a strong positive correlation ($r = 0.99$) with grain yield. This meant that an increase in productive tiller number per hill resulted from higher tiller number at the tillering stage. This meant the production of more leaves and more leaf areas that contributed to more light interception for photosynthesis. In general, the shorter leaf blade length genotypes have erect leaves and better leaf arrangement for photosynthesis. Thus, an increase in productive tiller per hill could result to an increase in the grain yield.

Number of filled grains per hill of the two inbreds, IR64 and IR72, was found to be significantly higher than the SL-8 hybrid, which was due to their higher number productive tillers. High filled grain number per hill was found to be closely correlated with low duration of leaf elongation ($r = -0.99$). Prolonged duration of leaf elongation affects the carbohydrate accumulation in the culm during the vegetative stage. Low accumulated carbohydrates partitioned to the grains resulted to higher number of unfilled grains per hill at maturity. Eventually, grain yield was reduced.

The significantly lower number of unfilled grain per hill of the IR64 inbred than both IR72 inbred and SL-8 hybrid provided an edge to overcome the yield of the latter genotypes. The low number of unfilled grains of IR64 that resulted from the higher carbohydrates partitioned to the grains led to higher percent filled grain than that of the SL-8 hybrid and IR72 inbred. The high carbohydrates translocated to the roots in both for SL-8 and IR72, as mentioned earlier, resulted to heavier root dry matter weight than that of IR64. The unfilled grain number per hill had strong positive correlation with crop duration ($r = 0.99$). This condition indicated that there was a limitation of carbohydrate supply to the grains for the rice genotypes. Sink competitions occurred in the whole of the plant for plant cell survival.

In terms of 1000-filled grain dry weight, SL-8 hybrid had significantly heavier grain (25 g) than the two inbreds, IR64 and IR72, with 22.32 g and 21.56 g, respectively. Although SL-8 hybrid had higher filled grain weight than the two inbreds, its low productive tiller number and high number of unfilled grains resulted to lower grain yield. The 1,000-filled grain dry weight was negatively correlated with day LER ($r = -0.99$). This suggested that an increase in day LER due to high carbohydrate use led to low carbohydrate accumulation in the culm which in turn led to low carbohydrate partitioned to the grains. Takita (1986) stated that the 1,000-filled grain weight >26 g has low density and is usually not completely filled. In this study, 1000-filled grain weight <26 g was observed in all the three genotypes (IR64, SL-8, and IR72). Hence, the three genotypes had high grain density.

Conclusion

Grain yields of the three transplanted rice genotypes, two inbreds (IR64 and IR72) and one hybrid (SL-8), were influenced by leaf elongation rate (LER). Of the three genotypes, day LER was greater than night LER. Faster day and night LERs were observed in the two inbreds than the hybrid. Night LER was positively correlated with grain yield. The transition of day to night led to the reduction of leaf elongation rate in the three transplanted rice

genotypes. Leaf blade length was negatively correlated with grain yield. The two inbreds had faster night LER, shorter leaf blade length, thicker leaves and higher grain yield. Duration of leaf elongation was negatively correlated with filled grain number. Shorter duration of leaf elongation of IR64 inbred help increased carbohydrate accumulation in the culm which resulted to its higher percent filled grain or lower unfilled grain number at maturity. Root dry matter was negatively correlated with percent filled grain. Higher root dry matter were found in both IR72 and SL-8 than IR64 because of their low shoot:root ratios. Number of productive tillers had a strong positive correlation with the grain yield. Therefore, IR64 had higher grain yield than SL-8 and IR72 IR64 due to higher number of productive tillers, high shoot dry matter, high harvest index, higher shoot:root ratio, greater percent filled grain, and high grain density.

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Table 2. Yield components and other agronomic traits of the irrigated rice enotypes grown under transplanting with 1 seedling per hill.

Genotype	Grain yield (g hill ⁻¹)	Crop duration (day)	Harvest index (HI)	Shoot dry matter (g hill ⁻¹)	Root dry matter (g hill ⁻¹)	Shoot : Root (S:R) ratio	Productive tiller (no hill ⁻¹)	Filled grain number (no hill ⁻¹)	Unfilled grain number (no hill ⁻¹)	% Filled grain	1,000-filled grain dry weight (g)
IR64	17.22a	114c	0.46a	19.77a	2.58b	7.66a	14a	770a	70c	92a	22.32b
SL-8	14.35a	119b	0.45a	18.23a	3.84a	4.75b	7c	574b	126b	82b	25.00a
IR72	16.56a	126a	0.41a	22.03a	4.36a	5.05b	12b	768a	216a	78b	21.56b
CV (%)	13.59	0	10.65	11.54	18.61	19.00	10.16	9.55	25.70	5.54	3.23

Note: In a column, means followed by a common letter are not significantly different at $P \leq 0.05$ based on LSD.

Table 3. Leaf elongation rate and agronomics traits correlated with grain yield of irrigated rice genotypes grown under transplanting method with one seedling per hill.

	Day leaf elongation rate (mm hr ⁻¹)	Night leaf elongation rate (mm hr ⁻¹)	Duration of leaf elongation (day)	Leaf blade length (cm)	Crop duration (day)	Productive tiller (no hill ⁻¹)	% filled grain
Grain yield	ns	r = 0.99*	ns	r = -1.00**	ns	r = 0.99*	ns
Night leaf elongation rate (mm hr ⁻¹)	ns	ns	ns	r = -0.99*	ns	ns	ns
Root dry matter (g hill ⁻¹)	ns	ns	ns	ns	ns	ns	r = -0.99**
Productive tiller (no hill ⁻¹)	ns	ns	ns	r = -0.99*	ns	ns	ns
Filled grain number (no hill ⁻¹)	ns	ns	r = -0.99*	ns	ns	ns	ns
Unfilled grain number (no hill ⁻¹)	ns	ns	ns	ns	r = 0.99*	ns	ns
1,000 filled grain dry weight (g)	r = -0.99*	ns	ns	ns	ns	ns	ns

Note: r = correlation coefficient; ns =not significant; * = significant at 0.05 probability level; ** = significant at 0.01 probability level.