한작지(Korean J. Crop Sci.), 52(3): 249~258(2007)

Characterization of Biomass Production and Seedling Establishment of Direct-Seeded Nogyangbyeo, a Whole Crop Rice Variety for Animal Feed

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ABSTRACT Experiments were conducted with aims to (1) estimate the biomass yield potential, (2) characterize the biomass and digestible dry matter production, and (3) reveal the characteristic seedling establishment of a whole crop rice variety, Nogyangbyeo, in dry- and wet-seeded rice. Maximum aboveground total biomass of Nogyangbyeo was 18 t ha^{-1} in dry-seeded rice and 20 t ha^{-1} in wet-seeded rice. Biomass yield potential of Nogyangbyeo was lower than that of Dasanbyeo. Comparatively, Nogyangbyeo was straw-dependent and Dasanbyeo was grain-dependent for biomass accumulation. Percentage of digestible dry matter (DDM) was higher in panicles than straw. Digestible dry matter yield was determined mainly by biomass yield rather than DDM percentage. Number of seedling establishment in Nogyangbyeo was 73 m^{-2} in dry-seeded rice and 109 m^{-2} in wet-seeded rice. Poor seedling establishment of dry-seeded Nogyangbyeo in the field condition was the result of low seed germination under low temperature and poor seedling emergence by deep sowing. Low seedling emergence rate of Nogyangbyeo was attributed mainly to slow elongation growth by slow leaf development and partly to mesocotyl and 1st internode lengths, not to genetically defined leaf length. The slow elongation growth of Nogyangbyeo was the same even in the high daily mean temperature of 24℃. Results suggest DDM yield in rice can be improved simply by increasing biomass and whole crop rice varieties should be adaptable to direct-seeding.

Keywords : whole crop rice, Nogyangbyeo, direct-seeding, biomass, digestible dry matter, seedling establishment

Recently, alternative crop production in rice paddy is drawing more attention due to rice production in excess of consumers' demand as a food and possible future market conditions in Korea. Introduction of forage crops to replace rice in paddy has been suggested as a promising option, including maize, sorghum-sudan grass hybrid, barnyard grass, pearl millet, and rice (Kim *et al.*, 2006; Choi *et al.*, 2006). Among these crop species, only the production of maize increased by improving productivity through hybrid vigor, due to the importance as a silage crop in Korea (Jung, 1998). However, most upland crops cannot grow and yield well in lowland, particularly due to downpours during rainy season in July and August (Lee *et al.*, 1994; Kim *et al.*, 2006). Suggestions were made to domesticate wild plant species, such as *Panicum dichotomiflorum* Michx. (Jong *et al.*, 1995) and *Puccinellia coreensis* Honda (Kim *et al.*, 1994), as forage crops but the attempts were not so successful.

Among the above crop species as forage, it was suggested that cultivation of whole crop rice for animal feed should be considered as an alternative crop for rice for human diet in order to avoid overproduction of rice for human's consumption and supply more resource for animal feed, while maintaining lowland flooded not to lose its public advantages (Sung *et al.*, 2004; Kim *et al.*, 2006). Rice straw, as a by-product, has been utilized as roughage for cattle feeding but was reported nutritionally inferior that limited its utilization (Kim, 2004). Additives are known to improve silage quality of rice since rice straw has low sugar content (Kim *et al.*, 2004). Addition of formic acid or lactic ferments for the improvement of silage quality was suggested (Kim *et al.*, 1999; Leibensperger & Pitt, 1999; Wohlt, 1989). Formic acid was reported to improve silage quality by inhibiting degradation of protein through rapid decline of pH (Thomas, 1978) and by reducing dry matter

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loss during fermentation (Waldo, 1977).

To solve the nutritional inferiority of rice straw, insufficiency of forage crops, overproduction of rice for human diet, and to maintain public advantages of rice paddy, efforts have been made to breed whole crop rice varieties for animal feed. Lee *et al.* (2005) proposed a selection for high-tillering panicle number type with high harvest index and crude protein, and low neutral and acid detergent fiber contents in breeding program to improve biomass production and feed value of whole crop rice. It was suggested to harvest whole crop rice at yellow-ripe stage in consideration of biomass production, chemical components, and total digestible nutrient (Sung *et al.*, 2004). Kim *et al.* (2006), however, suggested the dough ripe stage as an optimum harvest time. Lee *et al.* (2005) selected four lines, Suweon468, Suweon498, Suweon490, and SR22058, based on the feed value and biomass production. Among them, Suweon490 had relatively non-shattering habit, resistance to lodging and pests, and stay-greenness (Choi *et al.*, 2006). This line was recently registered as Nogyangbyeo, a whole crop rice variety for animal feed.

It is suggested that the whole crop rice for animal feed should be direct-seeded for easier management and lower input than transplanting because not only grains but also straw is used for feeding animals, such that aboveground total biomass is more important than grain yield (Kim *et al.*, 2006). Seedling emergence is positively correlated with soil temperature and shows genotypic variation (Soh *et al.*, 1995), suggesting that genotypes for direct-deeded rice should have rapid seedling emergence at low temperature in seeding season. In relation to seedling emergence of dry-seeded rice, Kim *et al.* (1993) reported that seedling emergence was accelerated with GA_3 seed-spray due to lengthened plant height, which was attributed to elongated coleoptile and 2nd leaf blade + sheath. Lee & Myung (1995) stated that number of days to 50% of final emergence rate was negatively associated with lengths of incomplete leaf and mesocotyl + 1st internode + incomplete leaf. Park (1999) summarized the traits required for direct-seeded rice in Korea : low-tillering panicle weight type, rapid germination and emergence at low temperature, less inhibition of germination and elongation in hypoxia or anoxia, seedling vigor for rapid elongation growth and development, and resistance to plant lodging.

This study was conducted with specific aims to (1) estimate the biomass yield potential, (2) characterize the biomass and digestible dry matter production, and (3) reveal the characteristic seedling establishment of a whole crop rice variety, Nogyangbyeo, in direct-seeded rice.

MATERIALS AND METHODS

Field and indoor experiments were conducted at the research farm and walk-in temperature-controlled phytotron of National Institute of Crop Science (NICS), Rural Development Administration (RDA), Suwon, Republic of Korea (37°16'N, 126°59'E, 31 m elevation), in 2006.

Field Experiments

Nogyangbyeo was wet- and dry-seeded, along with a high-yielding Tongil-type rice variety, Dasanbyeo, for comparison. Five nitrogen rates (110, 140, 170, 200, and 250 kg ha^{-1} for wet-seeded rice and 140, 170, 200, 240, 300 kg ha^{-1} for dry-seeded rice) were applied to estimate biomass yield potential. Nitrogen was split-applied : 50% at basal, 30% at tillering initiation, and 20% at panicle initiation. Forty-five kg P ha^{-1} was applied as a basal fertilizer immediately before puddling the fields. Fifty-seven kg K ha^{-1} was split-applied : 70% at basal and 30% at panicle initiation. Fertilizer application methods conformed to the recommendation by RDA. Seventy kg seeds ha^{-1} were sown in rows (0.26 m between adjacent rows) by a seeder linked to a tractor on 9 May for dry-seed rice and 40 kg seeds ha^{-1} were hand-broadcasted on 11 May for wet-seeded rice. Plots were laid out in a randomized complete block configuration with four replications. The experimental fields for dry-seeded rice were flooded at 5-leaf stage of rice plants after kept dry from seeding. For wet-seeded rice, fields were kept drained for 10 days from seeding to enhance rooting and seedling establishment. Thereafter, experimental fields for both wet- and dry-seeded rice were flooded and 5-10 cm water depth was maintained until seven days before final harvest, except for a week when they were drained during maximum tiller number stage to stimulate root growth by soil aeration. Weeds and pests were intensively controlled by chemicals to prevent biomass loss. Other cultural methods followed a standard cultural practices proposed by RDA.

Number of seedling stand was counted at 30 days after seeding (DAS) in 0.25 m^2 area (0.5×0.5 m) for wet-seeded rice and 0.26 m^2 area (1 m × 1 row) for dry-seeded rice with 8 replications. Plants in 0.25 m^2 for wet-seeded rice and 0.26 m^2 for dry-seeded rice were sampled at flowering (FL), 20 days after FL (DAF), and 40 DAF. Whole plants sampled at FL, and panicles and straw harvested at 20 and 40 DAF were oven-dried at 75℃ to constant weight to determine aboveground biomass production. These samples were ground to powder for acid detergent fiber (ADF) assay. ADF was determined essentially following the methods by Goering & Van Soest (1979). One-hundred mL ADF reagent (20 g cetyl trimethylammonium bromide dissolved in 1 L H_2SO_4) was added to about 1 g of ground plant tissue in a beaker. After adding 2 mL decahydronaphthalene, samples were boiled for 60 min, avoiding formation of the bubbles. These were filtered through glass filters, while washing them with hot distilled water. The filters were washed 1-2 times again with acetone, then oven-dried at 105℃ for 24 hours. Digestible dry matter (DDM) was calculated from ADF by a following equation and DDM yield was calculated as a product of DDM percentage and dry weight.

$$\mathrm{DDM}(\%) = 88.9-(0.779\times\mathrm{ADF})$$

Indoor Experiments

Indoor experiments were conducted in a phytotron to characterize seed germination, seedling emergence, and early elongation growth of dry-seeded Nogyangbyeo, along with Dasanbyeo and Donganbyeo (a variety adaptable to direct-seeding culture) for comparison. All treatments were designed following a randomized complete block configuration with three replications.

Seed germination was tested under the daily mean temperatures of 15, 18, and 24℃ by placing 100 seeds for each replication on two layers of Whatman filter paper, moistened with distilled water, in a Petri dish. Germinated seeds were counted everyday for 15 days from treatment initiation until no more germinated seeds were seen at 15℃.

One-hundred seeds for each replication were manually sown in rows for dry-seeding culture in a tray (length 48 × width 27 × height 15 cm), using the same three varieties, under the daily mean temperatures of 18℃ and 24℃ since genotypic variation was the greatest in 18℃ in the preliminary experiment. Seeds were sown at 1, 3, and 5 cm depths and provided with water through holes punctured at the bottom of trays. Emerged seedlings from the soil were counted every 1-2 days from seeding and final seedling establishment was determined at 30 DAS. Morphological traits, associated with early elongation growth of rice, were characterized at 30 DAS by measuring the lengths of mesocotyl, coleoptile, 1st internode, incomplete leaf, seedling height, and leaf number in 10 seedlings for each replication.

Statistical Analysis

Data were analyzed following analysis of variance (SAS, 1982) and means of genotypes were compared based on the least significance difference test at the 0.05 probability level.

RESULTS

Biomass Production

Wet-seeded rice produced the total aboveground biomass generally more than dry-seeded rice in both Nogyangbyeo and Dasanbyeo (Fig. 1). Dasanbyeo demonstrated a linear relationship between N rate and biomass production in both dry- and wet-seeded rice at all stages during grain filling (Fig. 1C & D). However, Nogyangbyeo exhibited a curvilinear relationship between them in both seeding cultures (Fig. 1A & B). Aboveground total biomass increased with the growth progress after FL in all treatments. In dry-seeded rice, maximum biomass yield of 18 t ha^{-1} was achieved in Nogyangbyeo, applied with 300 kg N ha^{-1}, at 40 DAF (Fig. 1A). In wet-seeded rice, however, maximum biomass yield of 23 t ha^{-1} was obtained in Dasanbyeo, applied with 250 kg N ha^{-1}, at 40 DAF (Fig. 1D). Maximum biomass yield in wet-seeded Nogyangbyeo was 20 t ha^{-1} at 170 kg N ha^{-1} and more N application maintained or reduced biomass production of the variety (Fig. 1B).

Same as in aboveground total biomass (see fig. 1), wet-seeded rice generally produced more straw and panicle biomass than dry-seeded rice (Fig. 2). When compared genotypes, Nogyangbyeo demonstrated more straw biomass production than Dasanbyeo in both dry- and wet-seeded rice. Straw dry weight for Nogyangbyeo demonstrated no more increase above 240 kg N ha^{-1} in dry-seeded rice and 170 kg N ha^{-1} in wet-seeded rice. Difference in straw biomass between 20 DAF and 40 DAF was negligible in all treatments.

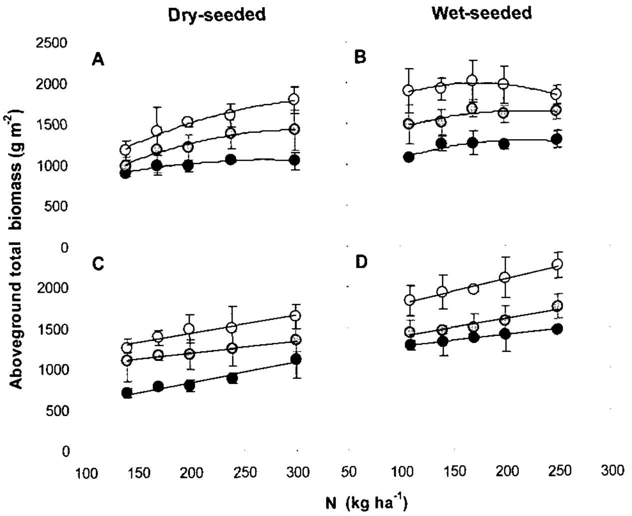

Fig. 1. Aboveground total biomass production of Nogyangbyeo (A & B) and Dasanbyeo (C & D), sampled at flowering (●), 20 days after flowering (◍), and 40 days after flowering (○), at different nitrogen (N) rates in dry- and wet-seeded rice. Each data point is the mean of four replications and error bars are standard deviations.

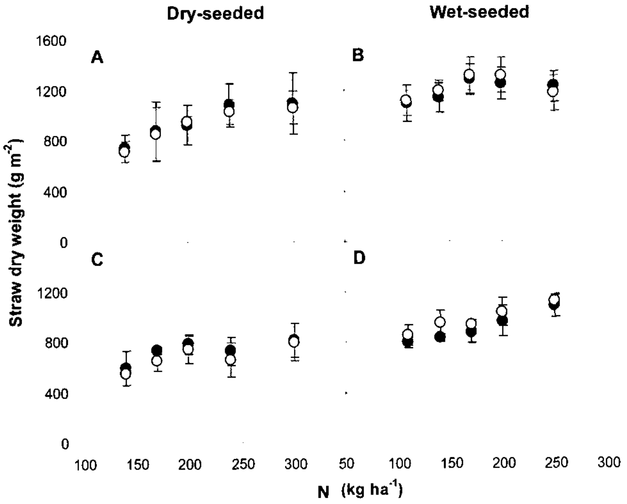

Fig. 2. Straw biomass of Nogyangbyeo (A & B) and Dasanbyeo (C & D), sampled at 20 days (●) and 40 days after flowering (○), at different nitrogen (N) rates in dry- and wet-seeded rice. Each data point is the mean of four replications and error bars are standard deviations.

Aboveground total biomass was closely associated with both panicle and straw dry weight in both genotypes when data were pooled across the two direct-seeding cultures (Fig. 3). Nogyangbyeo allocated biomass to straw more than Dasanbyeo (Fig. 3A), while Dasanbyeo allocated biomass to panicles more than Nogyangbyeo at the same total biomass production (Fig. 3B).

DDM Yield

When considered on the aboveground total biomass basis at FL, 20 DAF, and 40 DAF, DDM yield was significantly different depending on seeding method and growth stage, but not variety (Table 1). Significance in aboveground total biomass was consistent with DDM yield. DDM percentage was significantly different depending on growth stage and variety, but not seeding method. When analyzed on each

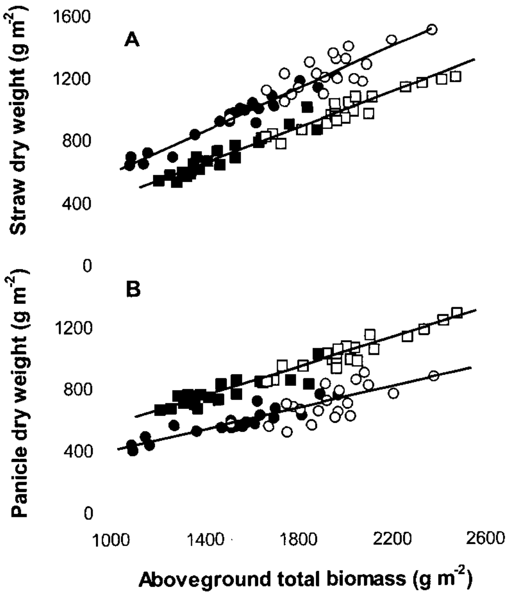

Fig. 3. Relationship of aboveground total biomass with straw dry weight (A) and panicle dry weight (B) in dry- (●, ■) and wet-seeded (○, □) Nogyangbyeo (●, ○) and Dasanbyeo (■, □) sampled at 40 days after flowering. Each data point is a replication for each genotype (*n*=40 for each genotype).

of the straw and panicle dry weight basis at 20 DAF and 40 DAF, DDM yield and biomass were significant depending on seeding method, growth stage, and plant organ, but not variety (Table 2). DDM percentage was significantly different on growth stage and plant organ, but not seeding method and variety.

When data were pooled across three stages, DDM yield was positively correlated with both DDM percentage and biomass on aboveground total biomass basis (Fig. 4A). But DDM yield was associated with biomass production more closely than DDM percentage. Variation in DDM percentage was fairly small while that in biomass was much greater.

Table 1. Significances in analysis of variance for digestible dry matter (DDM), aboveground total biomass (BIO), and DDM yield (DDMY) as affected by direct-seeding methods, growth stages, and rice varieties.

Variable	Seeding method‡	Growth stage	Variety
DDM (%)	ns†	***	**
BIO (g m^{-2})	***	***	ns
DDMY (g m^{-2})	***	***	ns

†ns; not significant, ** and ***; significant at 1% and 0.1% probability, respectively.
‡Seeding methods; dry- and wet-seeding culture, Growth stages; flowering, 20 and 40 days after flowering, Varieties; Nogyangbyeo and Dasanbyeo.

Table 2. Significances in analysis of variance for digestible dry matter (DDM), aboveground total biomass (BIO), and DDM yield (DDMY) as affected by direct-seeding methods, growth stages, varieties, and plant organs.

Variable	Seeding method‡	Growth stage	Variety	Organ
DDM (%)	ns†	***	ns	***
BIO (g m^{-2})	***	***	ns	***
DDMY (g m^{-2})	***	***	ns	***

†ns; not significant, ***; significant at 0.1% probability.
‡Seeding methods; dry- and wet-seeding culture, Growth stages; 20 and 40 days after flowering, Varieties; Nogyangbyeo and Dasanbyeo, Organs; straw and panicle.

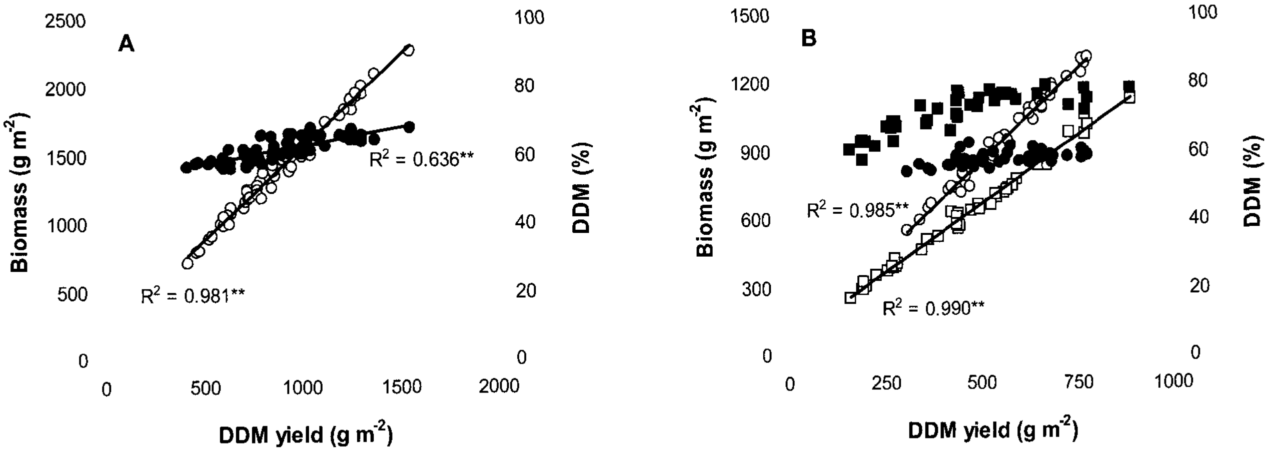

Fig. 4. A ($n = 60$): relationship of digestible dry matter (DDM) yield with DDM percentage (●) and aboveground total biomass (○). B ($n = 40$): relationship of DDM yield with DDM percentage of straw (●) and panicles (■), and with biomass of straw (○) and panicles (□). Each data point is the mean of four replications. Data were pooled across two seeding methods and two varieties for both panels, and three growth stages (flowering, 20 and 40 days after flowering) for upper and two growth stages (20 and 40 days after flowering) for lower panel.

When the relationship was tested for each of straw and panicle, DDM percentage demonstrated small variations and weak correlations with DDM yield whereas biomass revealed large variations and close relationships with DDM yield for both straw and panicle (Fig. 4B). Meanwhile, panicle showed DDM percentage higher than straw, resulting in more straw biomass required for same DDM yield production than panicle biomass.

Seedling Establishment

In the field study, number of seedling stand was 73 m^{-2} and 109 m^{-2} in dry- and wet-seeded Nogyangbyeo, and 117 m^{-2} and 90 m^{-2} in dry- and wet-seeded Dasanbyeo, respectively (Fig. 5).

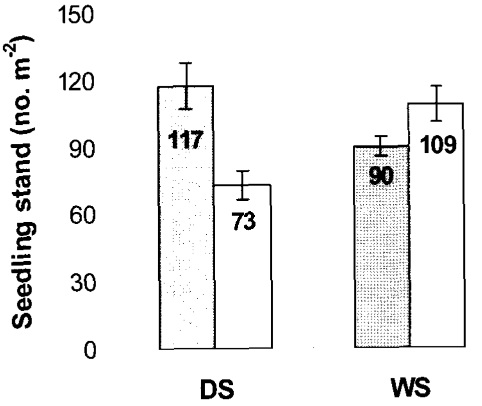

Fig. 5. Number of seedling stand of Nogyangbyeo (□) and Dasanbyeo (▨) at 30 days after seeding in dry- (DS) and wet-seeded rice (WS). Each data point is the mean of five nitrogen treatments, each of which with eight replications. Error bars are standard deviations.

When tested under the daily mean temperature of 24℃ in a phytotron, Nogyangbyeo demonstrated significantly lower seed germination than Dasanbyeo and Donganbyeo, both of which were not significantly different from each other (Fig. 6C). However, difference in seed germination among the genotypes was quite small under that temperature condition. Under the 15℃ and 18℃, seed germination in Nogyangbyeo was delayed and lowered in a greater extent than the other two varieties, compared with 24℃ (Fig. 6A & B).

Daily mean temperature of 18℃ lowered and delayed seedling emergence of dry-seeded rice in all varieties and sowing depths, compared with 24℃ (Fig. 7). At 1 cm sowing depth, Nogyangbyeo and Dasanbyeo demonstrated seedling emergence rates similar to each other but much lower seedling emergence rate than Donganbyeo in both 18℃ and 24℃ (Fig. 7A & D). At 3 cm sowing depth, seedling emergence rate and final seedling establishment at 30 DAS were not considerably different among genotypes in both temperatures (Fig. 7B & E). When seeds were buried at 5 cm deep in soil, Nogyangbyeo demonstrated lower seedling emergence rate and consequently lower seedling establishment at 30 DAS than Dasanbyeo and Donganbyeo, especially under the daily mean temperature of 18℃ (Fig. 7C & F).

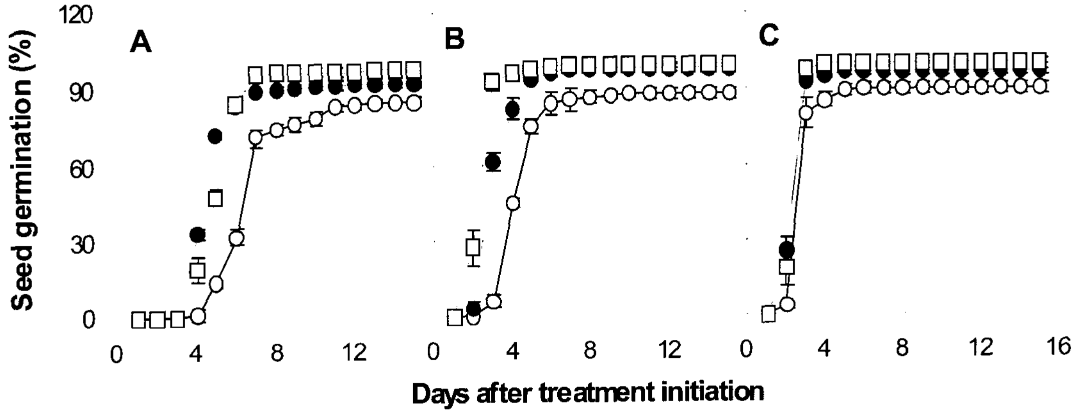

Fig. 6. Seed germination of Nogyangbyeo (○), Dasanbyeo (●), and Donganbyeo (□) under the daily mean temperatures of 15℃ (A), 18℃ (B), and 24℃ (C). Each data point is the mean of three replications and error bars are standard deviations.

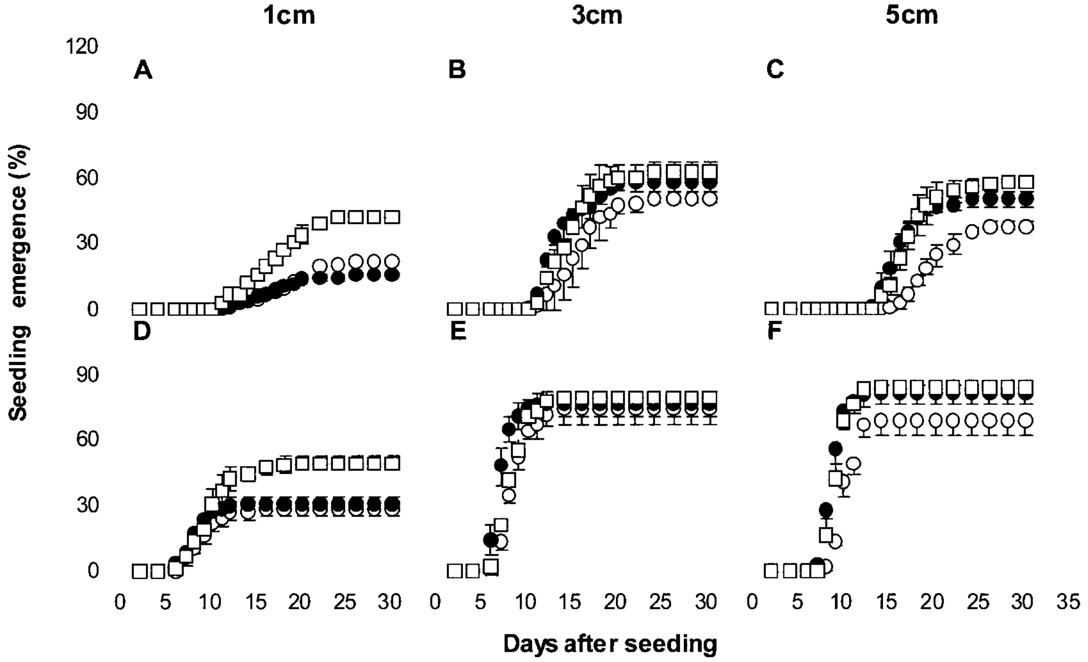

Fig. 7. Seedling emergence of dry-seeded Nogyangbyeo (○), Dasanbyeo (●), and Donganbyeo (□) at 1, 3, and 5 cm sowing depths, under the daily mean temperatures of 18℃ (A-C) and 24℃ (D-F). Each data point is the mean of three replications and error bars are standard deviations.

When measured from the emerged seedlings at 30 DAS, seedling height was the greatest at 3 cm sowing depth in 18℃, and similarly higher at 3 cm and 5 cm sowing depth in 24℃ (Table 3). It was the longest in Donganbyeo followed by Dasanbyeo and Nogyangbyeo in all temperatures and sowing depths. Leaf number was the greatest at 3 cm sowing depth for both 18℃ and 24℃. More leaves were produced in Donganbyeo than Dasanbyeo and Nogyangbyeo, and in Dasanbyeo than Nogyanbyeo at all sowing depths under 18℃. In all sowing depths under 24℃, Nogyangbyeo bore lesser leaves than Dasanbyeo and Donganbyeo, both of which had leaf numbers similar to each other. Elongations of mesocotyl, coleoptile, 1st internode, and incomplete leaf were stimulated by deep sowing in both temperatures. Mesocotyl was the shortest in Nogyangbyeo and the longest in Donganbyeo in all temperatures and sowing depths. First internode did not elongate at 1 cm sowing depth, generally the longest in Dasanbyeo, and the shortest in Nogyangbyeo in both temperatures. Coleoptile and incomplete leaf of Nogyangbyeo were not shorter than those of the other varieties in both temperatures. Seedling height, leaf number, mesocotyl, and 1st internode were considerably longer in 24℃ than 18℃. But coleoptile length and incomplete leaf length were not significantly different between 18℃ and 24℃.

DISCUSSION

Nogyangbyeo, a whole crop rice variety for animal feed, demonstrated a biomass yield potential of 18 t ha^{-1} in dry-seeded rice and 20 t ha^{-1} in wet-seeded rice (Fig. 1). In the previous studies, biomass yield potentials of 16 t ha^{-1} (Lee *et al.*, 2005) and 18 t ha^{-1} on average (Choi *et al.*, 2006) were achieved for the variety. As considering the target biomass of 20 t ha^{-1} in breeding programs, it could be achieved by N management and cultural practices. However, biomass production in Dasanbyeo higher than in Nonganbyeo suggests that more biomass production could be achieved by breeding program. Aboveground total biomass increased with the growth progress after FL in any direct-seeding cultures, N rates, and varieties. This is attributed to accumulation of the grain dry weight since there was little difference in straw dry weight between 20 DAF and 40 DAF (Fig. 2). Little difference in straw biomass be-

Table 3. Elongation growth-associated morphological traits of rice seedlings taken at 30 days after dry-seeding at different sowing depths, under the daily mean temperatures of 18℃ and 24℃.

Sowing depth	Variety	Length (cm)					LN (no.)
		MC	CT	1st	IL	SH	
				18℃			
1 cm	Nogyangbyeo	0.00 a[†]	0.85 a	0.00 a	1.87 a	6.4 c	2.31 c
	Dasanbyeo	0.00 a	0.82 a	0.00 a	1.75 a	9.1 b	2.89 b
	Donganbyeo	0.00 a	0.87 a	0.00 a	1.81 a	11.9 a	3.25 a
	Average	0.00 b	0.85 c	0.00 b	1.81 c	9.2 c	2.82 b
3 cm	Nogyangbyeo	0.11 b	1.98 a	0.02 a	3.04 a	13.4 b	2.84 c
	Dasanbyeo	0.17 a	1.76 a	0.03 a	2.98 a	14.6 b	3.03 b
	Donganbyeo	0.23 a	1.77 a	0.00 a	3.25 a	18.2 a	3.38 a
	Average	0.17 a	1.84 b	0.02 b	3.09 b	15.4 b	3.09 a
5 cm	Nogyangbyeo	0.13 b	2.78 a	0.00 a	4.00 a	11.9 c	2.34 b
	Dasanbyeo	0.26 a	2.63 a	0.06 a	3.72 a	14.4 b	3.04 a
	Donganbyeo	0.29 a	2.95 a	0.43 ab	4.11 a	16.4 a	3.15 a
	Average	0.23 a	2.79 a	0.34 a	3.94 a	14.2 a	2.84 b
				24℃			
1 cm	Nogyangbyeo	0.07 a	0.93 a	0.00 a	2.01 a	18.6 c	3.44 b
	Dasanbyeo	0.11 a	0.61 b	0.00 a	1.81 a	29.0 b	4.88 a
	Donganbyeo	0.15 a	0.72 b	0.00 a	1.97 a	32.3 a	4.85 a
	Average	0.11 c	0.76 b	0.00 b	1.93 c	26.6 b	4.39 b
3 cm	Nogyangbyeo	0.20 c	2.14 a	0.00 b	3.55 a	24.0 b	3.94 b
	Dasanbyeo	0.34 b	1.87 a	0.57 a	3.52 a	30.8 a	5.23 a
	Donganbyeo	0.42 a	1.89 a	0.07 b	3.28 b	33.5 a	5.15 a
	Average	0.32 b	1.97 a	0.21 ab	3.45 b	29.4 a	4.77 a
5 cm	Nogyangbyeo	0.34 b	-[‡]	0.11 b	4.42 a	23.3 c	3.54 b
	Dasanbyeo	0.54 b	-	0.20 a	4.29 a	32.5 b	5.03 a
	Donganbyeo	0.92 a	-	0.17 b	3.27 b	35.3 a	5.12 a
	Average	0.60 a	-	0.49 a	3.99 a	30.4 a	4.56 b

Data are means of three replications. MC; mesocotyl, CT; coleoptile, 1st; 1st internode, IL; incomplete leaf, 2nd; 2nd internode, SH; seedling height, LN; leaf number.

[†] Within columns, LSD (0.05)-based letters following means for varieties are for the comparison of genotypes in each sowing depth and those following averages of three varieties are for the comparison of sowing depths in each temperature treatment.

[‡] Not all seedlings maintained coleoptile at harvest.

tween the two stages appears the result of loss in leaf biomass and gain in leaf sheath + culm biomass since straw biomass during ripening generally demonstrated such a trend in another study with different genotypes and cultural practices (data not shown).

Generally, Nogyangbyeo produced more straw biomass (Fig. 2) but lesser aboveground total biomass (Fig. 1), resulting in the greater biomass allocation to straw than Dasanbyeo. This result implies that, comparatively, Nogyangbyeo is straw-dependant and Dasanbyeo is grain-dependant for biomass production. On the average, Nogyangbyeo had harvest index of 0.31 at 40 DAF in both dry- and wet-seeded rice, which was much lower than current rice genotypes for human diet. It needs to verify if more biomass allocation to straw is advantageous. According to the suggestion by Lee *et al.* (2005), more biomass should be allocated to grains for whole crop rice varieties to improve relative feed value. Indeed, panicles demonstrated DDM percentage higher than straw (Fig. 4B). However, Kim *et al.* (2006) mentioned that appropriate harvesting time of whole crop rice for animal feed was dough ripe stage, indicating that it should be harvested when harvest index is not high. These opposed suggestions make it difficult to determine whether biomass production of whole crop rice should rely more either on straw or grains. Preference, nutrition, digestibility, additives, and other related characteristics may be considered for this determination.

Biomass and DDM percentage are the components of DDM yield, which is only the digestible portion of biomass. Therefore, DDM yield should be more important rather than biomass production. When compared DDM percentage and biomass, however, the latter was much more closely associated with DDM yield than the former (Fig. 4A). Moreover, DDM on whole plant basis demonstrated a fairly small range of 56.3-68.3% when data were pooled across all genotypes, N rates, stages, and cultural methods, indicating it is difficult to improve DDM percentage by means of breeding program, crop management, and cultural practices. Meanwhile, aboveground total biomass ranged 716-2264 g m^{-2} in the same pooled data, which was the much greater variation than DDM percentage on a same scale. These results imply DDM yield can be improved simply by increasing biomass. When compared each of straw and panicle, DDM yield was strongly correlated with biomass but weakly with DDM percentage (Fig. 4B). It is notable that panicles exhibited greater DDM percentage than straw, as previously reported by Lee *et al.* (2005) and Kim *et al.* (2006). This result indicates producing more grain biomass could improve DDM yield on a same total biomass. Only two genotypes were compared in this study. Hence, genotypic variation in DDM percentage and its contribution to DDM yield, in comparison of biomass, need to be elaborated further with more genetic resources of rice.

Seedling establishment of Nogyangbyeo was poor particularly in dry-seeded rice, showing 73 m^{-2} in dry-seeded rice and 109 m^{-2} in wet-seeded rice (Fig. 5). When tested in the following indoor study to clarify the reasons, with an additional variety adaptable to direct-seeding culture, Donganbyeo, seed germination of Nogyangbyeo was delayed and lowered at a greater extent under the daily mean temperature of 15℃ and 18℃, compared to 24℃ (Fig. 6). This result indicates that Nogyangbyeo is relatively susceptible to low temperature for seed germination, possibly due to its tropical japonica origin (personal communication). Interestingly, Dasanbyeo, a Tolngil-type rice variety, showed final percentages of seed germination similar to Donganbyeo, a temperate japonica variety, even under 15℃ and 18℃. Seedling emergence was the fastest at 3 cm sowing depth, followed by 5 cm and 1 cm in both 18℃ and 24℃ (Fig 7). This result is inconsistent with previous observations that seedling emergence was inhibited by deep sowing (Lee & Myung, 1995; Lee *et al.*, 1993). However, in all replications for the three genotypes, seedling emergence was the poorest at 1 cm seeding depth in this study. At 1 cm deep sowing, Donganbyeo showed the higher seedling emergence rate than Nogyangbyeo and Dasanbyeo in both 18℃ and 24℃ but seedling emergence rate was not significant between Nogyangbyeo and Dasanbyeo (Fig. 7A & D). Genotypic difference in seedling emergence rate at 3 cm deep sowing became very narrow (Fig. 7B & E). These results were different from the seedling establishment in the field condition (see Fig. 5). However, at 5 cm sowing depth, Nogyangbyeo exhibited seedling emergence rate lower than Dasanbyeo and Donganbyeo in both temperatures, but particularly in 18℃ (Fig. 7C & F). This result implies that poor seedling establishment of dry-seeded Nogyangbyeo in the field study was partly the result of inhibited seedling emergence by deep sowing under the low temperature in seeding season. This interpretation recommends, for better seedling emergence in dry-seeded rice, Nogyangbyeo should not be sown deeper than 3 cm soil. Table 3 summarized morphological traits associated with seedling emergence of dry-seeded rice. Under the daily mean temperature of 18℃, seedling height and leaf number were the greatest at 3 cm, followed by 5 cm and 1 cm sowing depth, which was a manner similar to seedling emergence depending on genotypes (see Fig. 7). At all sowing depths, Nogyangbyeo seedlings were shorter and bore lesser leaves than the others in both temperatures. But coleoptile and incomplete leaves of Nogyangbyeo were not shorter than those of other varieties, indicating that inherent leaf length was not the factor that inhibited elongation and emergence of seedlings. Nogyangbyeo was shorter in mesocotyl and 1st internode lengths than Dasanbyeo and Donganbyeo at 5 cm sowing depth in 18℃ but the genotypic difference was small, showing 0.16 cm for mesocotyl length and 0.6 cm for 1st internode length. Nevertheless, low seedling emergence rate of Nogyangbyeo may be partly attributed to the shorter mesocotyl and internode. Leaf number, which explains the progress in plant development, in Nogyangbyeo was consistently lower than the other two genotypes. Significant but small genotypic variation in coleoptile and 1st internode length, non-significant coleoptile and incomplete leaf length, and considerably lower leaf number in Nogyangbyeo explain that the poor seedling emergence rate due to short seedling height in the variety is attributed not to the genetically defined morphological length but mainly to the slower progress of development, e. g. slow leaf development. Moreover, same as in 18℃, Nogyangbyeo demonstrated consistently shorter seedling height and less leaf number than the others in 24℃, indicating that rate of elongation growth and development during seedling establishment period of Nogyangbyeo are inherently slow. This result was the same in wet-seeded rice (data not shown). Therefore, it is concluded that low elongation growth rate by slow leaf development was the main cause of low seedling establishment of dry-seeded Nogyangbyeo.

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