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Absorption and Partition of ^{15}N-labeled Fertilizer in Rice under Different Nitrogen Application Time and Rate Conditions

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ABSTRACT: The nitrogen (N) absorption and partition of the rice plants are important indicators that can be used to improve the N use efficiency (NUE) of the plants. Improving the plant NUE can help to avoid nutrient waste that may cause environmental pollution. To investigate the N absorption and partition of the rice plants, *Hwaseongbyeo* (Japonica) and *Dasanbyeo* (indica/japonica) were applied with N fertilizers at the rates of 60, 120, and 180 kg N per ha in paddy field. Also micro plots of 0.81 m^2 were established inside each plot for application of ^{15}N-labeled fertilizer. The differences in N utilization of the rice plants were associated with the total N absorption and partitioning after the heading stage. In the grain filling period, the increase of nitrogen content in the total and leaf blades of *Dasanbyeo* was higher than that of *Hwaseongbyeo.* Soil N was the main contributor for the increase of total N of *Dasanbyeo* during the grain filling period. The N fertilizer uptake rate of *Hwaseongbyeo* rapidly increased with the increment of N fertilization rate. In *Dasanbyeo,* N fertilizer uptakes were similar under all rates and times of N application. From heading stage to harvest, *Dasanbyeo* continued accumulating nitrogen, whereas *Hwaseongbyeo* had small changes. In conclusion, the difference in nitrogen absorption and partition after heading of the two cultivars was caused by the ability of *Dasanbyeo* to accumulate and remobilize soil nitrogen to the grains during the grain filling period.

Keywords: rice, nitrogen, ^{15}N, absorption, partition, nitrogen use efficiency (NUE)

Among the various plant nutrients, nitrogen highly affects the growth and yield of rice. Recently, the high cost of fertilizer and over production of agricultural products followed by the low price of the products reduced the total application of N fertilizer per unit land area. The need to improve the rice grain quality also reduced the application of N fertilizer. The suspicion on adverse effects of nitrate and nitrite to human health and environment had also been the main concern of the society. (Lea and Morot-Gaudry, 2001). Consequently recent researches are being focused on how to increase the N efficiency applied to the field.

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The need of the plants for N fertilizer varied with the plant types and their growing conditions (Mikkelsen *et al.*, 1995). Studies on cultivars of different plant types often showed differences in nitrogen uptake and use efficiency (Guindo *et al.*, 1994). In rice, the high-yielding semi-dwarf cultivars have higher NUEs than tall cultivars, at high rates of N fertilizer application. However, there are still limited literatures regarding the comparison of nitrogen absorption and partition between semi-dwarf and tall rice cultivars. This study was conducted to investigate the N absorption and partition of ^{15}N-labeled fertilizer in different rice (*Oryza sativa* L.) cultivars using split fertilizer application of N in paddy field.

There were several methods in determining the NUEs of the plants. The chlorophyll meter (SPAD-502) was one simple, quick, and nondestructive method for estimating the N concentration on a dry weight basis of plant materials. However, the linear relationship between the dry weight and SPAD value were not existed depend on the different growth stages and cultivars of rice. Hussain *et al.* (2000) demonstrated that the chlorophyll meter readings were significantly affected by the N management practices, the time of N application, and cultivars. Hence, it is necessary to use a different SPAD value to determine the right time to apply the N fertilizer topdressing for the various rice cultivars.

Roberts *et al.* (1993) concluded that the grain and straw production significantly differed between the tall and semi-dwarf cultivars and that the harvest index should be stabilized to increase yield as applied N fertilizer rates were increased.

Novoa and Loomis (1981) defined the efficiency of applied N fertilizer as the recovery of available or applied nitrogen, or the ratio of the biomass (kg) or weight of grain (kg) to the applied nitrogen (kg). The NUE can be expressed as follows:

Agronomic efficiency = Physiological efficiency × Recovery fraction

$$= \frac{kg\ grain}{kg\ N\ applied} = \left(\frac{kg\ grain}{kg\ N\ absorbed}\right)\left(\frac{kg\ N\ absorbed}{kg\ N\ applied}\right) \text{ or}$$

$$\text{Recovery fraction} = \left(\frac{kg\ N\ absorbed}{kg\ N\ supplied}\right)\left(\frac{kg\ N\ supplied}{kg\ N\ applied}\right).$$

The ratio of kg grain over kg N absorbed, focuses on the physiological efficiency in the use of N that is actually absorbed. The physiological efficiency depends on the nitrogen efficiency of biomass formation, the effect of nitrogen on carbohydrate partitioning, nitrate reduction efficiency, the remobilization of protein nitrogen from senescent tissues, and the transport and storage system of the plant. The recovery efficiency fraction is a better index than NUE, for evaluating fertilizer management practices. The term of kg N absorbed over kg N supply, represents the uptake efficiency, which depends on the root properties such as distribution, surface area, and uptake per unit surface. The uptake efficiency of the rice plant varies greatly among the new high-yielding varieties and their growing environments. In most cases, the inefficient recovery of applied nitrogen by the plant highly decreased agronomic efficiency. The uptake efficiency usually ranged from 20% to 40%, with mean value of about 30% (Shoji *et al.*, 1986). Most new high-yielding varieties had similar physiological NUEs when grown under similar conditions. Usually, the physiological NUE was decreased as plant nitrogen uptake increased.

The research on NUE using ^{15}N-labeled fertilizer showed that NUE of the rice plant was about 50% when N fertilizer topdressing was applied during the panicle formation stage, and about 44-46% when applied at meiosis stage, 34% at tillering stage, and 25% to 36% at heading stage. The NUE of plants with basal fertilizer was 22% to 27%. The applied N left in the soil was about 18% to 21% of the basal N fertilizer and about 3% to 10% of topdressing N fertilizer (Jo *et al.*, 1995).

The NUE has been usually miscalculated because of the estimate on the amount of N recovered in the grains, and there was no simple relationship between the nitrogen content of the grain and grain yield (Novoa and Loomis, 1981).

The partial factor productivity for N (PFP_N) is another indicator useful in determining NUE as it provides an integrative index that quantifies total economic output relative to utilization of nitrogen resources in the system, including indigenous soil nitrogen and N fertilizer. Cassman *et al* (1996) defined PFP_N as the ratio of the grain yield to the nitrogen applied or

$$PFP_N = \left(\frac{kg\ grain\ Yield}{kg\ N\ applied}\right).$$

As rates of applied N fertilizers were increased, agronomic efficiency and partial factor productivity (PFP_N, a useful measure of NUE including indigenous soil nitrogen and N fertilizer), were decreased (Cassman, 1996).

MATERIALS AND METHODS

Soil characteristics and climatic conditions

This experiment was carried out at the university farm, Seoul National University, Suwon, Korea in 2002. The experimental field has sandy loam soil texture and 'Gyuam' (mixed, non-acidic, and mesic family of Fluvaquentic Eutrudepts) soil series. The physico-chemical characteristics of the soil were generally similar to the paddy fields in Korea, but with little lower exchangeable cations.

During the 20 days before heading stage, the air temperature (23.5 °C) was lower about 1.4 °C and the solar radiation time (2.6 hours) was shorter about 3.1 hrs than those of average year. Precipitation was equal to the average in Suwon area. Low temperatures and short day lengths at heading and milk-ripe stages induced seed weights and ripened grains to drop-off, and thereby decreasing the crop yield (Lee and Oh 1996).

Cultivars and field plot design

This experiment was carried out using two rice cultivars, *Hwaseongbyeo* and *Dasanbyeo* planted in a paddy field. *Hwaseongbyeo* (Suwon 330, japonica) was a tall variety with culm length of 82 cm and medium maturing. *Dasanbyeo* (Suwon 405, indica/japonica) was semi-dwarf variety with culm length of 73 cm, medium maturing, and high yielding.

Experimental plots were arranged in a completely randomized design. The application levels of N treatments were 60, 120, and 180 kg N per ha considering recommended rates of N fertilizer. Phosphate and potassium were applied using conventional methods. All fertilizer was applied in split amount.

Before puddling, micro plots of 0.81 m^2 (0.9 m × 0.9 m) were established inside each plot for application of ^{15}N-labeled fertilizer. The seedlings were transplanted at 22 hills per m^2 (30cm×15cm) with three seedlings per hill. Experimental plots were fertilized with urea {$(^{14}NH_2)_2CO$}, while micro plots were fertilized with ^{15}N-labeled urea {5 atom%, $(^{15}NH_2)_2CO$, Isotec Inc.}.

Data collection and analysis

Plants from the micro plots were collected five times from two hills at 10 days interval after basal fertilizer application, at seven days interval after topdressing at tillering stage, and at two days interval after topdressing at panicle initiation stage. Plants were collected from four hills at heading and harvest time.

The samples were divided into parts: the leaf blade, leaf sheath and stem, and panicle. Growth characteristics such as plant height, number of tillering, and SPAD value (using SPAD-502, Minolta) were measured during the maximum tillering and heading stages. Photosynthetic rate (using Photosynthesis Analyzer LI-6400, Li-Cor Inc.) was also measured at the heading stage. Yield and growth characteristics were determined from samples taken from the micro plots. Yield components were also determined from four replications taken from the center of each plot at harvest stage. All biomass above the ground were harvested manually. Grain dry matters were measured by adjusting the grain moisture to 14%. Biological yield was calculated by combining the dry weights of the grains and straws. The harvest index was calculated as grain dry weight over biological yield.

Plant materials were dried constantly at 60 °C for 48 hours and mechanically ground (using Cyclotec 1093 sample mill, Tecator) to pass a 0.5-mm-mesh screen. Total nitrogen and ^{15}N contents were determined by using the stable isotope mass spectrometer (Isoprime-EA, Micromass) of the National Instrumentation Center for Environmental Management (NICEM), Seoul National University. The ratio of the nitrogen derived from fertilizer (NDFF), based on the ^{15}N content, was calculated as follows (Lajtha and Michener, 1994):

$$\mathrm{NDFF}(\%) = \left(\frac{plant\ ^{15}N\ atom\% - 0.3708}{fertilizer\ ^{15}N\ atom\% - 0.3663}\right) \times 100 .$$

RESULTS

Growth characteristics

At maximum tillering stage, about 40 days after transplanting, the plant heights of the two cultivars were significantly different from each other. *Hwaseongbyeo* plants were taller than *Dasanbyeo* except at 60 kg N fertilizer application rate. The other growth characteristics such as number of tillering, chlorophyll meter reading (SPAD value), and dry matter weight were not significantly different between the cultivars. The other growth characteristics of both cultivars increased as applied N fertilizer rates increased (Table 1).

Heading stage is the best period for determining the amount of nitrogen assimilated during vegetative growth stage and the grain yield. The growth characteristics at heading stage have been used to predict the crop growth and yield. At heading stage, *Hwaseongbyeo* was taller and had more tillers than *Dasanbyeo except* at 60 kg N fertilizer level. The plant height and number of tillering increased as applied N fertilizer rates increased. The nitrogen content of the leaf blade of *Dasanbyeo* was lower than that of *Hwaseongbyeo.*

Leaf area index (LAI) was significantly lower when N fertilizer was applied at 60 kg per ha (Table 2). *Hwaseongbyeo* had higher total dry matter weight at heading stage than *Dasanbyeo*. But at harvest, total dry matter weight of *Hwaseongbyeo* did not significantly differ from *Dasanbyeo*. This means that during the grain filling period, the total dry matter accumulation of *Dasanbyeo* was larger than that of *Hwaseongbyeo* at all rates of N fertilization. Also, the dry matter accumulation into the leaf blade of *Dasanbyeo* was larger than that of *Hwaseongbyeo* during this grain filling period (Table 3).

Table 1. Growth characteristics according to different N fertilizer levels applied at maximum tillering stage.

Cultivar	N fertilizer rate (kg/ha)	Plant height (cm)	Number of tiller per hill	SPAD value
Hwaseongbyeo	60	39.7 ± 0.79c	19 ± 1.3b	35.8 ± 0.35b
	120	50.2 ± 0.85a	23 ± 1.0a	39.0 ± 0.42a
	180	50.2 ± 0.52a	24 ± 0.9a	40.2 ± 0.46a
Dasanbyeo	60	45.1 ± 1.00b	20 ± 0.9b	36.3 ± 0.30b
	120	45.8 ± 0.56b	21 ± 1.5ab	37.0 ± 0.40b
	180	47.0 ± 0.61b	24 ± 1.0a	38.1 ± 0.39a

All data were indicated as mean value ± standard error.
†Within a column, means not followed by the same letter are significantly different at based on LSD.

Table 2. Growth characteristics according to the different N fertilizer levels applied at heading stage.

Cultivar	N fertilizer rate (kg/ha)	Heading date	Plant height (cm)	Number of tillering per hill	Leaf area index
Hwaseongbyeo	60	Aug. 9	85.6 ± 1.04e	15 ± 0.9c	4.4 ± 0.19b
	120	Aug. 12	104.4 ± 1.12b	20 ± 1.1b	6.9 ± 0.87a
	180	Aug. 14	108.4 ± 1.30a	23 ± 0.9a	7.7 ± 0.70a
Dasanbyeo	60	Aug. 6	86.3 ± 1.00e	16 ± 0.6c	4.4 ± 0.69b
	120	Aug. 8	92.8 ± 1.17d	16 ± 0.6c	7.0 ± 0.35a
	180	Aug. 10	99.4 ± 1.83c	20 ± 0.8b	7.5 ± 0.84a

Table 3. Comparison of dry matter weight of plant parts according to growth stage and the rates of N fertilizer application.

N fertilizer rate (g/m^2)	Plant parts	Dry matter (g/m^2)			
		Hwaseongbyeo		Dasanbyeo	
		Heading	Harvest	Heading	Harvest
6	Leaf blade	215	644	172	675
	Leaf sheath+stem	500	169	401	158
	Panicle	95	523	107	481
	Total	810	1,336	680	1,314
12	Leaf blade	332	924	251	1,089
	Leaf sheath+stem	689	252	515	279
	Panicle	144	707	129	735
	Total	1,164	1,883	896	2,103
18	Leaf blade	395	1,097	304	1,246
	Leaf sheath+stem	703	369	525	349
	Panicle	147	927	135	838
	Total	1,245	2,393	964	2,433

Table 4. Yield and yield components according to the different N fertilizer levels.

Cultivar	N fertilizer rate (kg/ha)	Panicle numbers per m^2	Spikelet numbers per panicle	Ripened grains (%)	1000-grain weight (g)
Hwaseongbyeo	60	359 ± 8bc	105 ± 2.4c	89.4 ± 0.55a	26.0 ± 0.07c
	120	417 ± 11b	114 ± 2.5bc	73.8 ± 1.23c	25.4 ± 0.06d
	180	480 ± 12a	114 ± 2.5c	83.3 ± 0.63b	23.8 ± 0.07e
Dasanbyeo	60	290 ± 7d	127 ± 3.3ab	81.7 ± 1.88b	29.7 ± 0.06a
	120	316 ± 12d	138 ± 3.9a	76.5 ± 0.90c	29.6 ± 0.07a
	180	371 ± 11c	145 ± 3.9a	75.8 ± 0.94c	29.4 ± 0.06b

Table 5. Comparison of two cultivars for grain, straw, and biological yields, and harvest index under the different N fertilizer levels.

Cultivar	N fertilizer rate (kg/ha)	Grain yield (g/hill)	Straw yield (g/hill)	Biological yield (g/hill)	Harvest index
Hwaseongbyeo	60	28.3 ± 4.39a	32.4 ± 3.81a	60.7a	0.47a
	120	40.7 ± 3.80b	44.9 ± 3.30b	85.6b	0.48a
	180	48.3 ± 3.29b	60.5 ± 3.21c	108.8c	0.44a
Dasanbyeo	60	29.7 ± 4.49a	30.0 ± 3.68a	59.7a	0.50b
	120	47.9 ± 3.91b	47.6 ± 3.28b	95.6b	0.50b
	180	54.8 ± 3.81b	55.7 ± 3.03c	110.6c	0.50b

Grain yield and yield components

The numbers of tillers and panicles per unit land area of Dasanbyeo were lower than those of Hwaseongbyeo at all N fertilization rates. But, *Dasanbyeo* had more number of spikelets per panicle than *Hwaseongbyeo* at all levels of N fertilization. Also, *Dasanbyeo's* seed weights were significantly heavier than that of *Hwaseongbyeo* (Table 4). These corresponded to the difference of harvest index between the two cultivars (Table 5).

The straw and grain yields did not differ significantly between the two cultivars at all N fertilization rates. Percentage of ripened grains of *Dasanbyeo* was lower than that of *Hwaseongbyeo.* The weather condition during grain filling stage was supposed to be the cause of low percentage of ripened grains of *Dasanbyeo.*

The harvest index (HI) is a measure of the efficiency of partitioning in the grain. At all rates of N fertilization, *Dasanbyeo* exhibited improved harvest index over *Hwaseongbyeo* (Table 5). The harvest indices of *Dasanbyeo* were stable at all N fertilization rates. On the other hand, HIs of *Hwaseongbyeo* ranged from 0.44 to 0.48 and decreased as the applied N fertilizer rates increased. This suggests that the steady and high harvest index of *Dasanbyeo* contributes remarkably to its high yields.

Nitrogen absorption and partition

The rates of N fertilizer uptake of *Hwaseongbyeo* rapidly increased with the increment of N fertilization under each split application. In *Dasanbyeo*, N fertilizer uptakes were similar in all rates and times of N application (Fig. 1). The SPAD value showed the similar pattern of responses to N fertilizer in both cultivars. The different root properties of

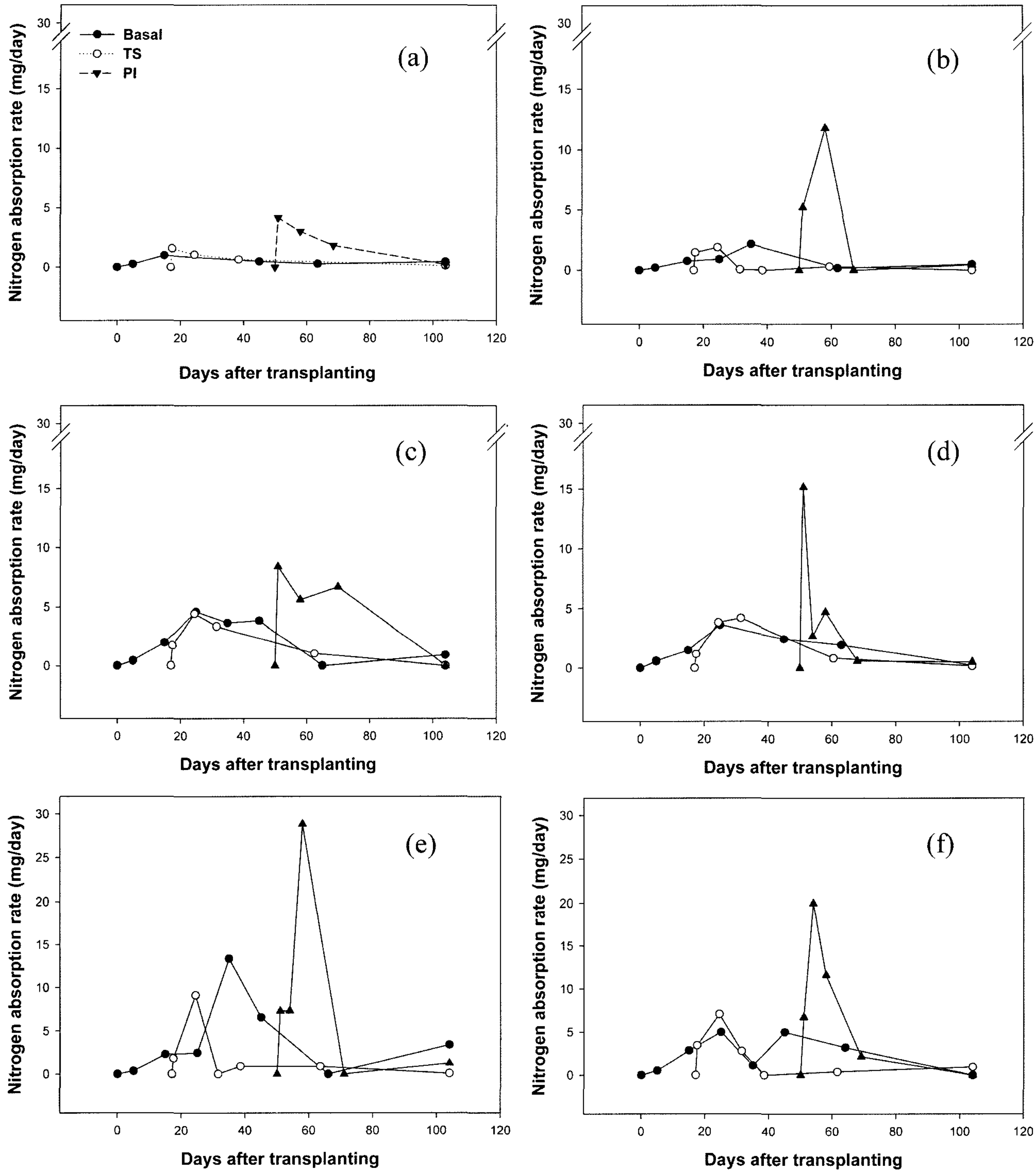

Fig. 1. Seasonal changes of N fertilizer absorption rates under the each split application in paddy field: (a) Hwaseongbyeo 60N, (b) Dasanbyeo 60N, (c) Hwaseongbyeo 120N, (d) Dasanbyeo 120N, (e) Hwaseongbyeo 180N, (f) Dasanbyeo 180N (TS: Topdressing at tillering stage, PI: Topdressing at panicle initiation stage).

two cultivars were inferred from the difference of immediate absorption of N top-dressed at panicle initiation stage.

The *Dasanbyeo* had a tendency to have high photosynthetic rates, but the differences with *Hwaseongbyeo* were not statistically significant (data not shown). The biological yield and photosynthetic capacity of a crop increased with

Table 6. Nitrogen uptake and partitioning according to the plant part at heading and harvest.

N fertilizer rate (g/m^2)	Plant parts	Plant nitrogen (g/m^2)			
		Hwaseongbyeo		Dasanbyeo	
		Heading	Harvest	Heading	Harvest
6	Leaf blade	4.77	6.78	3.55	5.91
	Leaf sheath+stem	2.93	0.88	2.98	1.07
	Panicle	1.96	7.36	2.15	7.39
	Total	9.66	15.02	8.67	14.37
12	Leaf blade	9.62	10.63	6.46	10.23
	Leaf sheath+stem	5.74	1.69	4.47	2.07
	Panicle	3.06	10.37	2.62	11.12
	Total	18.42	22.68	13.54	23.42
18	Leaf blade	12.18	12.80	8.78	15.54
	Leaf sheath+stem	6.07	3.28	5.88	3.75
	Panicle	3.10	13.80	2.28	9.68
	Total	21.35	29.88	16.94	28.97

Table 7. Nitrogen derived from fertilizer under the each nitrogen split application at heading and harvest stage in paddy field.

N fertilizer rate (g/m^2)		Nitrogen derived from fertilizer (g/hill)					
		Hwaseongbyeo			Dasanbyeo		
		Heading	Harvest	Increment	Heading	Harvest	Increment
6	Basal	0.03	0.05		0.03	0.05	
	TS	0.02	0.02		0.02	0.02	
	PIS	0.03	0.04		0.02	0.04	
	TNDFF	0.08	0.11	0.03	0.07	0.11	0.04
	Soil	0.36	0.57	0.21	0.33	0.54	0.21
	TN	0.44	0.68	0.24	0.40	0.65	0.25
12	Basal	0.14	0.18		0.11	0.12	
	TS	0.09	0.09		0.07	0.08	
	PIS	0.16	0.10		0.07	0.09	
	TNDFF	0.39	0.37	0.00	0.25	0.29	0.04
	Soil	0.45	0.64	0.19	0.37	0.77	0.40
	TN	0.84	1.01	0.17	0.62	1.06	0.44
18	Basal	0.10	0.23		0.23	0.21	
	TS	0.11	0.11		0.09	0.14	
	PIS	0.09	0.15		0.18	0.15	
	TNDFF	0.30	0.49	0.19	0.50	0.50	0.00
	Soil	0.67	0.87	0.20	0.27	0.82	0.55
	TN	0.97	1.36	0.39	0.77	1.32	0.55

TS: Tillering stage, PIS: Panicle initiation stage
TNDFF: Total nitrogen derived from fertilizer, TN: Total nitrogen

the increment of N application rates (Table 5). This supported the hypothesis that photosynthetic rate may increase as nitrogen content of the leaf blade increased (Jo *et al.*, 1995). Hence, the increased yield of the semi-dwarf cultivars could be attributed to the increased photosynthetic capacity of plants (Roberts *et al.*, 1993). This suggested that there was a significant difference in the total photosynthesis of the whole plant as the applied N fertilizer rates increased.

The plants absorbed the basally applied N fertilizer for about 50 days from the transplanting. The plants at tillering stage absorbed fertilized N until 21 days after application, while at panicle initiation stage until 20 days after top-dressing.

The total nitrogen content increased in proportion to applied N fertilizer. *Hwaseongbyeo* accumulated more nitrogen on the leaf blades than *Dasanbyeo* at heading stage. During the grain filling period, the increment of nitrogen content in leaf blades of *Dasanbyeo* was higher than that of *Hwaseongbyeo,* as applied N fertilizer rates increased. The increase in total nitrogen accumulation of *Dasanbyeo* was also larger than that of *Hwaseongbyeo* (Table 6).

Regarding the source of nitrogen, the amounts of soil nitrogen accumulated during the grain filling period were significantly different between two cultivars applied with 12 and 18 g m^{-2} N fertilization (Table 7). *Dasanbyeo* accumulated more soil nitrogen at grain filling period, at high N fertilizer rates. Whereas for *Hwaseongbyeo*, the amount of nitrogen accumulated from soil did not increase by applied N fertilizer rates. The total nitrogen content of the whole plants of both cultivars was not significantly different from each other, at harvest.

Nitrogen use efficiency

The NUEs of aboveground biomass of tested cultivars as affected by different N fertilizer levels were presented in

Table 8. Nitrogen use efficiency of aboveground biomass according to the different N fertilizer levels.

Cultivar	N fertilizer rate (kg/ha)	Application timing	Recovery fraction	Physiological efficiency	PFP-N
Hwaseongbyeo	60	Basal	0.39		
		TS	0.27		
		PIS	0.79		
		Total	0.42	30	96
	120	Basal	0.66		
		TS	0.52		
		PIS	0.95		
		Total	0.68	24	49
	180	Basal	0.57		
		TS	0.44		
		PIS	0.91		
		Total	0.60	29	32
Dasanbyeo	60	Basal	0.40		
		TS	0.26		
		PIS	0.74		
		Total	0.41	31	98
	120	Basal	0.44		
		TS	0.48		
		PIS	0.87		
		Total	0.54	30	53
	180	Basal	0.50		
		TS	0.56		
		PIS	0.92		
		Total	0.62	25	35

TS: Tillering stage, PIS: Panicle initiation stage

Table 8. The recovery fraction or recovery efficiency in *Dasanbyeo* was highest in plants collected from the plot applied with 180 kg N fertilizer per ha, while in *Hwaseongbyeo*, the recovery efficiency was highest at 120 kg N fertilizer per ha. Therefore, it was concluded that the appropriate level of N fertilizer for the highest yield of *Hwaseongbyeo* was 120 kg N per ha, and for *Dasanbyeo* it was 180 kg N per ha.

The NUEs had no significant differences between two cultivars. In split N application, the plants recovered more N when N fertilizer was applied through top dressing at the panicle initiation stage than the former stages. This implies that the panicle initiation stage was the best time to apply topdressing N-fertilizer, so that plants can recover more N.

DISCUSSION

It is suggested that the different SPAD values can be used to determine the time of topdressing N application for different rice cultivars. The SPAD value showed similar patterns of responses, to N fertilizer, of the two cultivars as shown by their rates of N fertilizer uptake. The nitrogen contents of *Hwaseongbyeo* rapidly increased with the increment of N fertilizer application rates under all N split application. In *Dasanbyeo*, the nitrogen contents were similar in all N fertilization rates.

During the ripening stage, about 70% of the nitrogen absorbed by the straw will be translocated to the grain. But in grain filling period, nitrogen in leaf blade of *Dasanbyeo* increased. These results could suggest that the nitrogen utilization differences between two cultivars were associated with the total nitrogen absorption and partition of the cultivars after heading. To produce high yields, it is essential to maintain the level of leaf nitrogen required for high photosynthetic activity. This requirement can be met when nitrogen absorption by a crop continues after heading (Yosida, 1981). Therefore, it is concluded that high nitrogen uptake and accumulation in the leaf blades and in the whole plant (including the leaf blades, leaf sheaths, and stems) can induce high yield in *Dasanbyeo.*

Also, the two cultivars had a big difference in their harvest indices. *Hwaseongbyeo* had lower harvest index at all N rates. The higher harvest index of *Dasanbyeo* implies that the remobilization ability after heading was higher in *Dasanbyeo*. Therefore, it can be concluded that *Dasanbyeo's* active N uptake and translocation from the roots during the grain filling period was influenced by the nitrogen remobilization to grain. There is still a need to conduct further studies on improving the root biomass and vigor and uptake efficiency in high-yielding varieties such as *Dasanbyeo.*

The biological yield, an indicator of the plant's photosynthetic capacity, did not differ significantly between *Hwaseongbyeo* and *Dasanbyeo* at heading. This shows that the photosynthetic capacity of the two cultivars was not significantly different from each other at heading. There remains, however, a necessity for further studies on photosynthetic capacity by growth stage, especially after heading. Because it was supposed that *Dasanbyeo* has higher photosynthetic capacity than *Hwaseongbyeo* with the increase of leaf blade N after heading and high biological yield.

It was concluded that the difference between the two cultivars in total nitrogen accumulated during the grain filling period was largely due to nitrogen derived from soil, rather than the applied N fertilizer. Probably, the nitrogen derived from the soil during the grain filling period was attributed to the increase in the harvest index of *Dasanbyeo.*

Regarding the NUEs, as applied N fertilizer rates increased, the PFP_N decreased. This may suggest that the decrease of NUE with the increment of N fertilizer application rate can result in waste of applied N fertilizer and subsequent pollution due to nitrogen wastage in the soil. Probably, the low temperature during heading possibly affected the NUEs. Micro plot was supposed the cause of over estimation of recovery fraction.

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