SPATIAL YIELD VARIABILITY AND SITE-SPECIFIC NITROGEN PRESCRIPTION FOR THE IMPROVED YIELD AND GRAIN QUALITY OF RICE

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Abstract

Rice yield and protein content have been shown to be highly variable across paddy fields. In order to characterize this spatial variability of rice within a field, the two-year experiments were conducted in 2002 and 2003 in a large-scale rice field of 6,600 m^2. In year 2004, an experiment was conducted to know if prescribed N for site-specific fertilizer management at panicle initiation stage (VRT) could reduce spatial variation in yield and protein content of rice while increasing yield compared to conventional uniform N topdressing (UN, 33 kg N/ha at PIS) method. The trial field was subdivided into two parts and each part was subjected to UN and VRT treatment. Each part was schematically divided in 10 x 10m grids for growth and yield measurement or VRT treatment. VRT nitrogen prescription for each grid was calculated based on the nitrogen (N) uptake (from panicle initiation to harvest) required for target rice protein content of 6.8%, natural soil N supply, and recovery of top-dressed N fertilizer. The required N uptake for target rice protein content was calculated from the equations to predict rice yield and protein content from plant growth parameters at panicle initiation stage (PIS) and N uptake from PIS to harvest. This model equations were developed from the data obtained from the previous two-year experiments. The plant growth parameters for this calculation were predicted non-destructively by canopy reflectance measurement. Soil N supply for each grid was obtained from the experiment of year 2003, and N recovery was assumed to be 60% according to the previous reports.

The prescribed VRT N ranged from 0 to 110 kg N/ha with average of 57 kg/ha that was higher than 33 kg/ha of UN. The results showed that VRT application successfully worked not only to reduce spatial variability of rice yield and protein content but also to increase rough rice yield by 960 kg/ha. The coefficient of variation (CV) for rice yield and protein content was reduced significantly to 8.1% and 7.1% in VRT from 14.6% and 13.0% in UN, respectively. And also the average protein content of milled rice in VRT showed very similar value of target protein content of 6.8%. Although N use efficiency of VRT

compared to UN was not quantified due to lack of no N control treatment, the procedure used in this paper for VRT estimation was believed to be reliable and promising method for managing within-field spatial variability of yield and protein content. The method should be received further study before it could be practically used for site-specific crop management in large-scale rice field.

Introduction

Significant spatial variability of plant growth, and grain yield and quality has been visualized anywhere although uniform management is practiced. Management of this spatial variability is a fundamental objective of site-specific management (SSM), with expectations of improving profits while reducing environmental pollution caused by agricultural production. Significant crop yield variability and their causal factors in upland fields have been reported by numerous researchers (Paz, 2000; Beckett et al., 1971; McBratney et al., 1997; Miller et al., 1995) and this information enabled site-specific crop management to be justified (Machado et al., 2000; Bahman Eghball and Gary E. Varvel, 1997; Cahn et al., 1994; Jin and Cheng Jiang, 2002). In lowland rice, within-field spatial variation in crop growth and yield in relation to soil properties has been reported by Dobermann (1994), Dobermann et al. (1995), Nguyen et al. (2004), and Yanai et al. (2000). Nevertheless, fertilizer has been uniformly applied in rice field without regard to the spatial variability of soil properties. This uniform management of fertilizer might have resulted in under-fertilizer application in a location but over-fertilizer application in the other location. Under-application in some locations restricted crop production whereas over-application resulted in high risk of pollution of environment and also increased cost of product (Verhagen et al., 1995; Booltink et al., 2001; Verhagen, 1997;Bouma, 1997).

To prescribe a site-specific N fertilizer amount for rice crop field, it is important to understand the response of grain yield and quality to rates of nitrogen application in combination with spatial variation in soil properties, plant growth status before N application and other factors. Spatial variation in crop yield response to fertilizer nitrogen under variable soil conditions for winter wheat, spring barley (Delin et al., 2002), and for maize (Kahabka et al., 2004) have been reported. Although variation in plant growth and N nutrition status of rice crop was reported to be an important factor determining rice yield and its response to N application at panicle initiation stage (PIS) (Cui and Lee, 2002; Yoshida, 1981; Peng et al., 1996), consideration of variation in plant growth and N nutrition status for variable N rate prescription was rare or not available in Korea and other countries.

The fertilizer prescription based on the measurement of plant growth status is usually laborious, expensive and cannot meet the time requirement. However, recently a fast and inexpensive in-situ measurement for crop growth variables such as biomass, nitrogen concentration, and uptake using advanced remote sensing technique have been reported (Casanova et al., 1998; Hansen and Schjoerring, 2003; Nguyen and Lee, 2004), promising the use of crop growth status for site specific nitrogen management.

Information of spatial variability of rice yield and its causal factors obtained previously at the two trial fields in 2002 and 2003 indicated that plant growth, soil properties, and grain yield were highly variable within the present trial field (Nguyen et al., 2004). However, a question of how to manage within-field spatial rice yield variability is still remained. An experiment was carried out to test whether variation in plant growth status may be used for the prescription of variable N rate top-dressing at PIS. The objectives of the study, therefore, were (1) to formulate the site-specific prescription rule for prescribing nitrogen topdressing amount at PIS using available spatial plant variability information and (2) to test if the prescription rule significantly reduces spatial variability of rice yield and protein content as well as improving rice yield.

Materials and Methods

1. Site description and experimental design

A paddy field located in experimental farm of National Institute of Crop Science, Rural Development Administration (37^{0}16'N), Korea was designed as a trial field for testing a possibility of management of spatial yield variability of rice in 2004. The field was used to investigate spatial variation of plant growth and yield in relation to soil properties under direct-seeded rice and the uniform fertilizer application of 110 N: 70 P: 80 K (kg/ha) in 2002, and treated with no N fertilizer under transplanting rice culture in 2003.

The field with areas of 6,600 m^2 was divided schematically into 66 grids (10m x 10m) (Fig. 1). Whole field was managed uniformly in 2002 and 2003 throughout the rice growing season. However, An upper part consisting of 33 grids was applied with prescribed N topdressing amount (VRT) while lower part consisting of 33 grids was applied with conventional uniform nitrogen top-dressing (UN) of 33 kg N/ha at PIS in 2004. The whole field was applied with 44 and 33 kg N/ha as basal and tillering fertilizer, respectively. Potassium fertilizer (80 kg/ha) was applied in two splits of 70-30% as basal-panicle fertilizer while phosphorus fertilizer (70 kg/ha) in one split (100%) as basal fertilizer.

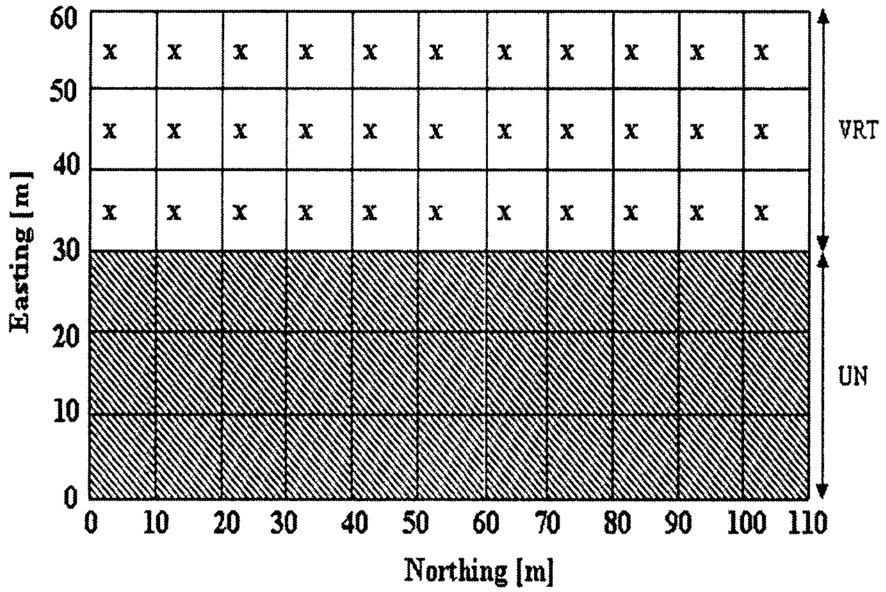


Fig.1. Design of experimental field for site-specfic N topdressing at panicle initiation stage in 2004 (upper 30 grids were used for variable rates of N topdressing (VRT) and lower 30 grids for conventional uniform management (UN) with 110 N kg/ha)

2. Crop cultivation and plant growth measurements

Japonica rice (Oryza sativa L.) variety “Daeanbyeo” was machine-transplanted. Field management practices followed a standard practices typical for Korean farmer’s field. Plant growth parameters such as shoot dry weight (DW), number of tiller (Til), shoot nitrogen concentration (SN), shoot nitrogen uptake (Nup) and SPAD reading (Minolta SPAD 502), etc. were measured at panicle initiation stage (PIS), heading stage (HD) and harvest stages (HA) of rice. Nitrogen nutrition index (NNI) was calculated with measured SN and DW according to Cui et al. (2000). Tiller number was counted for 20 hills at the center part of each grid, and the five hills were randomly sampled for plant dry weight and nitrogen concentration measurement. Sampled plants were dried at 70^0C for two days, weighed for DW, and ground through 40-mesh sieve for nitrogen analysis. Nitrogen concentration was analyzed by CNS analyzer (Leco CNS 2000). Grain yields were measured with sample harvested from the area of 6 m^2 for each grid. Final yield of rough rice was adjusted to 14% of water content.

3. Prescription of site-specific nitrogen topdressing at panicle initiation stage

3.1. Prescription formula of topdressing N amount

Nitrogen topdressing amount at panicle initiation stage was basically calculated based on the following formulae:

$$P_{SFN} = \frac{\text{N uptake - Natural N supply}}{\text{N recovery at PIS}} \qquad \text{(Eq.1)}$$

Where,

P_{SFN}: N amount prescribed for site-specific N fertilizer

Natural N supply: Natural N supply from PIS to harvest (estimated from 2003 experiment in the same field where no N fertilizer application was applied.

N recovery at PIS: recovery of N applied at panicle initiation stage (60% was used as reported by Kim (2004)

N uptake: uptake from PIS to harvest required for a target protein content of milled rice (P).

The calculation of N uptake from PIS to harvest for a target protein content of milled rice was presented in the next section (section 3.2).

3.2. Estimation of N uptake requirement for targeting grain yield and protein content in relation to plant growth parameters at panicle initiation stage

In order to estimate nitrogen uptake amount (from panicle initiation to harvest stage) required for target rice yield and protein content, we firstly formulated regression equation of rice yield (Y) and protein content (P) response to plant growth parameters such as shoot dry weight (DW), shoot nitrogen concentration (SN), nitrogen nutrition index (NNI) at PIS and nitrogen uptake (Nup) from PIS to harvest with the data obtained from the previous two years experiments (Table 1a). Equations from Tables 1.a showed that crop parameters at PIS in combination with Nup successfully explained rice yield and protein content of milled rice (R^2>0.94). Thus, we converted these equations to get Nup for target yield and protein content (Table 1.b).

To estimate N top-dressing amount at PIS using Eq.1, Nup for each grid have to be calculated from the equations in Table 1b with the target rice yield/protein content and the measured or predicted plant growth parameters prior to N top-dressing at PIS. In this study, we applied canopy reflectance method using hand-held spectroradiometer (GER Inc. USA; GER 1500) for in-situ determination of crop growth parameters at PIS. The detailed information of the method may be found in reports from Nguyen and Lee (2004), Nguyen et. al. (2004), and Hansen and Schioerring (2003) and the details of the applied method for determination of plant growth variables at PIS in this study was presented in the next section (section 3.3).

Table 1.a. Regression equations of grain yield (Y) and protein content (P) response to plant growth parameters

Items	Regression equations	R2
Protein content (P)	$P=4.69+0.0144Nup+0.063NNI$	0.9499
	$P= 5.00+0.0144Nup-0.23SDW+0.081DW^2$	0.9560
	$P= 4.433+0.0180Nup-0.000Nup^2+0.235SN$	0.9419
Rice yield (Y)	$Y=2266+27.9Nup+1517NNI$	0.984
	$Y= 5.00+0.0144Nup-0.23SDW+0.081DW^2$	0.989
	$Y= 2304+28.1Nup+77.9SN^2$	0.979

P: protein of rice (%)
Y: rice yield (kg/ha)
Nup: N uptake from panicle initiation stage (PIS) to harvest (kg/ha)
NNI: Nitrogen nutrition index at PIS
DW: shoot dry weight at PIS (ton/ha)
SN: Shoot nitrogen concentration at PIS (%)

Table 1.b. Equations to estimate N uptake amount (Nup) from panicle *initiation* stage (PIS) to harvest stage required for target rice yield (Y) and grain protein content (P) in relation to plant growth parameter at PIS

Item	N uptake (Nup) required for targeting
Protein content of grain (P)	$Nup= (P-4.691-0.639NNI)/0.0144$ $Nup= (P-5.008+0.238DW-0.0813SDW^2)/0.0144$ $Nup= (P-4.433+0.000Nup^2-0.235SN)/0.0186$
Rice yield (Y)	$Nup=(Y-2266-1517NNI)/27.9$ $Nup= (Y-5.00+0.23DW-0.081DW^2)/0.0144$ $Nup= (Y-2304-77.9SN^2)/28.1$

3.3. Prediction of plant parameters using canopy reflectance at panicle initiation stage

To estimate Nup for target yield and protein content in the present experiment, canopy reflectance of rice before applying N fertilizer at PIS was measured by GER 1500. The procedure of canopy measurement using GER 1500 for the prediction of rice crop growth variables using canopy reflectance data were descried in detail by Nguyen and Lee (2004) and Nguyen et al. (2004). The measured DW was presented in Fig. 2, indicating that rice growth is spatially variable prior to nitrogen top-dressing at PIS while plant parameters such as DW, NNI and SN predicted from canopy reflectance data by partial least square method were presented in comparison with the observed values in Fig.3. The significant close correlation between predicted and observed values of dry weight and NNI in Fig.3 ($R^2>0.73$, n=66) suggested that partial least square using canopy reflectance of rice is reliable method for in-situ rice growth status measurement.

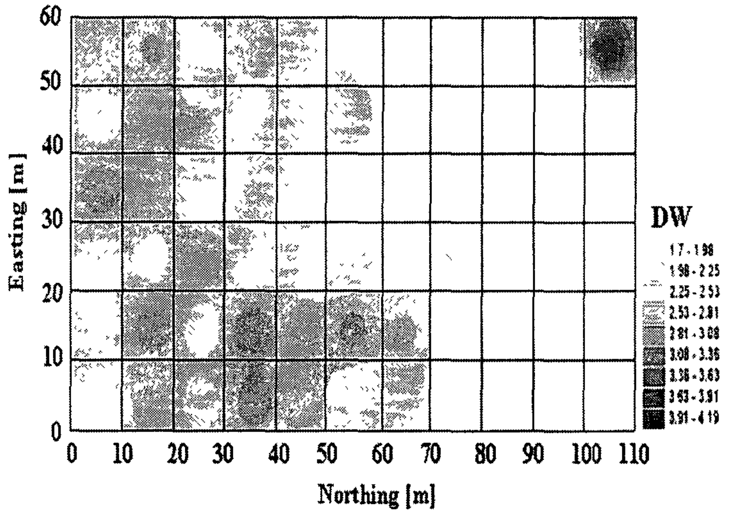


Fig. 2 Kriged map of spatial variation of shoot dry weight (DW) at panicle initiation stage prior to nitrogen topdressing

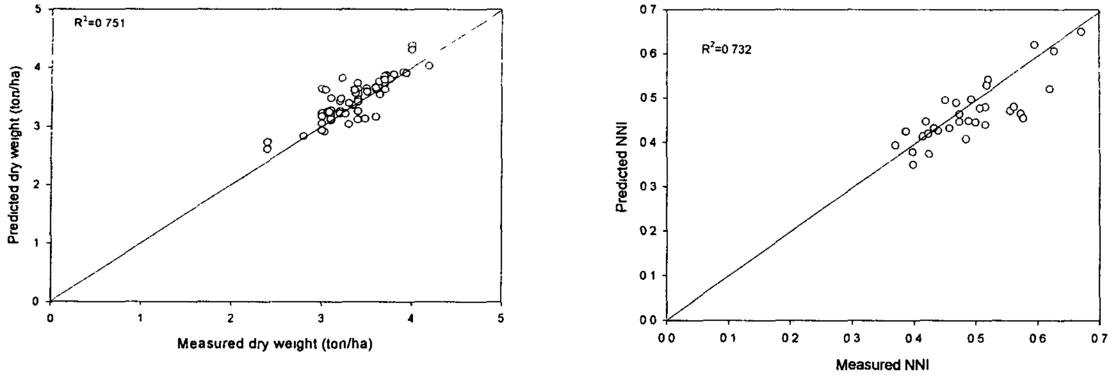


Fig. 3 Comparison of nitrogen nutrition index (NNI) and shoot dry weight (DW) at panicle initiation stage between measured and predicted by canopy reflectance for N topdressing prescription

3.4. Prescribed N topdressing amount

Nitrogen topdressing amount were prescribed for targeting rice protein content of 6.8 % instead of targeting rice grain yield as the Nup for maximizing rice grain yield is too high because of the decreasing internal N use efficiency at high N level (Witt et al., 1999) and protein content is a good criterion of rice quality in terms of its palatability. Nitrogen topdressing amounts prescribed based on predicted NNI, DW, and SN were compared in Fig. 4 and they showed good agreement each other with R^2>0.99. The prescribed nitrogen amounts ranged from 0 to 110 kg N/ha, depending on each grid of the field and the average was 57kg/ha. The spatial variation of protein content in year 2003 without fertilizer application (Fig. 5a) was presented in comparison with the prescribed N topdressing amount in this study in year 2004 (Fig. 5b). The grid that higher protein content occurred was prescribed with less nitrogen topdressing amount.

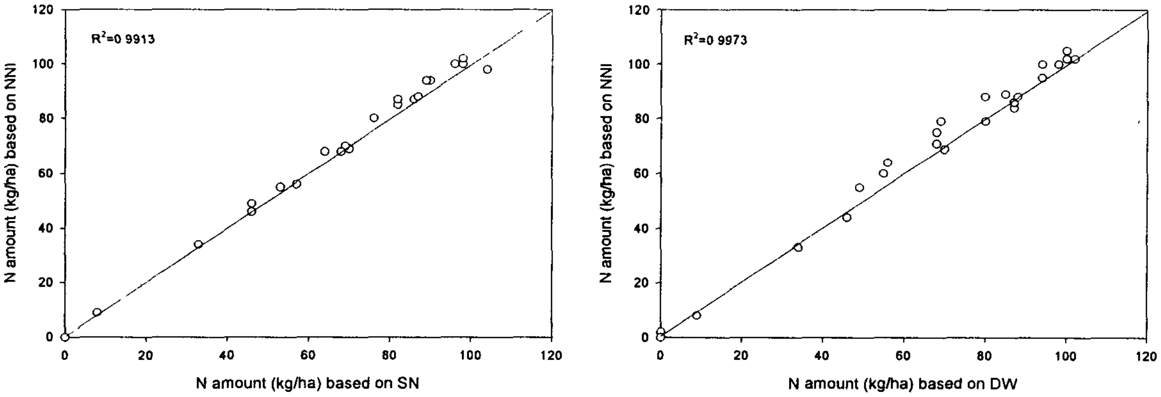
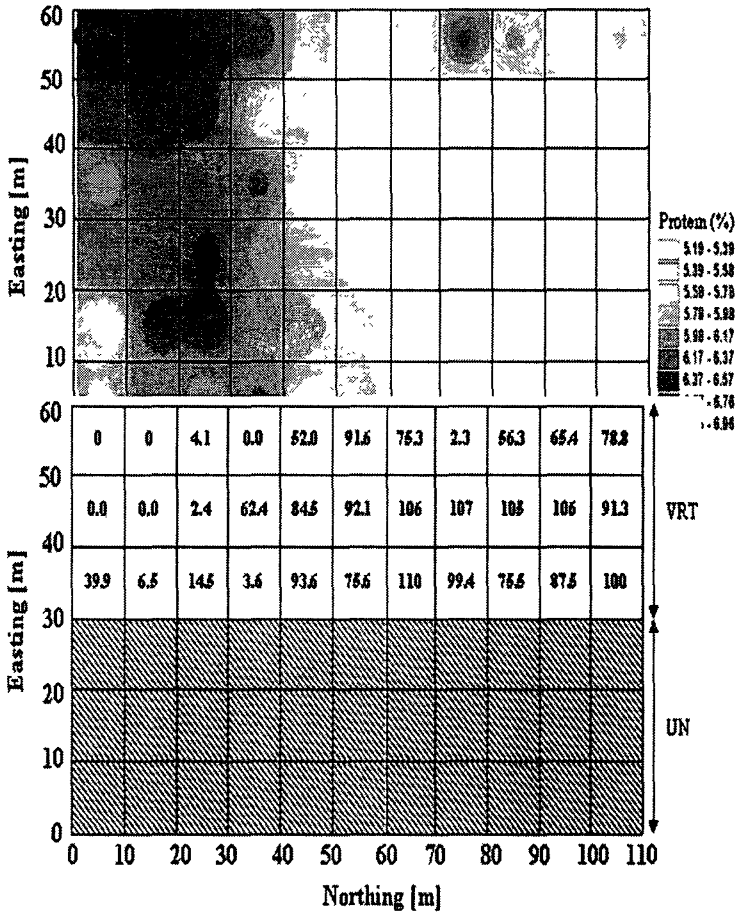


Fig. 4. Comparison of N topdressing amount prescribed based on plant growth variables (NNI, SN and SDW) estimated by canopy reflectance at panicle initiation stages



0	0	4.1	0.0	52.0	91.6	75.3	2.3	56.3	65.4	78.2
0.0	0.0	2.4	62.4	84.5	92.1	106	107	105	106	91.3
39.9	6.5	14.5	3.6	93.6	76.6	110	99.4	75.5	87.5	100

Fig. 5. Kriged map of spatial variation of grain protein content at the experimental field in 2003 (A) and prescribed N topdressing amount (B) (kg/ha) for targeting protein content of 6.6% (VRT: 33 grids treated with prescribed N amount and UN: 33 grids with uniform application of (33 N kg/ha at panicle initiation stage).

4. Data analysis

Descriptive statistical analysis was used for presenting the spatial variability of rice yield and protein content: mean, minimum, maximum, range, and coefficient of variation (CV). Multiple linear regression was use to formulate regression equation of rice yield and protein content response to plant growth variables, including NNI, SN and DW. Partial least square (PLS) procedure (Nguyen et al. 2004) was used to predict NNI, SN and DW from canopy reflectance data measured by GER 1500 at PIS. kriging map of spatial variation of yield and protein content and other related parameters was performed using Acview GIS (ESRI, 1996). Data analysis and processing were carried out using SAS (SAS institute inc. 8.12).

Results

1. Comparison of spatial plant growth variability between VRT and UN

Variation of plant growth at panicle initiation stage (PIS) and heading stages (HD) of VRT and UN in comparison with no N treatment in year 2003 were presented in Table 2. Most of plant parameters were highly variable in prescribed nitrogen application (VRT) and conventional uniform nitrogen application (UN) at PIS. Coefficient of variation (CV) ranged from 5.3% for SPAD reading to 22.4% for shoot nitrogen uptake. Some plant growth parameters such as DW, SN, and NNI at VRT field seem to be reduced at heading stage compared with UN (Table 2.). Moreover, at harvest stage, variation of plant growth parameters at the field with VRT were significantly reduced compared with UN (CV for shoot nitrogen uptake at VRT was 17% while at UN is 22%). Shoot nitrogen uptake was also found to be the most variable among plant growth parameters of rice while SPAD reading was the least variable parameter at all stages (Table 2).

Table 2. Comparison of spatial variation of growth parameters between the prescribed and uniform N topdressing (33 grids)

Parameter		Panicle initiation stage		Heading stage		Harvest stage	
		Prescribed Nitrogen	Uniform Nitrogen	Prescribed Nitrogen	Uniform Nitrogen	Prescribed Nitrogen	Uniform Nitrogen
DW	Range	1.7-4.1	2.3-3.7	5.2-10.3	5.2-9.4	8.0-14.6	7.1-15.8
	C.V.	22.1	14.0	15.5	15.1	17.1	22.4
SN	Range	1.3-2.0	1.5-2.0	1.0-1.8	1.0-1.7	0.7-1.2	0.8-1.2
	C.V.	11.4	6.98	10.8	13.1	13.1	14.2
Nup	Range	26-66	41-79	54-176	55-152	67-147	62-187
	C.V.	22.4	18.7	20.4	25.5	20.1	30.2
NNI	Range	0.3-0.6	0.4-0.6	0.4-0.9	0.4-0.8	ND	ND
	C.V.	15.7	8.3	19.7	13.1	ND	ND
SPAD	Range	29-38	32-38	31-45	30-43	ND	ND
	C.V.	9.99	5.33	8.0	8.31	ND	ND

DW: Shoot dry weight (ton/ha)
SN: Shoot nitrogen concentration (%)
Nup: Shoot nitrogen uptake (kg/ha)
NNI: Nitrogen nutrition index
SPAD: SPAD reading
ND: Not measured

2. Comparison of spatial variability of rice yield and grain protein content between VRT and UN.

2.1 Spatial variation of rice yield

Spatial variation of rice yield at VRT and UN were presented in Table 3. Rice yield at VRT ranged from 6000 to 9000 kg/ha while 5500 to 8500 kg/ha was recorded for UN. An average of about 960 kg/ha of rice at VTR was higher than that of UN.

Table 3.Comparison of spatial variation of rice yield between 33 grids with prescribed N and 33 grids with conventional uniform N

	Prescribed field section		Conventional field section	
	No fertilizer 2003	Prescribed N 2004	No fertilizer 2003	Uniform N 2004
Minimum	3323	6413	3204	5546
Maximum	6171	9249	5541	8672
Mean	4460	7954	4207	7019
Standard deviation	954.0	647.9	656.0	1033
Coefficient of variation (%)	21.3	8.13	15.5	14.7

Spatial rice yield variability in 2004 was also significantly reduced at VTR in comparison with UN. Coefficients of variation were 8.13% and 14.6% for VRT and UN, respectively. Data of rice yield measured under no fertilization condition in 2003 at the same field as in the present study of 2004 was also presented in Table 3 for comparison of the variation between 2003 and 2004. The spatial variability of rice yield was significantly reduced from 21.3 % in 2003(no fertilization) only to 8.1% in 2004 (VRT) in VRT prescription, while no conceivable difference in the spatial variability was detected between years in UN. The kriged map of spatial variation distribution of rice yield at VTR and UN field were shown in Fig. 6. These maps also clearly indicate that spatial variation of rice yield was reduced due to the site-specifically prescribed nitrogen topdressing.

2.2. Spatial variation in grain protein content of milled rice

Variation of grain protein content at VRT was also significantly reduced compared with UN (Table 4). Grain protein content of milled rice at VRT ranged from 5.60% to 7.92% with CV of 7.05% while at UN it ranged from 4.41-7.66% with CV of 13.0%. And spatial variability of protein content was rather lower in 2004 (VRT N) than 2003 (no fertilizer application) at the VRT field, while the CVs increased significantly from 6.51% in 2003 to 13% in 2004 at UN field. kriged map of spatial variation distribution of protein content at VRT and UN were also compared (Fig. 7). These maps also clearly indicate that spatial variation of rice protein content was reduced due to the site-specifically prescribed nitrogen topdressing

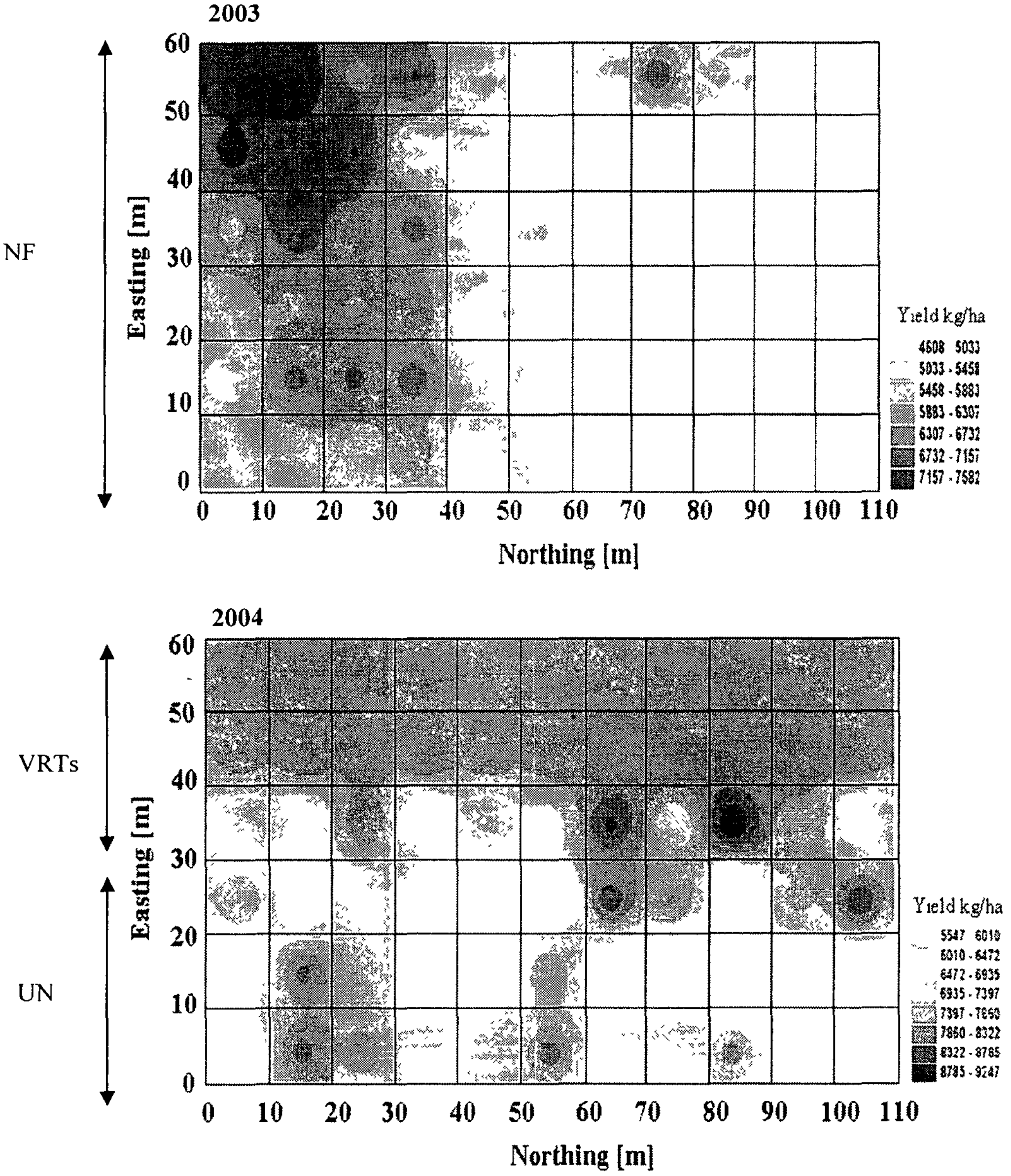


Fig. 6. Kriged of spatial variation of rice yield at the experimental field subjected to uniform and prescribed N topdressing at panicle information stage (NF: No fertilizer application in 2003 and VTR: variable rate of N topdressing in 2004).

Table 4 Comparison of spatial variation of grain protein content between 33 grids for the prescribed N and 33 grids with conventional uniform N

	Prescribed field section		Conventional field section	
	No fertilizer 2003	Prescribed N 2004	No fertilizer 2003	Uniform N 2004
Minimum	4.68	5.60	4.73	4.41
Maximum	6.29	7.92	5.92	7.66
Mean	5.34	6.87	5.28	6.04
Standard deviation	0.44	0.52	0.35	0.91
Coefficient of variation (%)	8.23	7.05	6.51	13.0

Discussion

1 Procedures to derive fertilizer recommendation for site-specific crop management

Methods for measurement of spatial crop variability were reported by Seney (1998), and Naiqian (2002) discussed several alternative managements of spatial crop variability. Variable rate technology (VRT) is often used for managing the spatial variability, for example, VRT of fertilizer application, seed or pesticides etc. Estimation of nitrogen requirements is an important technique for VRT of fertilizer application for managing crop spatial variability (O'Neal et al., 2000). In this experiment, the method for VRT of N top-dressing requirement at PIS was derived for rice. and examined its feasibility.

Regression equations for predicting rice yield and protein content were well formulated using the information on rice yields, protein contents, plant nitrogen and biomass etc. from the previous year experiment in 2003 (Table 1a and Table 1b). In addition, partial least square (PLS) procedure was used to predict DW, NNI, and SN from canopy reflectance with acceptable precision and accuracy (Fig.3). With these procedures, nitrogen uptake (Nup) required from PIS to harvest for target rice yield or grain protein contents could be well estimated and used for calculation of variable nitrogen topdressing prescription. Site-specific N top-dressing amount determined for targeting rice protein content ranged from 0 to 110 kg N/ha with average of 57 kg N/ha. The high spatial variation in prescribed N levels (Fig.5) reflected the high spatial variation of natural soil N supplies that was obtained in the previous experiment of year 2003.

The method for site specific N fertilizer prescription for managing spatial rice yield variability is successful only if basic data on spatial variation in soil conditions and variation in plant growth status at PIS before N prescription of the same year are available. Firstly, the basic field information of the study

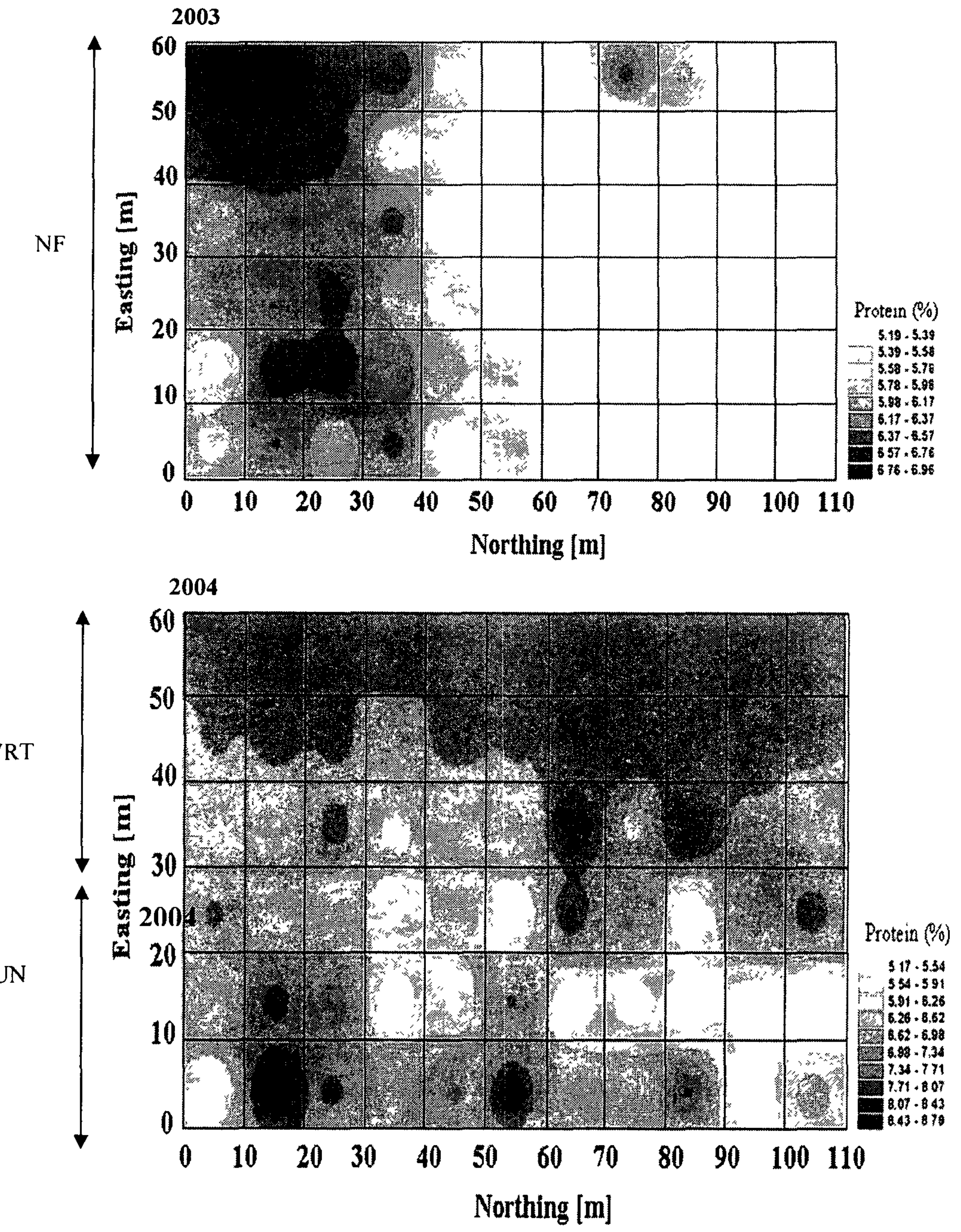


Fig. 7. Kriged of spatial variation of rice protein content at the experimental field subjected to uniform and prescribed N topdressing at panicle initiation stage (NF: No fertilizer application in 2003 and RTR: variable rate of N topdressing in 2004).

sites includes spatial distribution of natural soil N supplies and N recovery as well as spatial variation in yield or protein content in response to plant growth status at PIS. Although this information may be obtained from field research, its temporal variation among years should be considered. If the relative temporal variation in a given parameter is small compared to spatial variation, the spatial variation information obtained from one year or average over several years are useful information for site specific N fertilizer prescription, otherwise it is useless. That is why quite stable soil parameters such as CEC, clay content or organic matter was preferred to other high temporal variation parameters such as NO_3-N and exchangeable cations (Dobermann, 1994; Cox et al., 2003). Secondly, the prediction of crop variables at PIS by fast and nondestructive canopy reflectance method is required (Nguyen and Lee, 2004; Nguyen et al., 2004; Hansen and Schjoerring, 2003). However, the precision and accuracy of the method depends on several factors such as weather condition, data analysis and skills of technicians.

2. Spatial variation of plant growth under VTR and UN

Spatial yield variability of rice was significantly caused by plant growth variations due to soil conditions (Dobermann, 1994; Casanova et al., 1999) and management of plant growth variation was considered important for site-specific crop management (Naiqian, 2002). Variation of plant growth under VRT and UN were measured at several growth stages of rice crop. It is expected that most of plant growth parameters were equally varied at PIS because the whole field was managed uniformly until PIS. The differences in mean and CV of plant growths at PIS between two parts (VRT and UN) were probably due to different variation in soil properties. At heading stage, some plant parameters in VRT turned out to reduce in variation suggesting that prescription of nitrogen topdressing potentially reduced the variation in plant growth. The variation of plant growth reduced by VRT was clearer at harvest, most of plant parameters such as shoot N concentration and uptake being smaller in CV at VRT than at UN parts (Tables 2).

3. Spatial yield variability and grain protein contents under VTR and UN

Obtained results of spatial variability of rice yield and protein content at VRT and UN (Tables 3 and 4) confirmed that the method and procedure we developed for prescribing nitrogen topdressing at panicle initiation stage have successfully worked to manage spatial yield and protein variability in paddy field. Variation of rice yields and grain protein content of VTR were significantly reduced compared with

UN. kriged maps of rice yield and grain protein contents (Fig. 6 and 7) also presented quite homogeneous distribution in all grids of VTR while they were highly variable among grids of UN.

One of the limitations of the study possibly was that the results did not show the N use efficiency or economic return from VRT in comparison with UN. The limitation was due to lack of a control treatment without N application at PIS at VRT and UN parts. We would like to recommend this remaining issue for further study. In conclusion, the research was carried out as just a case study for confirming the possibility of spatial variability management of rice crop. However, there is no doubt to recommend the result from this research for further examination to implement the site-specific crop management in large-scale rice field in Korea.

Conclusion

A possibility for management of spatial yield variability and grain protein contents using prescribed nitrogen topdressing at panicle initiation stage have been examined in a paddy field of Korea and obtained results of this research can be summarized as follows: The prescription of N fertilizer requirement for management of spatial variation in rice yield and protein contents at PIS using basic spatial information for previous study and in-situ prediction of variation in plant growth status was formulated successfully. Spatial variation of plant growth at VTR turned out to reduce slightly at HD after the prescription treatment of nitrogen topdressing and, especially, spatial variation of plant growths was significantly reduced at harvest stage. Design of experimental field for testing a possibility of management of spatial yield variability using prescription of nitrogen at PIS has successfully worked not only to reduce spatial yield and protein content variability but also increase rice yield in a paddy field. The developed method and procedure for estimation of nitrogen topdressing amount for site-specific fertilizer management was quite reliable. However, this was just a case study, further improvement is necessary before this procedure could be practically used for the site-specific rice management in large-scale rice field.

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