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Spikelet Number Estimation Model Using Nitrogen Nutrition Status and Biomass at Panicle Initiation and Heading Stage of Rice

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ABSTRACT : Spikelet number per unit area(SPN) is a major determinant of rice yield. Nitrogen nutrition status and biomass during reproductive stage determine the SPN. To formulate a model for estimating SPN, the 93 field experiment data collected from widely different regions with different japonica varieties in Korea and Japan were analyzed for the upper boundary lines of SPN responses to nitrogen nutrition index(NNI), shoot dry weight and shoot nitrogen content at panicle initiation and heading stage. The boundary lines of SPN showed asymptotic responses to all the above parameters(X) and were well fitted to the exponential function of $f(X)=\alpha\cdot\{1-\beta\cdot\exp(\gamma\cdot X)\}$. Excluding the constant, from the boundary line equation, the values of the equation range from 0 to 1 and represent the indices of parameters expressing the degree of influence on SPN. In addition to those indices, the index of shoot dry weight increase during reproductive stage was calculated by directly dividing the shoot dry weight increase by the maximum value ($800\ g/m^{-2}$) of dry weight increase as it showed linear relationship with SPN. Four indices selected by forward stepwise regression at the stay level of 0.05 were those for NNI (I_{NNI_p}) at panicle initiation, NNI(I_{NNI_h}) and shoot dry weight(I_{DW_h}) at heading stage, and dry weight increase(I_{DW}) between those two stages. The following model was obtained : $SPN=48683\cdot I_{DW_H}{}^{0.482}\cdot I_{NNI_P}{}^{0.387}\cdot I_{NNI_H}{}^{0.318}\cdot I_{DW}{}^{0.355})$. This model accounted for about 89% of the variation of spikelet number. In conclusion this model could be used for estimating the spikelet number of japonica rice with some confidence in widely different regions and thus, integrated into a rice growth model as a component model for spikelet number estimation.

***Keywords*: rice, spikelet number, nitrogen nutrition index, boundary line, model.

The spikelet number per unit land area is a most important determinant of rice grain yield (Yoshida, 1981; Wang *et al.*, 1997), its variation accounting for about 80% of seasonal variability of rice grain yield (Yoshida and Parao, 1976). The spikelet number that is determined by the number of panicles per unit area and the number of spikelets per panicle has a close relationship with nitrogen nutrition. Nitrogen deficiency leads not only to the panicle number decrease during early growth stage but also to the panicle size decrease due to the increased spikelet degeneration during reproductive stage (Wada, *et al.* 1968; Yoshida, 1981). Many researchers have reported that spikelet number showed good relationship with shoot nitrogen and dry matter accumulation from panicle initiation to flowering (Kropff, *et al.* 1994a; Hasegawa, *et al.* 1994; Wang, *et al.* 1997) and these relationships differed among regions and cultivars (Hasegawa, *et al.*, 1994; Kropff, *et al.*, 1994a; Yoshida and Parao, 1976). This interregional and varietal variation has not been elucidated yet and provides a major limitation of spikelet number estimation in crop growth model. Nitrogen nutrition index (NNI), which quantifies the nitrogen status of plant (Lemair, *et al.*, 1989) can be used in dynamic models to take account of the effects of nitrogen on crop growth and yield (Justes *et al.*, 1997). Jeuffroy and Bouchard (1999) characterized some nitrogen deficiency parameters based on the changes in time course of NNI and estimated wheat grain number per unit area using the relationship between this parameter and grain number. However, NNI was not evaluated in relation to spikelet number in rice.

The aim of the present study was to establish spikelet number estimation model that could be used as a component model of rice crop growth model. For the model formulation were adopted the boundary line analyses for the responses of spikelet number to nitrogen nutrition status and biomass accumulation at panicle initiation and heading stage of rice.

MATERIALS AND METHODS

The data in this analysis were from six N fertilization experiments including dry direct-seeding and transplanting rice culture for two years on a sandy loam soil of paddy fields at College Farm, Seoul National University, Suwon (37°16'N), Korea. the cultivars and the fertilizer N treatments were shown in table 1 and table 2. In addition the data from three experiments in Japan were included for the analyses as well : Hokkaido (Shiga and Sekiya 1976; Miyazaki et *al.*, 1981) and Hiroshima (Ohyama and Nishi. 1979).

The measurement data of the above experiments were

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Table 1. Summary of transplanted rice field experiments in Suwon, Korea.

No.	Year	Cultivars	N fertilizer treatment kg ha^{-1}	Transplanting or seeding date	Sampling times (before heading)
1	1999	Hwasung(Japonica)	0-75-150-200-225-300[a)]	May 9(seeding date)	11
2	1999	Hwasung(Japonica)	60-120-180-240-360[b)]	May 16(Transplanting date)	9
3	2000	Hwasung(Japonica)	0-140-220[b)]	May 27(″)	9
4	2000	Dongjin(Japonica)	0-140-220[b)]	May 27(″)	9
5	2000	Odae(Japonica)	0-140-220[b)]	May 27(″)	9
6	2000	Hwasung(Japonica)	120-240-360-480[c)]	May 19(″)	7

[a)] Nitrogen fertilizer application treatments were shown in table 2.

[b)] The basal, tillering and panicle fertilizer were applied in the ratio of 40%, 30% and 30%.

[c)] N fertilizer were applied five times at an interval of 14 days from May 18.

Table 2. Summary of nitrogen split application treatments in dry direct-seeding rice culture in Suwon Korea, in 1999.

Treatment	Basal Fertilizer (kg ha^{-1})	Tillering Fertilizer (kg ha^{-1})	Panicle Fertilizer (kg ha^{-1})	Total (kg ha^{-1})
1-1	0	0	0	0
1-2	0	0	75	75
1-3	0	75	0	75
1-4	0	75	75	150
1-5	0	75	150	225
1-6	0	150	0	150
1-7	0	150	75	225
1-8	0	150	150	300
1-9	50	75	75	200
1-10*	0			200
1-11**	0			300

*2.5 kg N/10a was appled eight times at an interval of 10 days from 4-leaf stage to heading

**3.75 kg N/10a was appled eight times at an interval of 10 days from 4-leaf stage to heading

composed of the dry weight and nitrogen concentration of shoot at panicle initiation and heading stage, and the final number of spikelets per square meter. All the nitrogen concentrations were determined by the Kjeldahl method. The shoot nitrogen content was calculated by shoot nitrogen concentration x shoot dry weight (g m^{-2}). The nitrogen nutrition index(NNI) at each growth stage was calculated as follows according to Lemaire and Gastal (1997).

$$NNI = \frac{N_m}{N_c}$$

where N_m is the measured nitrogen concentration and N_C is the critical nitrogen concentration estimated form the critical nitrogen dilution curve for rice (Cui, *et al.*, 2002).

The boundary line analysis was performed according to Schnug *et al.* (1996) for the relationship of spikelet number with NNI, shoot dry weight, and shoot nitrogen content at panicle initiation and heading stage. Spikelet number was plotted against each parameter above-mentioned. From the graph the upper boundary points were selected arbitrarily by eye and fitted to the following exponential function by NLIN procedure of SAS:

$$Y = \alpha \cdot \{1 - \beta \cdot \exp(\gamma \cdot X)\} \qquad (1)$$

where Y is the spikelet number (m^{-2}), X indicates parameter such as shoot dry weight, NNI and shoot nitrogen content at the time of panicle initiation and heading, and α, β and γ are constants. Excluding the parameter of α in equation (1), Y values are ranging from 0 to 1 and these were used as the indices expressing the of degree of influence on spikelet number. The indices for the above parameters were used to formulate the model to predict the spikelet number.

RESULTS AND DISCUSSION

Boundary line analysis

To determine the relationships of spikelet number with the shoot dry weight, NNI and shoot nitrogen content at the time of panicle initiation and heading, boundary line analyses were conducted for these parameters. The scatter plots of spikelet number against the parameters, the boundary points and the boundary lines were shown in Fig 1 and Fig 2.

The upper boundary point that indicate the maximum spikelet number attainable at a given level of each parameter was chosen arbitrarily by eye. The boundary point values showed asymptotic relationship to the increase of each parameter and the upper boundary lines connecting the points were well fitted to the exponential functions of equation (1) as in table 3. Excluding the parameter of α in equation (1), Y values range from 0 to 1 and these values can be used as the indices expressing the degree of influence on spikelet number.

In addition, a good linear relationship between the spikelet number and the shoot dry weight increase over the period

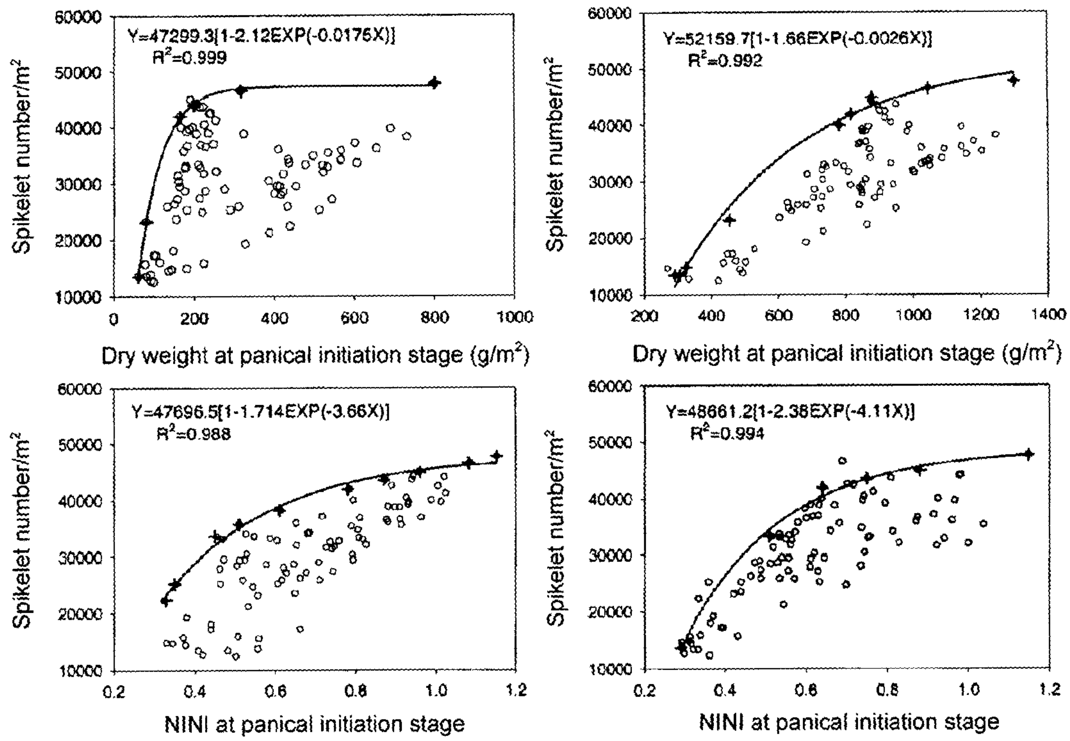

Fig. 1. Scattergram and boundary lines of spikelet number responses to NNI and shoot dry weight at the time of panicle initation and heading. (+) on the grah represets the boundary point selected arbitrarily.

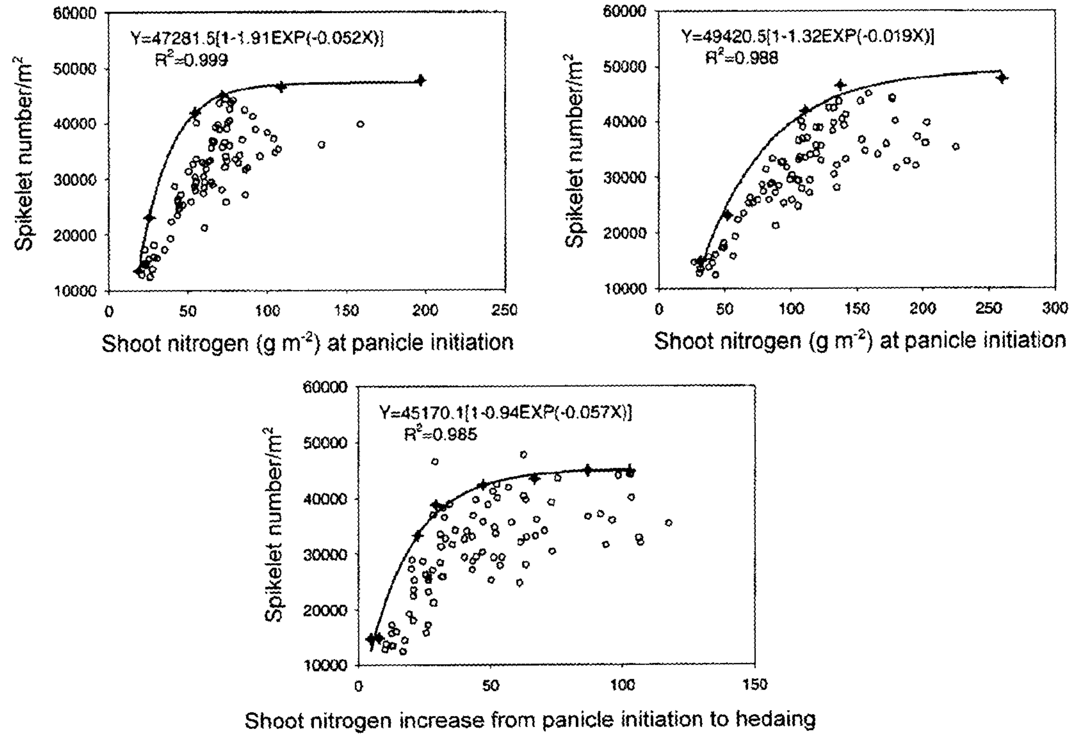

Fig. 2. Scattergram and boundary lines of rice spikelets number responses to the nitrogen conents in shoot at the time of paricle initiation and heading and the shoot nitrogen increase between the two stages. (+) on the graph represents the boundary point selected arbitrarily.

Table 3. Boundary line formulas for the responses of spikelet number per square meter to shoot dry weight, NNI and shoot nitrogen content at panicle initiation and heading stage of rice.

Parameter	Boundary line formula	Index formula	R^2
DW_P	$f(DW_P)=47299.3[1-2.12EXP(-0.017DW_P)]$	$I_{DW_P}=1-2.12EXP(-0.017DW_P)$	0.999
NNI_P	$f(NNI_P)=47696.5[1-1.71EXP(-3.661NNI_P)]$	$I_{NNI_P}=1-1.71EXP(-3.661NNI_P)$	0.988
DW_H	$f(DW_H)=52159.7[1-1.66EXP(-0.003DW_P)]$	$I_{DW_H}=1-1.66EXP(-0.003DW_P)$	0.992
NNI_H	$f(NNI_H)=48661.2[1-2.38EXP(-4.114NNI_H)]$	$I_{NNI_H}=1-2.38EXP(-4.114NNI_H)$	0.994
N_P	$f(N_P)=47281.5[1-1.91EXP(-0.051N_P)]$	$I_{NNI_H}=1-1.91EXP(-0.051N_P)$	0.999
N_H	$f(N_H)=49420.5[1-1.32EXP(-0.019N_H)]$	$I_{NNI_H}=1-1.32EXP(-0.019N_H)$	0.988
N_{H-P}	$f(N_{H-P})=45170.1[1-0.94EXP(-0.057N_{H-P})]$	$I_{N_{H-P}}=1-0.94EXP(-0.057N_{H-P})$	0.985

DW_P : Shoot dry weight ($g\ m^{-2}$) at panicle initiation.
NNI_P : Nitrogen nutrition index at panicle initiation.
DW_H : Shoot dry weight ($g\ m^{-2}$) at heading.
NNI_H : Nitrogen nutrition index at heading.
N_P : shoot nitrogen content ($g\ m^{-2}$) at panicle initiation.
N_H : shoot nitrogen content ($g\ m^{-2}$) at heading.
N_{H-P} : shoot nitrogen increase ($g\ m^{-2}$) from panicle initiation to heading.

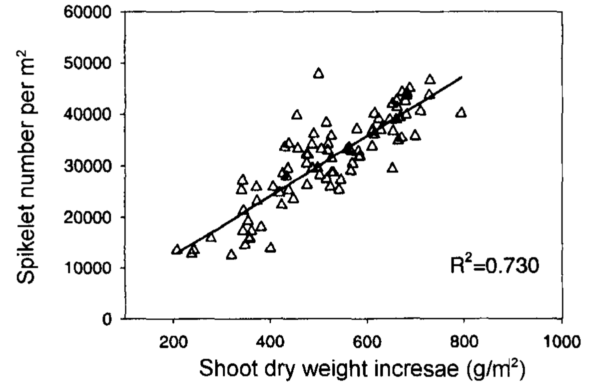

Fig. 3. Relationship between spikelet number and shoot dry weight increase from panicle initiation to heading stage.

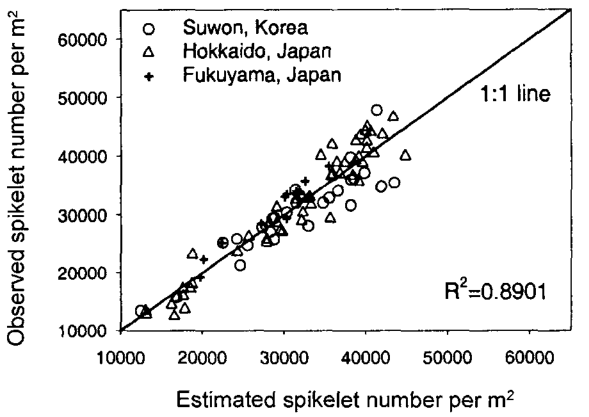

Fig. 4. Relationship between the observed and the estimated spikelet number by model equation (3).

from panicle initiation to heading was found (Fig. 3). Some rice growth model uses this relation to estimate the rice spikelet number (Kropff *et al.*, 1994b). In order to reflect the effect of shoot dry weight increase during reproductive stage on spikelet number, the index of shoot dry weight increase was calculated by dividing the actual shoot dry weight increase by the maximum value (800 $g\ m^{-2}$) of shoot dry weight increase.

Model for estimating spikelet number

A regression model for estimating spikelet number (SPN) was developed using those indices (I's) obtained from boundary line analysis and shoot dry weight increase index. The model was supposed to have the following form with different weighting power for each index.

$$SPN=\alpha \cdot I_1^{\alpha} \cdot I_2^{\beta} \cdots I_n^{\omega} \quad (2)$$

Taken the natural logarithm on both sides of equation (2), the equation is transformed into multiple linear regression. Using SAS, forward stepwise regression was performed with stay level probability of 0.05. Four among eight indices as in table 3 were included in the model like the following equation (3).

$$SPN=48683 \cdot I_{DW_H}^{0.482} \cdot I_{NNI_P}^{0.387} \cdot I_{NNI_H}^{0.318} \cdot I_{DW}^{0.355} \quad (3)$$

The spikelet number calculated based on model equation (3) was plotted against the measured spikelet number (Fig. 4). Despite that the data were collected from three locations with very different climates, the model equation could account for about 89% of the variation of spikelet number (R^2=0.8901, n=93).

As the model was derived from upper boundary line analysis of the data representing a wide range of climatic conditions, it can be concluded that it could be used to estimate spikelet number in widely different regions with considerable confidence and as component model for rice growth model.

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