Korean J. Crop Sci. 44(2) : 149~153(1999)

Relationship between Plastochrone and Development Indices Estimated by a Nonparametric Rice Phenology Model

Byun Woo Lee*[1], Taeg Su Nam*, and Young Seon Yim*

ABSTRACT

Prediction of rice developmental stage is necessary for proper crop management and a prerequisite for growth simulation as well. The objectives of the present study were to find out the relationship between the plastochrone index(PI) and the developmental index(DVI) estimated by non-parametric phenology model which simulates the duration from seedling emergence(DVI=0) to heading(DVI=1) by employing daily mean air temperature and daylength as predictor variables, and to confirm the correspondency of developmental indice to panicle developmental stages based on this relationship. Four japonica rice cultivars, Kwanakbyeo, Sangpungbyeo, Dongjinbyeo, and Palgumbyeo which range from very early to very late in maturity, were grown by sowing directly in dry paddy field five times at an interval of two weeks. Data for seedling emergence, leaf appearance, differentiation stage of primary rachis branch and heading were collected. The non-parametric phenology model predicted well the duration from seedling emergence to heading with errors of less than three days in all sowings and cultivars. PI was calculated for every leaf appearance and related to the developmental index estimated for corresponding PI. The stepwise polynomial analysis produced highly significant square-rooted cubic or biquadratic equations depending on cultivars, and highly significant square-rooted biquadratic equation for pooled data across cultivars without any considerable reduction in accuracy compared to that for each cultivar. To confirm the applicability of this equation in predicting the panicle developmental stage, DVI at differentiation stage of primary rachis branch primordium was calculated by substituting PI with 82 corresponding to this stage, and the duration reaching this DVI from seedling emergence was estimated. The estimated duration revealed a good agreement with that observed in all sowings and cultivars. The deviations between the estimated and the observed were not greater than three days, and significant difference in accuracy was not found for predicting this developmental stage between those equations derived for each cultivar and for pooled data across all cultivars tested.

* Division of Plant Science, College of Agriculture and Life Sciences, Suwon 441-744, Korea. *[1] Corresponding author: (E-mail) leebw@snu.ac.kr (Phone)+82-331-290-2303. Received 18 Mar. 1999.

Keywords : developmental index, panicle development stage, phenology model, plastochrone index, rice.

Accurate prediction of phenological development stages in crop is very important not only for the proper timing of cropping operations such as irrigation management, fertilizer and other agrochemicals application etc., but also for the accurate simulation of crop growth processes. Panicles of rice plants develop in close relation to leaf appearance(Goto et al., 1990; Hoshikawa, 1989; Matsushima et al., 1955; Matsushima & Manaka, 1959). Matsushima et al.(1959) reported close correspondence of the young panicle development stage with PI in rice plants producing 16 leaves and also proposed the correction method of PI of rice plants with a different number of leaves from 16, so called, the corrected plastochrone index(cPI). However, cPI corresponding to a certain panicle developmental stage showed greater deviation as the final number of leaves deviated greater from 16(Goto et al., 1990; Matsushima, 1959; Matsushima & Manaka, 1959). In a study of the relationship between the leaf age of tillers of different order and the panicle development stage in an individual rice plant, Goto et al.(1990) found close correspondence of the panicle development stage with the complementary leaf number(cLN) which was counted backwards from the fully-expanded flag leaf(cLN=0). Thus, cPI and cLN could be used for the deduction of panicle development only after the stage had passed and for the prediction under a limited condition where the final leaf number does not change. However, the final number of leaves varied depending not only on the environmental and cultural conditions even within a cultivar but also on cultivars (Hoshikawa, 1989; Matsushima & Manaka, 1959), making it difficult to use cPI and cLN as the criteria for predicting the panicle development stage and, hence, requiring the development of a leaf developmental model and/or the parametrization of cPI and/or cLN in terms of DVI of a phenology model.

The objectives of the present study were to relate leaf appearance to DVI which was calculated by the non-parametric phenology model of rice plant(Lee, 1991) employing daily mean air temperature and astronomical daylength as predictor variables, and to investigate the possibility to predict the panicle developmental stage based on that relationship.

MATERIALS AND METHODS

Four japonica rice cultivars, Kwanakbyeo, Sangpungbyeo, Dongjinbyeo, and Palgumbyeo which range in maturity from very early to very late in the written order in Korea, were sown directly on dry paddy fields of the Experimental Farm of Seoul National University five times at two week intervals starting from April 26 in 1991. Seeding was done at a hill spacing of 25 cm × 15 cm with three seeds per hill. Plants were grown in dry paddy fields until three leaves emerged and afterwards in the flooded condition following the conventional cultivation practices in Suwon.

The dates when seedling emergence and heading reached 50 percent were recorded as the stages of seedling emergence and heading, respectively. The number of leaves was counted daily for 10 main stems and the date of appearance for every leaf was recorded. Emergence of the tip of the (n+1)th leaf from the penultimate leaf sheath was regarded as the appearance of the (n)th leaf. Date at which the (n)th leaf appeared in more than five among ten main stems investigated was recorded as the appearance date of the (n)th leaf. Five main stems were sampled four times at four day intervals around the panicle differentiation stage, and the panicle length was measured under dissecting microscope. The date of differentiation of primary rachis branch primordium was estimated from the measured panicle length in reference to the report by Hoshikawa(1989) and Matsushima (1959), and was expressed by the average of whole samples.

To overcome the shortcomings of cPI of Matsushima(1959) in which PI corresponding to the panicle development stage of rice plants with much smaller or greater number of final leaves than 16 leaves showed large variations(Goto et al., 1990; Matsushima, 1959; Matsushima & Manaka, 1959) and also to take into account that the panicle developmental stage showed close correspondence with cLN(Goto et al., 1990), PI was calculated as follows :

$$mPI = 78 \times pLn / (fLn - 3.5), \text{ for } mPI < 78$$
$$mPI = 100 \times [pLn + (16 - fLn)] / 16, \text{ for } mPI \geqq 78$$

where mPI, pLn and fLn mean the modified PI, the present and the final number of leaves, respectively. The numbers, 78 and 3.5 in the above formula, are correspondent to cPI and cLN at the first bract primordium differentiation stage of young panicle(Goto et al., 1990; Matsushima, 1959; Matsushima & Manaka, 1959; Matsushima et al., 1955; Yoshida, 1981).

DVI was calculated by summing up the daily developmental rates of the non-parametric model of rice development(Lee, 1991). Summation started from seedling emergence (DVI=0.0) and ended at heading stage(DVI=1.0). This model employed daily mean air temperature and astronomical daylength as predictor variables. Air temperature was measured by a thermocouple equipped with data logger and placed in the weather screen in the experimental field. Astronomical daylength was calculated from the latitude of the experimental site(37° 16′).

RESULTS AND DISCUSSION

The non-parametric phenology model of rice cultivars (Lee, 1991) was verified with the data sets of seedling emergence and heading dates of this experiment. These data sets included those of five sowing dates ranging from the earliest to the latest limit of sowings for the safe emergence and ripening in the region and of five varieties belonging to the earliest to the latest maturity group. The model predicted accurately the duration from seedling emergence to heading with errors of less than three days in all sowings and cultivars(Fig. 1), enabling a further analysis for the relationship between DVI and PI.

The panicle developmental stage showed close correspondence with PI of rice plants producing 16 leaves(Matsushima, 1959) and with cLN(Goto et al., 1990). However, cPI of rice plants producing leaves quite differently from 16 leaves showed a large discrepancy from PI at the same panicle developmental stage(Goto et al., 1990; Matsushima, 1959; Matsushima & Manaka, 1959). Thus, PI of rice plants with a greater or smaller number of final leaves was modified to have the same PI at the same panicle developmental stage and to follow the reports of Matsushima (1959) and Goto et al.(1990). The mPI was calculated

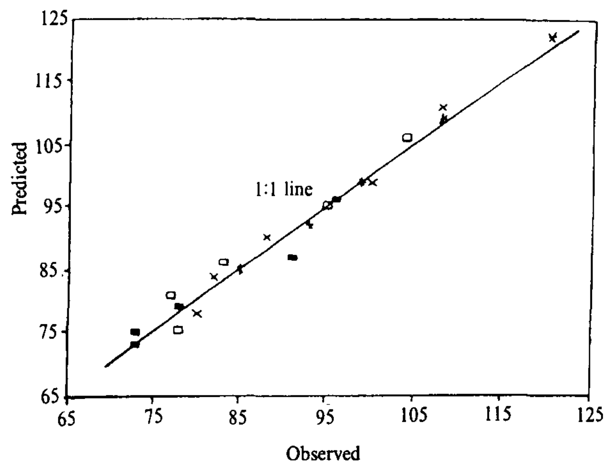

Fig. 1. Plot of the observed against the predicted number of days from seedling emergence to heading of four rice cultivars(■ Kwanakbyeo, □ Sangpungbyeo, × Dongjinbyeo, * Palgeumbyeo). Prediction was made by the rice phenology model of Lee(1991).

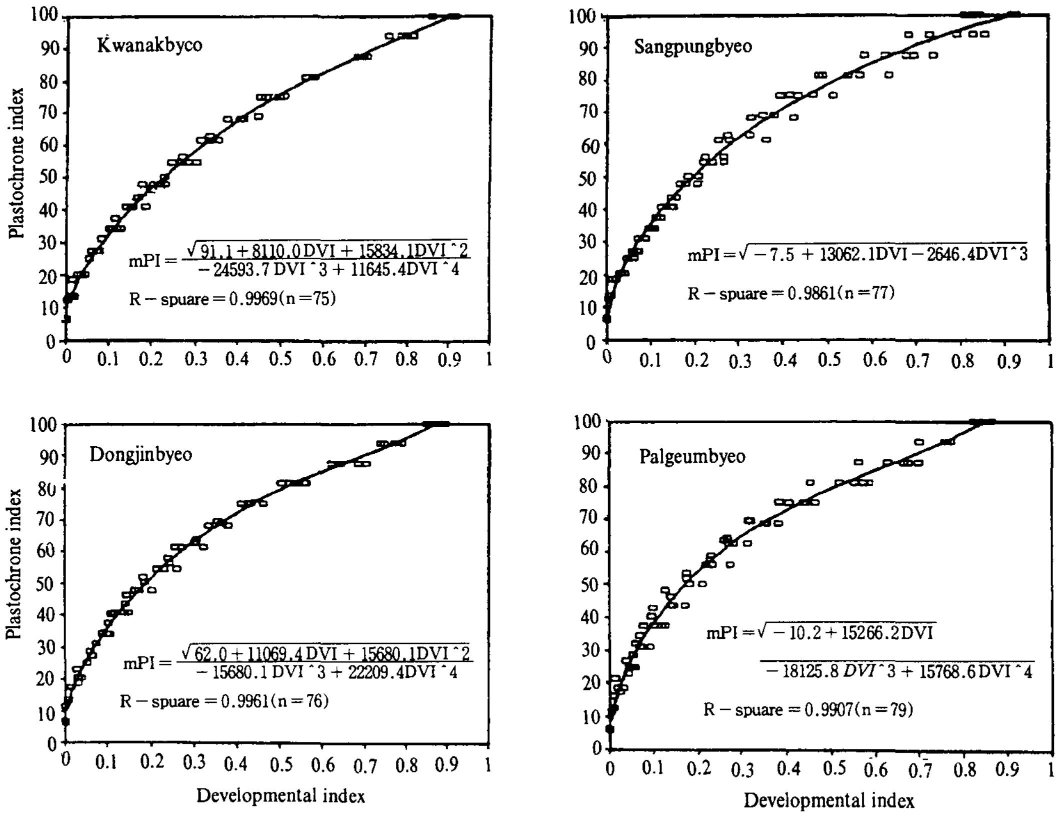

Fig. 2. Relationship between the modified plastochrone index(mPI) and the developmental index(DVI) in four rice cultivars.

for each leaf produced until heading and DVI was estimated for the date of each leaf appearance. The stepwise polynomial regression analysis for the data pooled across sowing dates in each cultivar revealed highly significant square-rooted biquadratic(Kwanakbyeo, Dongjinbyeo and Palgumbyeo) or cubic(Sangpungbyeo) relationship between mPI and DVI(Fig. 2). To improve the applicability the same analysis was done for the data pooled not only across sowing dates but also across cultivars. In this case the coefficient of determination was lowered slightly, but mPI and DVI showed a highly significant(R^2=0.989, n=307) square-rooted biquadratic relationship(Fig. 3).

DVI at mPI=82 corresponding to the differentiation stage of primary rachis branch primordium(Matsushima & Manaka, 1959; Yoshida, 1981) was calculated from the relationship between DVI and mPI shown in Fig. 2 and Fig. 3. The days elapsed from seedling emergence to DVI's at mPI=82 were estimated by the non-parametric phenology model, and were plotted against the observed duration from seedling emergence to the differentiation stage of primary rachis branch primordium(Fig. 4 and Fig. 5). The predicted duration from the relationship between DVI and cPI for each cultivar shown in Fig. 3 revealed a good agreement with the observed one in all cultivars tested. The

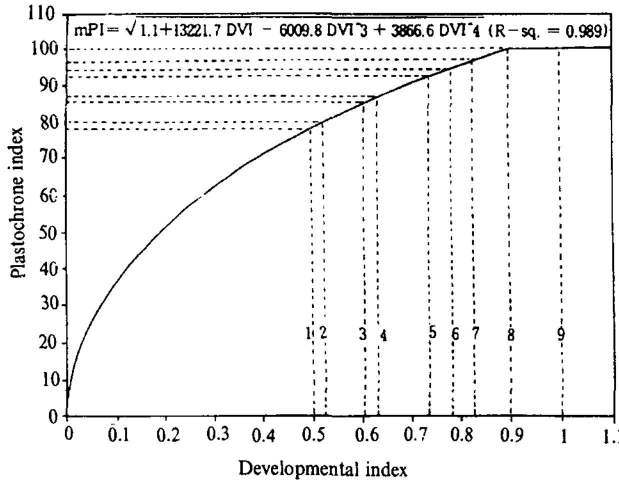

Fig. 3. Relationship between the modified plastochrone index(mPI) and the developmental index (DVI), and the corresponding developmental stage of rice. The data were pooled across four cultivars tested. The stages corresponding to the numbers in the figure are described in Table 1.

deviation between the predicted and the observed

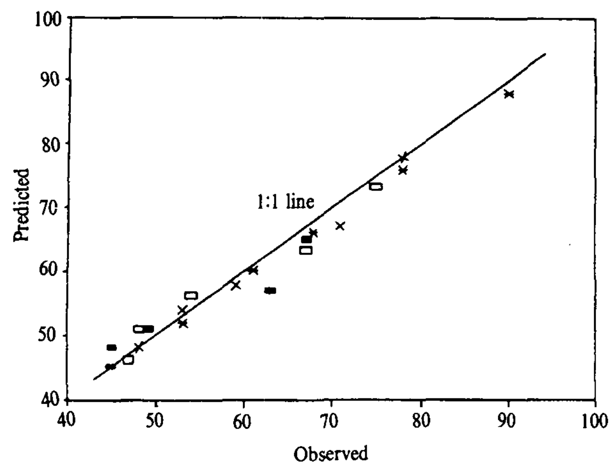

Fig. 4. Plot of the observed against the predicted number of days from seedling emergence to differentiation of primary rachis branch primordium of four rice cultivars. The symbols are the same as in Fig. 1. Prediction was made by calculating mPI = 82 from the equations derived for each cultivar as in Fig. 2.

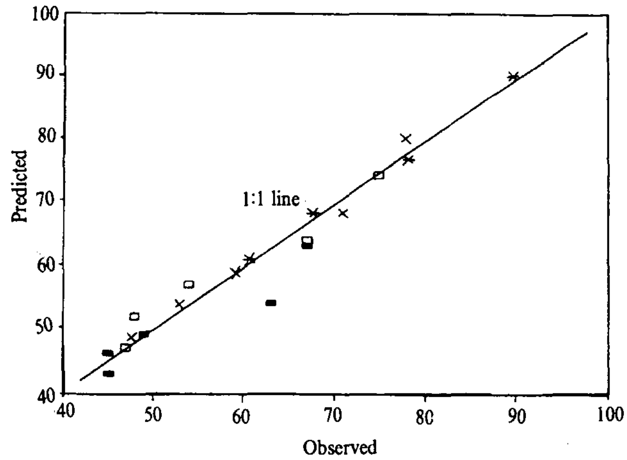

Fig. 5. Plot of the observed against the predicted number of days from seedling emergence to differentiation of primary rachis branch primordium of four rice cultivars. The symbols are the same as in Fig. 1. Prediction was made by calculating mPI = 82 from the equation derived from the data pooled across cultivars as in Fig. 3.

Table 1. Developmental stage of rice plant, corresponding plastochrone index(PI), and developmental index(DVI).

No.	Developmental stage	PI	DVI
0	Seedling emergence	1	0.00
1	First bract differentiation	78	0.50
2	Primary rachis branch differentiation	80	0.53
3	Secondary rachis branch differentiation	85	0.61
4	Initial stage of spikelet differentiation	87	0.54
5	Final stage of spikelet differentiation	92	0.74
6	Pollen mother cell differentiation	95	0.79
7	Meiosis of pollen mother cell	97	0.83
8	Formation of pollen exine	100	0.90
9	Heading stage	100	1.00

† PI was adopted from Yoshida(1981).
‡ DVI was calculated from the equation in Fig. 3.

durations was not greater than three days in all sowing dates and cultivars except that Kwanakbyeo showed a little greater deviation of five days in the sowing of June 7. The equation derived from the pooled data across cultivars predicted its duration well just like for each cultivar for all sowing dates and cultivars. In the case of Kwanakbyeo there was also a little greater deviation in the sowing of June 7. These results suggested that the relation between DVI and mPI could be used practically to predict the panicle developmental stage, and that the relationship between DVI and mPI for cultivars tested could be unified into an equation without any considerable reduction of accuracy in predicting the panicle developmental stage. However, it remains to be proven whether this result can be applicable to the varieties other than japonica cultivars tested.

DVI at each developmental stage was calculated from the equation derived from the pooled data across cultivars by substituting PI of each developmental stage reported by Yoshida(1981) (Table 1 and Fig. 3). Differentiation of first bract primordium which divides the vegetative and reproductive stages was estimated to start at DVI=0.50 of the non-parametric phenology model, primary rachis branch differentiation at DVI= 0.53, and so on. The information provided here will be useful not only for improving the performance of rice growth simulation model by introducing the non-parametric phenology model(Lee, 1991) as a component model but also for widening the applicability of itself to rice cultivation practices.

REFERENCES

Goto, Y., T. Tsuchiyama, and K. Hoshikawa. 1990. Tillering behavior in *Oryza sativa* L. Ⅶ. Relation between tiller age and panicle formation in the individual tillers. Japan. Jour. Crop Sci. 59(4): 701-707.

Hoshikawa, K. 1989. The Growing Rice Plant. An Anatomical Monograph. Nobunkyo, Tokyo: pp. 310.

Lee, B. W. 1991. Application of non-parametric model to prediction of heading date in direct-seeded rice. Korean Jour. Crop Sci. 36(2): 97-106.

Matsushima, S. 1959. Theory and technology of rice cultivation. - theory and application of yield determining process(2nd ed.). Yokendo, Tokyo: pp. 302.

_________. and T. Manaka. 1959. Analysis of developmental factors determining yield and its application to yield prediction and culture. LII. Developmental differences of young panicles in different maturing rice-varieties as affected by the time of cultivation and a method for identifying the developmental stages. Japan. Jour. Crop Sci. 28: 201-204.

________, ________, N. Komatsu, and T. Urabe. 1955. Crop scientific studies on the yield-forecast of lowland rice(preliminary report). XX. Tracing up developmental processes of young panicles on all individual tillers(1, 2). Japan. Jour. Crop. Sci. 23(4): 274-275.

Yoshida, S. 1981. Fundamentals of rice crop science. IRRI: pp. 316.