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The Effects of Transplanting Time and Meteorological Change to Variation of Phyllochron of Rice

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ABSTRACT This study was performed at Rice and Winter Cereal Crops Department of NICS during 2007 and 2008 to investigate the characteristics of rice leaf emergence and to obtain basic data which can be used for rice growth simulation model by which we can forecast rice growth stage and heading date accurately under different cultivars, transplanting date, and climatic conditions. To confirm leaf emergence rate according to rice maturing ecotype, we surveyed the leaf emergence rate and heading date of Unkwangbyeo, Hwayoungbyeo and Nampyeongbyeo which are early maturing, medium maturing and medium-late maturing cultivars, respectively, according to seedling raising duration and transplanting time. When seedling duration was 15 days, the growth duration between transplanting time and completion of flag leaf emergence on main culm were 51.5～78.3 days in Unkwangbyeo, 55.3～87.9 days in Hwayoungbyeo and 58.4～98.4 days in Nampyeongbyeo, respectively. When seedling duration was 30 days, they were 50.1～75.5 days in Unkwangbyeo, 52.4～84.7 days in Hwayoungbyeo and 56.4～93.8 days in Nampyeongbyeo, respectively. As transplanting time delayed, the emerged leaf number after transplanting decreased in all rice cultivars. The cumulative temperature between transplanting time to completion of flag leaf elongation on main culm were 1,281℃～1,650℃ in Unkwangbyeo, 1,344℃～1,891℃ in Hwayoungbyeo and 1,454℃～2,173℃ in Nampyeongbyeo, respectively. Leaf emergence rate on main culm were precisely represented by equation, $y = y_0 + a / [1 + exp(- (x - x_0) / b)]^c$, when we used daily mean temperature as variable.

Keywords : rice, climate change, phyllochron, leaf emergence rate, heading date

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Rice (*Oryza sativa* L.) is chiefly cultivated in the temperate latitudes of Asia which has monsoon climate, but it presently broadly cultivated from tropical region to northern 53 latitude. So rice can be divided indica, japonica and tropical japonica according to accustomed characteristics to each region.

Rice is classified as short-day plant (Vergara & Chang, 1985). And we can do ecotype grouping according to photo-sensitivity, thermo-sensitivity and basic vegetative growth (Lee *et al*, 1993). Especially, temperature and photoperiod are major environmental factors which determine panicle initiation stage and heading date.

Temperature and photoperiod have a critical effects on heading (Yin *et al*, 1996), and are close connection with leaf emergence rate (Ellis *et al*, 1993; Gao *et al*, 1992). The number of emerged leaf of rice is very important parameter to predict growth stage and we can predict heading date by the number of emerged leaves (Gao *et al*, 1992).

Leaf emergence rate can be different according to cultivars and environmental conditions, but usually it needs 4~5 days in the earlier stage and 8~10 days in later stage (Hirano *et al*, 1954).

As rice growth proceeding, leaf emergence rate become lower and is influenced by change of growth stage and environmental factors (Lee *et al*, 1964; Lee *et al*, 1987; Ellis *et al*, 1993; Matsushima *et al*, 1962).

Rice heading is mostly influenced by photoperiod (Vergara & Chang, 1985). As emerged leaves increasing, heading is hastened in short day condition, but delayed in long day condition (Katayama, 1963). Response to photoperiod is more sensitive in late maturing cultivars (Lim *et al*, 1981) than early maturing cultivars, and this difference become bigger in long day condition but not so big in short day condition.

Rice growth model using temperature and photoperiod have been generally used to predict growth amount and growth stage. Among growth model using temperature, there are many models using cumulative temperature (growth degree days, GDD) (Lee *et al*, 1980, 1983). This have a foundation that emerged leaf number have a linear relation with cumulative temperature (Muchow & Carberry, 1990; Slafer *et al*, 1994). Linear model is very effective and convenient in restricted temperature range (Baker *et al*, 1986; Boone *et al*, 1990), but error can become very larger in field conditions (Yin, 1996). So, by ground that leaf emergence rate of gramineous plant increase exponentially in accordance with temperature, there are growth model to explain the leaf emergence rate with power law ($y=ax^b$) by using temperature.

Excess use of fossil fuels such as petroleum and coal after the Industrial Revolution increase the content of global warming gas in atmosphere gradually. It has the capacity to seize global radiation, so earth temperature increase gradually. During last 100 years, the earth temperature increased 0.3～0.6, and this tendency accelerated more recently. IPCC (Intergovernmental Pannel on Climate Change) predicted that the earth temperature would increase 2～6℃ until 2100. During 30 years before 2000, temperature of Korea increased 1.04℃ and Korea meteorological administration predicted the temperature of Korea would increase 1.79℃ in preceeding 30 years from 2000. By analyzing recent 30 years, the temperature of winter season have become higher persistently, but the temperature of summer season have not showed big difference. So, the winter of korea have shorted 1 month and summer season became 1 month longer.

In accordance with weather change, we could do diverse rice cultivation such as early transplanting for the purpose of early harvesting before Korean Thanksgiving Day and late transplanting for the purpose of double cropping with economical crop. As rice cultivation environment change drastically, we need to predict rice growth stage precisely according to climate factors.

Consequently, in this study, we analyzed the effects of meterological factor to leaf emergence rate according to cultivars, transplanting time and seedling duration and developed leaf emergence rate model by its climate factors during rice culture season.

MATERIALS AND METHODS

This study was performed in experimental field of Rice and Winter Cereal Crops Department of NICS which is located in northern Jeolla province on 2007 and 2008. The experimental cultivars were early maturing Unkwangbyeo, medium maturing Hwayoungbyeo and medium-late maturing Nampyeongbyeo. We surveyed the variation of leaf emergen -ce rate according to rice maturing type and seedling duration and analyzed the correlation between environmental factors and leaf emergence rate and it's effect to heading.

To confirm the characteristics of rice which grows in diverse climate environment, we transplanted rice from May 1 to June 30 every 15 days. To prepare similar seedling stage, we did raising seedling for 35 days in transplanting on May 1 and May 16, 30 days in transplanting on May 31 and 25 days in transplanting on June 15 and June 30.

In transplanting from May 1 to May 31, planting density was 30×14cm and fertilizer amount was $N\text{-}P_2O_5\text{-}K_2O$ = 9-4.5-5.7kg/10a and fertilizer split application was basal-tillering stage-panicle initiation = 50-20-30. In transplanting on June 15 and June 30, planting density was 30×12cm and fertilizer amount was $N\text{-}P_2O_5\text{-}K_2O$ = 8-4.5-5.7kg/10a and fertilizer split application was basal-panicle initiation = 70-30. And in the other cultivation management, we observed rice standard culture of NICS.

Leaf emergence rate was surveyed from transplanting to completion of flag leaf elongation by marking on 10 leaves in each hills of each plot. Whenever new leaf was emerged in main culm, we surveyed it's time.

Meteorological data were collected from Campbell science datalogger which is established in Rice and Winter Cereal Crops Department of NICS. The difference of leaf emergence rate was analyzed by sigmaplot 8.0 and SAS (statistical analysis system 9.1).

RESULTS

Leaf emergence rate of Unkwangbyeo

Fig. 1 and 2 shows the meteorological change and variation of leaf emergence rate according to transplanting time and seedling duration in early maturing Unkwangbyeo. Trans-

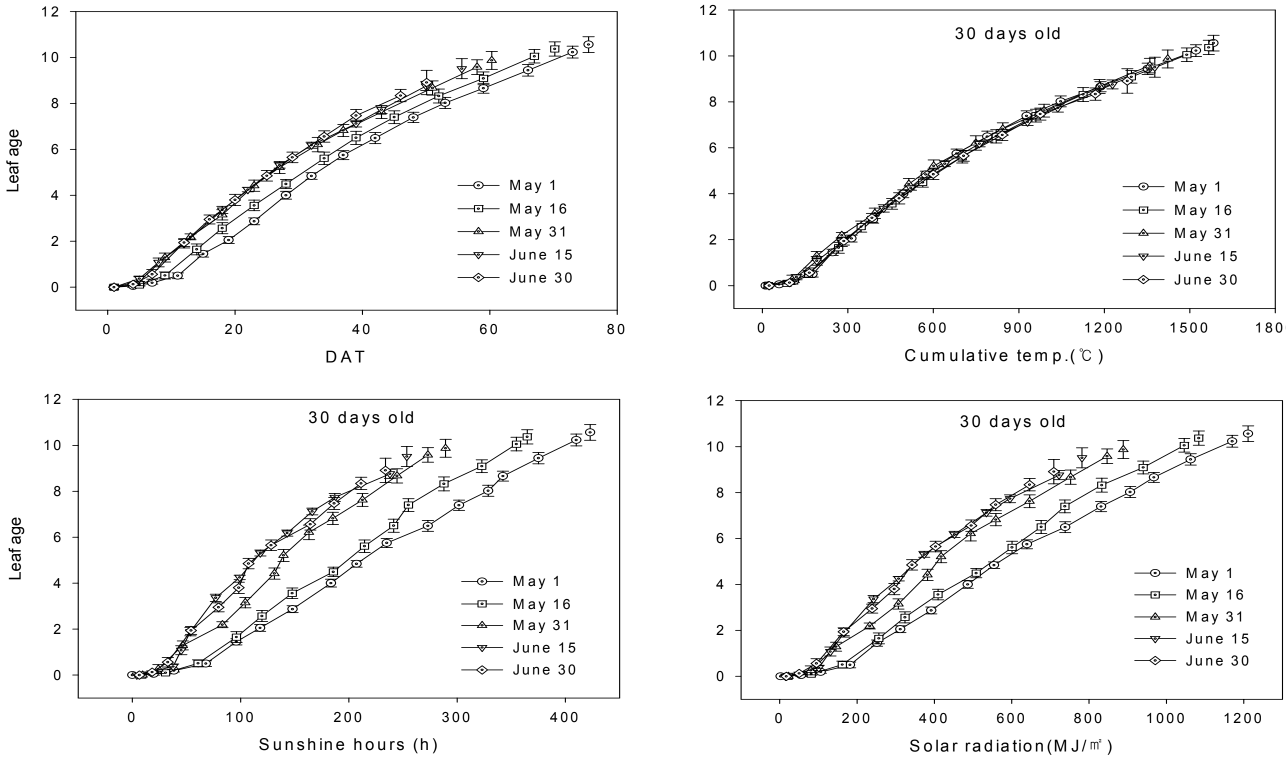

Fig. 1. Leaf emergence rate on main culm according to transplanting time and it's relation with meteorological factors in 30 days old Unkwangbyeo.

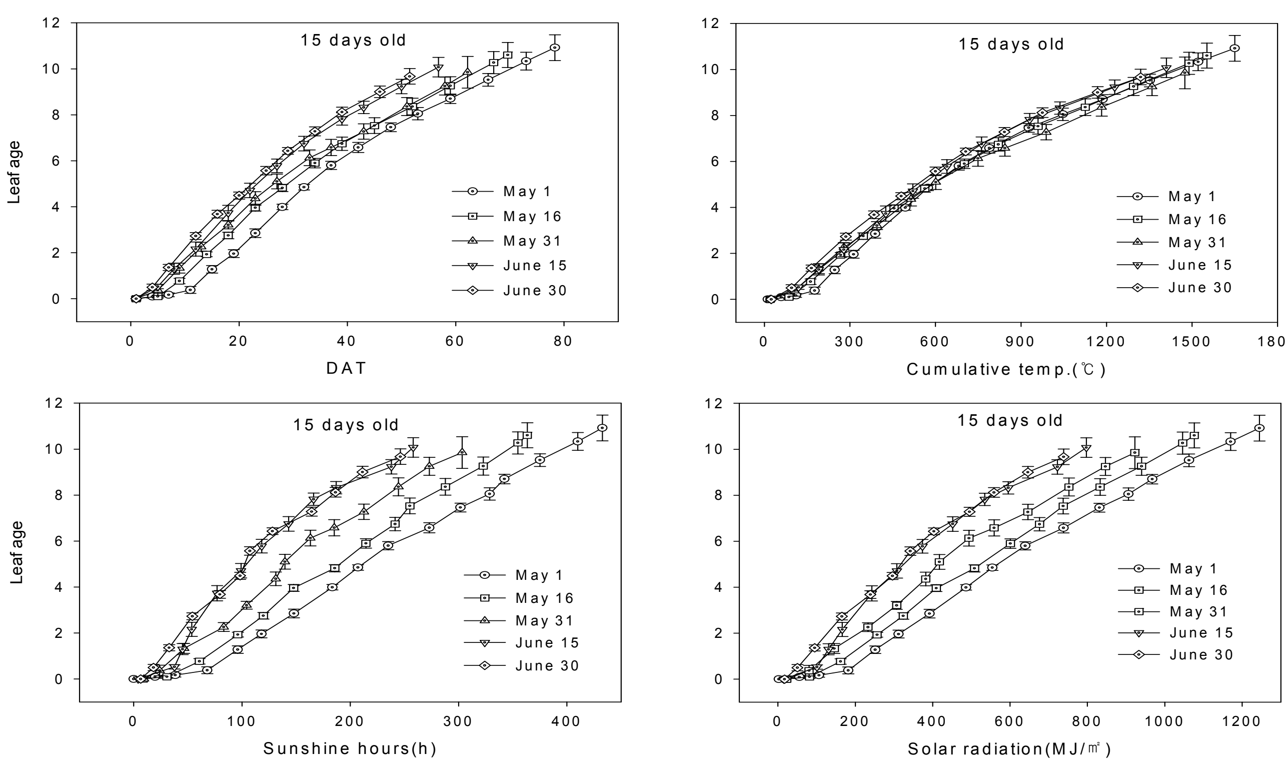

Fig. 2. Leaf emergence rate on main culm according to transplanting time and it's relation with meteorological factors in 15 days old Unkwangbyeo.

planting 30 days old seedling at Iksan, the number of emerged leaf decreased from 10.6 ± 0.3 in transplanting on May 1 to 8.9 ± 0.5 in transplanting on June 30. Transplanting 15 days old seedling, they were 10.9 ± 0.6 in transplanting on May 1 and 9.7 ± 0.3 in transplanting on June 30.

In same transplanting time, the difference of number of emerged leaf were small relatively in transplanting until May 31, but it showed tendency of increase from transplanting from June 15.

Transplanting 30 days old seedling, the completion time of flag leaf elongation were distributed from 195.5 (Julian day) in transplanting on May 1 to 229.1 (J.D.) in transplanting on June 30. Transplanting 15 days old seedling, they were distributed from 198.3 (J.D.) in transplanting on May 1 to 230.5 (J.D.) in transplanting on June 30.

Growth duration from transplanting to completion of flag leaf elongation were distributed from 75.5 ± 1.0 in transplanting on May 1 to 50.1 ± 2.4 in transplanting on June 30. Transplanting 15 days old seedling, they were distributed from 78.3 ± 2.3 in transplanting on May 1 to 51.5 ± 1.4 in transplanting on June 30. In same transplanting time, heading date was delayed 2~3 days in transplanting with 15 days old seedling compared to 30 days old seedling.

Transplanting 30 days old seedling, cumulative temperature was distributed from 1,583 ± 23℃ in transplanting on May 1 to 1,281 ± 66℃ in transplanting on June 30. Transplanting 15 days old seedling, they were 1,650 ± 55℃ in transplanting on May 1, and 1,320 ± 66℃ in transplanting on June 30.

Transplanting 30 days old seedling, sunshine hours were distributed from 423 ± 4 hr in transplanting on May 1 to 234 ± 19hr in transplanting on June 30. Transplanting 15 days old seedling, they were 433 ± 9hr in transplanting on May 1, and 246 ± 9hr in transplanting on June 30.

Transplanting 30 days old seedling Unkwangbyeo, solar radiations were distributed from 1,211 ± 13MJ/m^2 in transplanting on May 1 to 709 ± 48MJ/m^2 in transplanting on June 30. Transplanting 15 days old seedling, they were 1,245 ± 29MJ/㎡ in transplanting on May 1, and 739 ± 24MJ/m^2 in transplanting on June 30.

Leaf emergence rate of Hwayoungbyeo

Fig. 3 and 4 shows the meteorological change and variation of leaf emergence rate according to transplanting time and seedling duration in medium maturing Hwayoungbyeo. Trans-

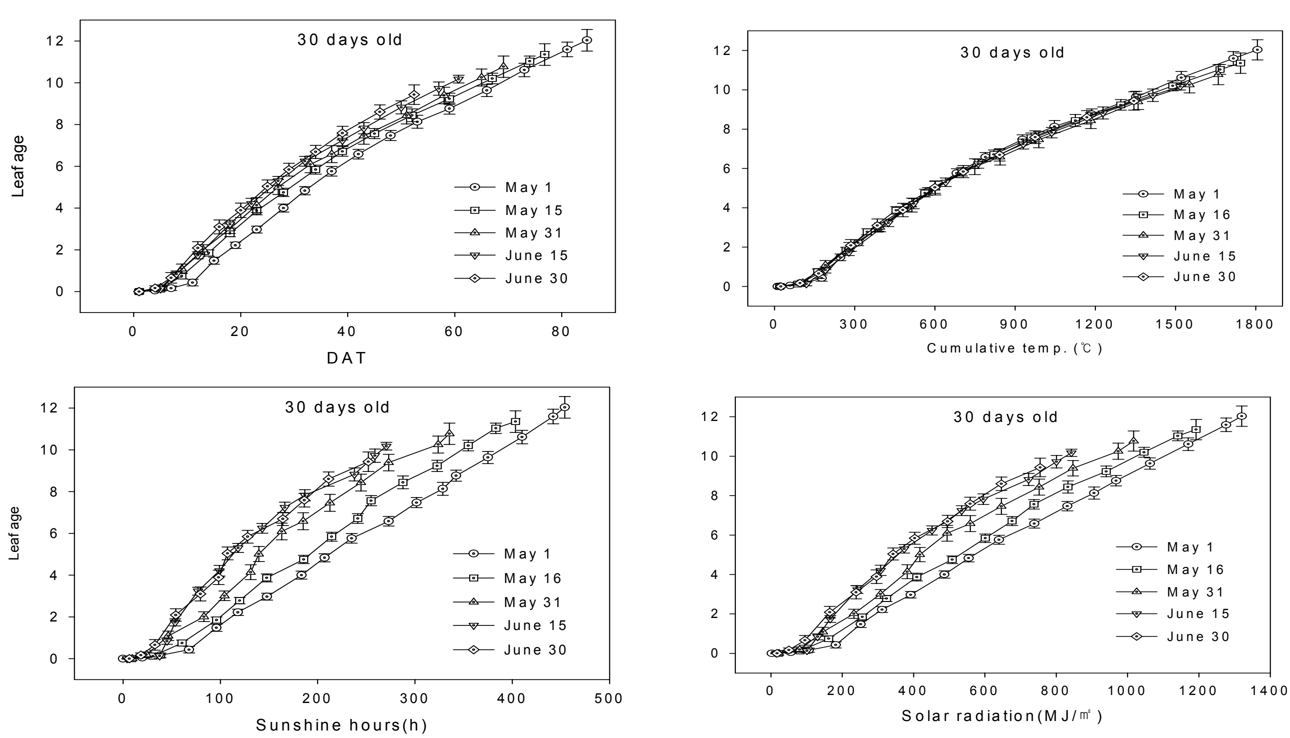

Fig. 3. Leaf emergence rate on main culm according to transplanting time and it's relation with meteorological factors in 30 days old Hwayoungbyeo.

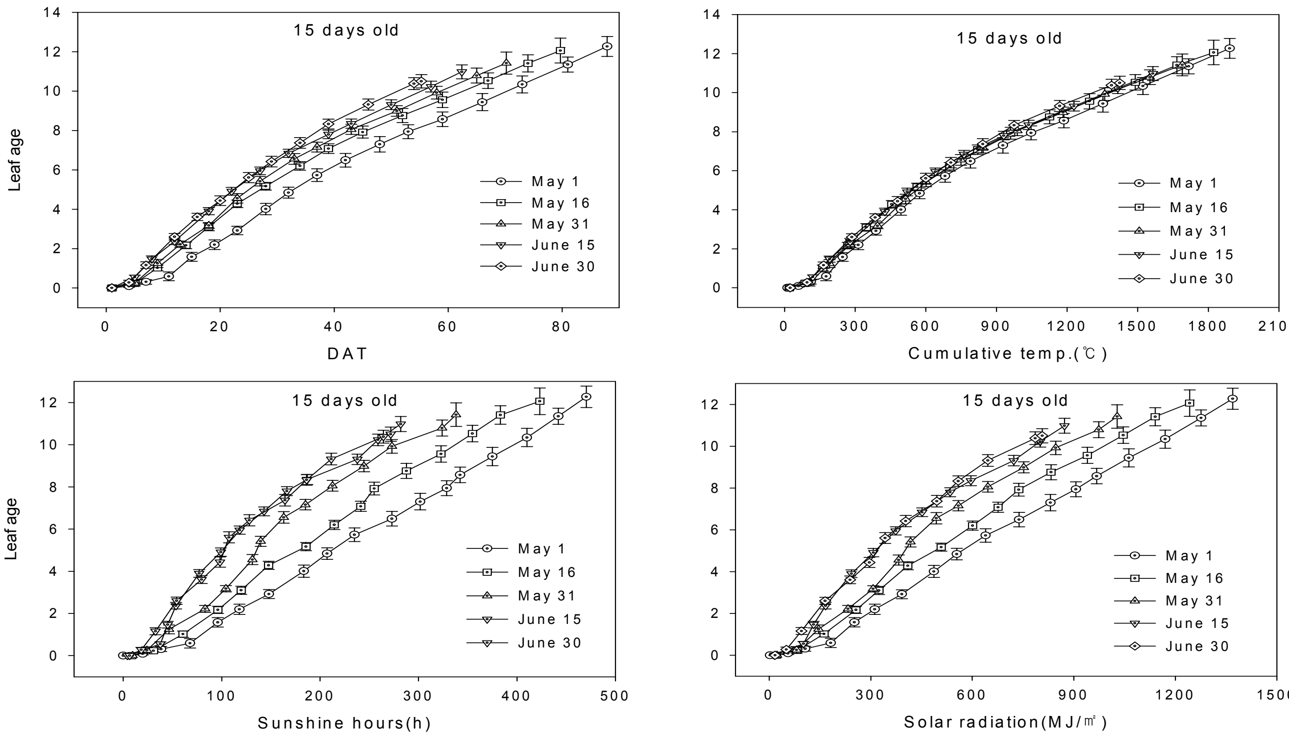

Fig. 4. Leaf emergence rate on main culm according to transplanting time and it's relation with meteorological factors in 15 days old Hwayoungbyeo.

planting 30 days old seedling, the number of emerged leaf decreased from 12.0 ± 0.5 in transplanting on May 1 to 9.4 ± 0.5 in transplanting on June 30. Transplanting 15 days old seedling, they were 12.3 ± 0.5 in transplanting on May 1 and 10.5 ± 0.3 in transplanting on June 30.

In same transplanting time, the difference of number of emerged leaf showed increasing tendency in accordance with delayed transplanting time.

Transplanting 30 days old seedling, the completion time of flag leaf elongation were distributed from 204.7 (J.D.) in transplanting on May 1 to 231.4 (J.D.) in transplanting on June 30. Transplanting 15 days old seedling, they were distributed from 207.9 (J.D.) to 234.3 (J.D.)

In same transplanting time, heading dates were delayed 2~3 days in transplanting with 15 days old seedling compared to those of 30 days old seedling.

Growth duration from transplanting to completion of flag leaf elongation were distributed from 84.7 ± 2.2 days in transplanting on May 1 to 52.4 ± 2.5 days in transplanting on June 30. Transplanting 15 days old seedling, they were distributed from 87.9 ± 2.1 days in transplanting on May 1 to 55.3 ± 1.6 days in transplanting on June 30.

Transplanting 30 days old seedling, cumulative temperature were 1,807 ± 57℃ in transplanting on May 1, and 1,344 ± 68℃ in transplanting on June 30. Transplanting 15 days old seedling, they were 1,891 ± 57℃ in transplanting on May 1, and 1,424 ± 43℃ in transplanting on June 30.

Transplanting 30 days old seedling, sunshine hours distributed from 454 ± 10hr in transplanting on May 1 to 252 ± 17hr in transplanting on June 30. Transplanting 15 days old seedling, they were 470 ± 13hr in transplanting on May 1, and 272 ± 11hr in transplanting on June 30.

Transplanting 30 days old seedling, solar radiations were distributed from 1320 ± 33MJ/m^2 in transplanting on May 1 to 755 ± 45MJ/m^2 in transplanting on June 30. Transplanting 15 days old seedling, they were 1,370 ± 36MJ/m^2 in transplanting on May 1, and 807 ± 29MJ/m^2 in transplanting on June 30.

Leaf emergence rate of Nampyeongbyeo

Fig. 5 and 6 shows the meteorological change and variation of leaf emergence rate according to transplanting time and

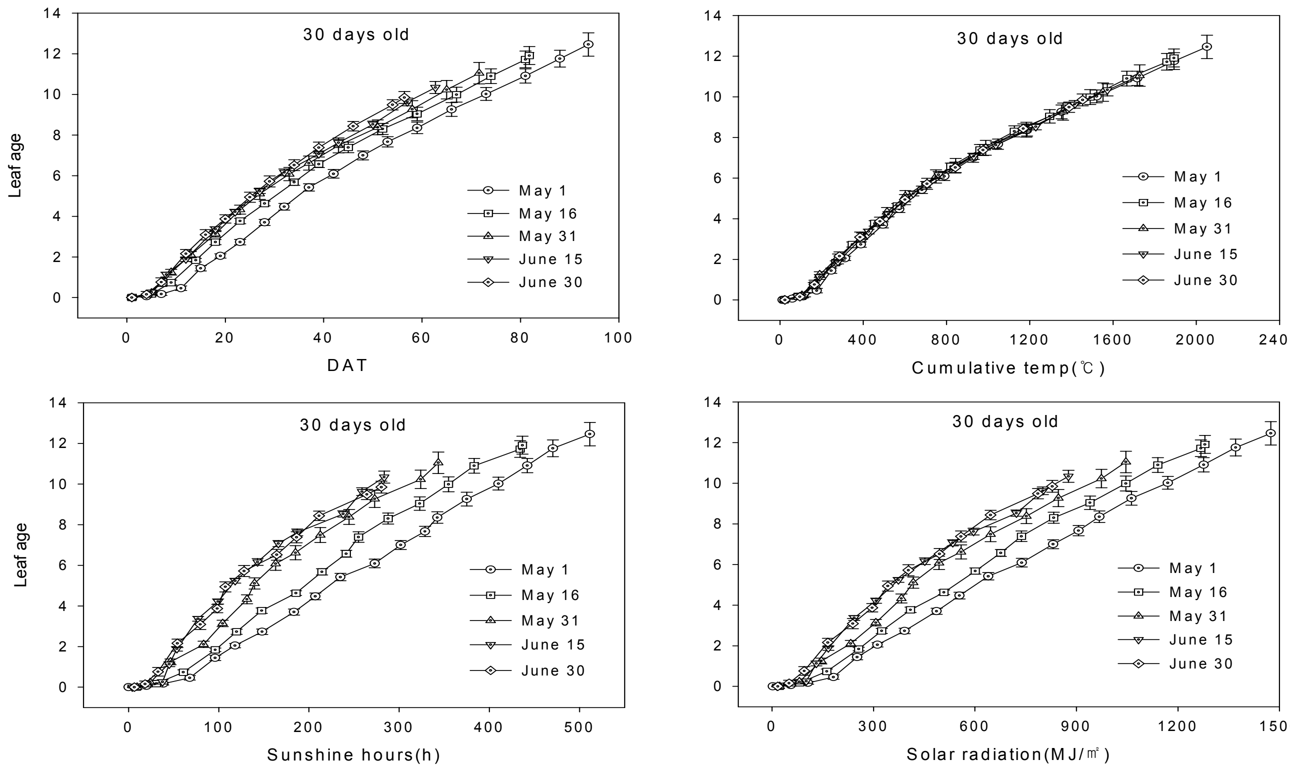

Fig 5. Leaf emergence rate on main culm according to transplanting time and it's relation with meteorological factors in 30 days old Nampyeongbyeo.

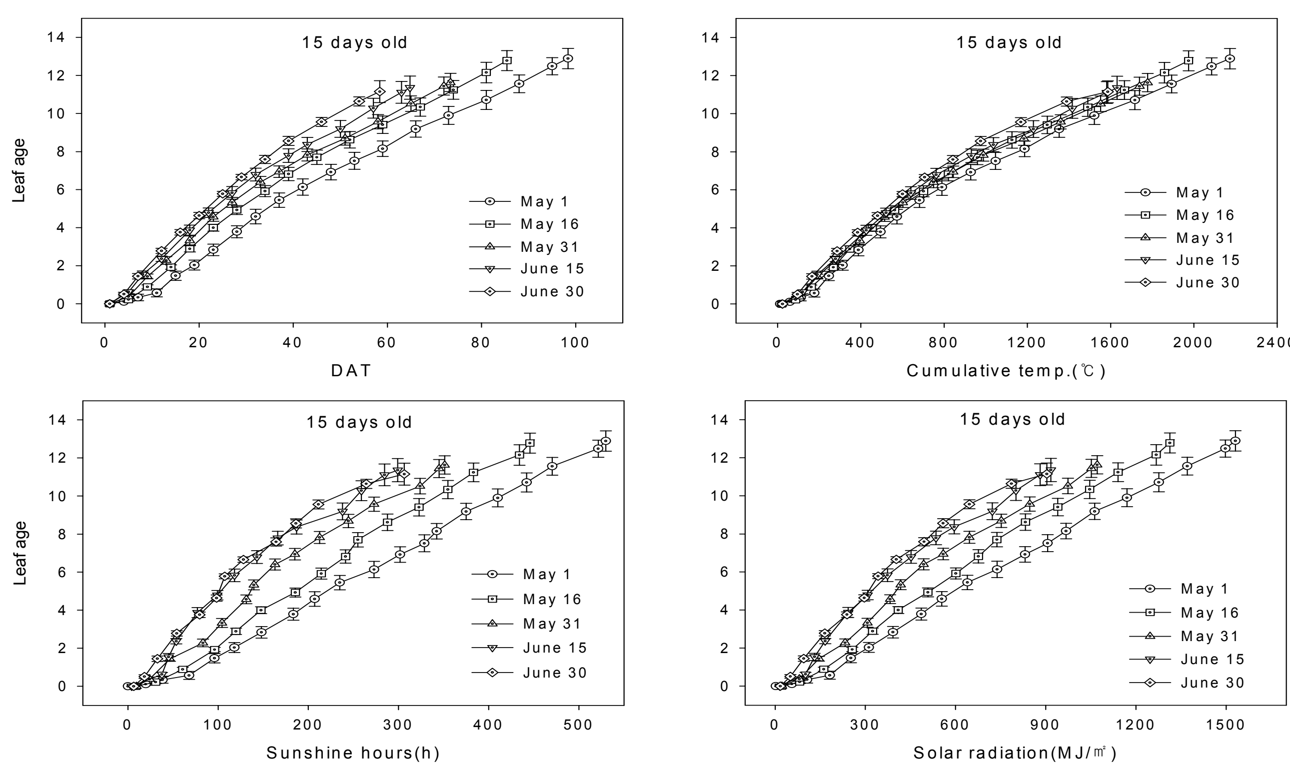

Fig 6. Leaf emergence rate on main culm according to transplanting time and it's relation with meteorological factors in 15 days old Nampyeongbyeo.

seedling duration in medium-late maturing Nampyeongbyeo. Transplanting 30 days old seedling, the number of emerged leaf decreased from 12.5 ± 0.6 in transplanting on May 1 to 9.9 ± 0.3 in transplanting on June 30. Transplanting 15 days old seedling, they were 12.9 ± 0.5 in transplanting on May 1, and 11.2 ± 0.6 in transplanting on June 30. In same transplanting time, the difference of number of emerged leaf showed increasing tendency in accordance with delayed transplanting time.

Transplanting 30 days old seedling, the completion time of flag leaf elongation were distributed from 213.8 (J.D.) to 235.4 (J.D.). Transplanting 15 days old seedling, they were distributed from 218.4 (J.D.) to 237.4 (J.D.). Compared to those of 30 days old seedling, in same transplanting time, heading date of transplanting on May 1 and May 16 delayed 4~5 days, but it decreased to 2~3 days in transplanting after May 31.

Growth duration from transplanting to completion of flag leaf elongation were distributed from 93.8 ± 2.3 days in transplanting on May 1 to 56.4 ± 2.0 days in transplanting on June 30. Transplanting 15 days old seedling, they were distributed from 98.4 ± 2.2 days in transplanting on May 1 to 58.4 ± 2.8 days in transplanting on June 30.

Transplanting 30 days old seedling, cumulative temperature decreased from 2,051 ± 63℃ in transplanting on May 1 to 1,454 ± 54℃ in transplanting on June 30. Transplanting 15 days old seedling, they were 2,173 ± 58℃ in transplanting on May 1, and 1,587 ± 17℃ in transplanting on June 30.

Transplanting 30 days old seedling, sunshine hours decreased from 511 ± 15hr in transplanting on May 1 to 280 ± 14hr in transplanting on June 30. Transplanting 15 days old seedling, they were 530 ± 6hr in transplanting on May 1, and 306 ± 10hr in transplanting on June 30.

Transplanting 30 days old seedling, solar radiations decreased from 1,475 ± 38MJ/m^2 to 828 ± 36MJ/m^2. Transplanting 15 days old seedling, they decreased from 1,531 ± 22MJ/m^2 to 903 ± 4M.J/m^2.

By analyzing relation between leaf emergence rate of Unkwangbyeo, Hwayoungbyeo and Nampyeongbyeo which have different maturing characteristics and growth duration, cumulative temperature, sunshine hours and solar radiation according to transplanting time and seedling duration, leaf emergence rate showed curvilinear relation according to growth duration and cumulative temperature. But according to sunshine hours and solar radiation, it showed linear relation in early transplanting time, but it became curvilinear relation gradually in late transplanting.

Accordingly, when we develop rice growth model in relation to climate factors which can be used in diverse transplanting time, sunshine hours and solar radiation have a weakness that observed value and predicted value have a more big divergence than those of growth duration and cumulative temperature. Moreover, we can conclude that leaf emergence rate model more easily converged to one curvilinear model by cumulative temperature than that of growth duration as showed in above Fig. 1~6.

Table 1 shows the parameters of leaf emergence rate model '$y = y_0 + a/[1 + \exp(-(x - x_0)/b)]^c$' according to cumulative temperature after transplanting when we cultivate rice in Iksan province. Observed values of 10 main culm of each plot were corresponded precisely with this model.

But we already confirmed that the number of emerged

Table 1. The parameters of leaf emergence rate model $y=y_0+a/[1+\exp(-(x-x_0)/b)]^c$ by cumulative temperature after transplanting.

Cultivars	Seedling day	Transplanting date	Estimated parameters					R^2
			a	b	c	x_0	y_0	
UK	15 days	May 1	14.3	528	10.78	-819	-2.26	0.993
		May 16	23.4	736	2.29	-548	-10.17	0.992
		May 31	32.0	941	3.35	-1572	-18.37	0.990
		June 15	15.4	468	2.21	-44	-4.05	0.993
		June 30	21.0	586	2.11	-400	-9.22	0.997
	30 days	May 1	14.1	494	4.72	-344	-2.50	0.995
		May 16	17.0	555	1.84	34	-4.95	0.994
		May 31	18.9	601	2.03	-216	-6.87	0.993
		June 15	15.2	552	4.16	-446	-3.67	0.996
		June 30	12.8	456	4.70	-318	-2.31	0.993

Table 1. The parameters of leaf emergence rate model $y=y_0+a/[1+\exp(-(x-x_0)/b)]^c$ by cumulative temperature after transplanting. (Countinued)

Cultivars	Seedling day	Transplanting date	Estimated parameters					R^2
			a	b	c	x_0	y_0	
HY	15 days	May 1	33.6	1077	2.87	-1404	-17.44	0.991
		May 16	52.2	1165	5.95	-3159	-36.13	0.993
		May 31	23.2	732	2.78	-657	-9.49	0.994
		June 15	26.8	767	3.15	-1016	-13.24	0.995
		June 30	22.5	629	2.00	-346	-9.50	0.995
	30 days	May 1	24.0	785	2.23	-446	-9.40	0.993
		May 16	28.6	899	2.86	-1084	-14.09	0.995
		May 31	23.3	771	2.23	-533	-9.94	0.990
		June 15	15.0	501	2.71	-98	-3.42	0.993
		June 30	16.2	513	1.96	-18	-4.78	0.990
NP	15 days	May 1	49.0	1451	3.74	-2923	-31.21	0.991
		May 16	51.8	1307	4.63	-3073	-34.48	0.992
		May 31	45.1	1130	4.80	-2660	-29.66	0.992
		June 15	36.1	967	3.58	-1719	-21.08	0.990
		June 30	35.0	880	3.08	-1390	-20.05	0.997
	30 days	May 1	30.9	1076	2.80	-1237	-14.86	0.994
		May 16	39.6	1160	3.58	-2116	-23.71	0.995
		May 31	41.5	1140	4.03	-2358	-26.21	0.991
		June 15	22.8	774	2.67	-686	-9.59	0.996
		June 30	20.7	675	2.14	-359	-8.19	0.994

leaves vary according to transplanting time and rice cultivar. So, to make leaf emergence rate model which can be broadly used in diverse transplanting time, cultivars and climate conditions, it is necessary to know previously the number of emerging leaf according to cultivars and transplanting time.

DISCUSSION

By global warming effect, the temperature of earth increase gradually. IPCC predicted that the temperature of earth will increase 2~6℃ until 2100.

In accordance with weather change, there are diverse rice cultivation system such as early transplanting for the purpose of early harvesting before Korean Thanksgiving Day and late transplanting for the purpose of double cropping with economical crop. As rice cultivation environment change drastically, we need to predict rice growth stage precisely according to climate factors.

Consequently, in this study, we analyzed the effects of meterological factor to leaf emergence rate according to maturing type, transplanting time and seedling growth day and developed leaf emergence rate model in diverse cultivation conditions.

1. As transplanting time delayed, the number of emerged leaf, growth duration, cumulative temperature, sunshine hours and solar radiation decreased gradually.
2. Compared to the number of emerged leaf of 30 days seedling, that of 15 days seedling increased more or less, and the difference of growth duration between transplanting time and completion of flag leaf elongation were 2~5 days according to cultivars and transplanting time.
3. Leaf emergence rate showed curvilinear relation according to growth duration and cumulative temperature. As to sunshine hours and solar radiation, it showed linear relation in early transplanting time, but changed gradually to curvilinear relation in late transplanting time.
4. Leaf emergence rate model more easily converged to one curvilinear model by cumulative temperature than that of growth duration.
5. Using cumulative temperature as variable, leaf emer-

gence rate was explained by '$y = y_0 + a/[1 + exp(-(x - x_0)/b)]$^c' precisely.

6. In predicting growth stage of rice according to climate factors, the number of emerged leaves can vary according to transplanting time and rice cultivar, thus it is necessary to know the number of emerging leaf according to cultivars and transplanting time previously.

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