RASTER MAP FOR PREDICTION OF HEADING DATE OF TIMOTHY BY NONPARAMETRIC DVR METHOD

T. Saigusa[1], K. Nakashima, M. Noshiro[2], M. Tsutsumi[3]
Konsen Agricultural Experiment Station, Nakashibetsu, Hokkaido, 086-11 Japan
[1]present address: Hokkaido National Agricultural Experiment station, Hitsujigaoka, Sapporo, Hokkaido, 062 Japan
[2]present address: Kitami Agricultural Experiment Station, Kun-neppu, Hokkaido, 099-14 Japan
[3]present address: Shintoku Animal Husbandry Station, Shintoku, Hokkaido. 081 Japan

ABSTRACT
A system for making a raster map for predicting the heading date of timothy (*Phleum pratense* L.) at first cutting for every 1km^2 plot was developed to supply information for smooth harvest of forage of good quality in a dairy farming area of Hokkaido. Daily mean air temperature for every 1km^2 plot was estimated with data from a network of meteorological observatories and data base of the Japan Meteorological Agency. Day length could be calculated from latitude and calendar day. Using these two environmental factors, heading date of timothy at first cutting for each area was predicted by nonparametric *DVR* method. Prediction errors due to the estimation process for daily mean air temperatures and the prediction process of heading date were less than ±5 days and less than ±2 days, respectively. Therefore, when a difference between predicted heading date and the observed one exceeded 5 days, the other local factors should be considered.

KEYWORDS
Daily mean air temperature, day length, developmental rate, heading date, smooth spline, *Phleum pratense* L., prediction, raster map.

INTRODUCTION
As grass grows, its yield increases but its quality decreases. Therefore, harvest of grass at heading stage is recommended to balance the yield with the quality. Because grass growth depends on climate, prediction of heading date of grass using meteorological data will be useful for smooth harvest of forage in dairy farming areas. As a new method for precise prediction of heading date, the nonparametric *DVR* method was established. Developmental rate (*DVR*), which is an index for the progress of growth stage for a day, depends on environmental factors such as temperature and day length (TAKEZAWA,1988). It is also important to estimate the distribution of environmental factors in a certain area in order to predict the distribution of heading dates. Recently, estimation of daily mean air temperature at every 1km^2 plot was made possible by using the data base of the Japan Meteorological Agency. Prediction of heading date of grass at every 1km^2 plot was expected to be possible by incorporating the former and the latter. In this paper, a system for predicting the distribution of the heading dates of timothy, which is the most popular grass species in Hokkaido, at first cutting was constructed, and the foreseeable prediction errors were estimated.

METHODS
1. Construction of system for predicting heading date
The state of plant development ($DVI(T_j,L_j)$) can be expressed as follows (TAKEZAWA and TAMURA,1991);

$$DVI(T_j,L_j) = \sum_{i=1}^{j} DVR(T_i,L_i) \qquad (1)$$

$$DVR(T_i,L_i) = DVRT(T_i) + DVRL(L_i) \qquad (2)$$

where $DVR(T_i,L_i)$ is a function representing the rate of development. T_i and L_i are the daily mean air temperature and the day length on ith day, respectively. If $DVR(T_i,L_i)$ is constructed so that $DVI(T_j,L_j)$ is zero on sprouting date and is 1.0 on the heading date of timothy, it is possible to predict the heading date by predicting the daily mean air temperature and day length. $DVRT(T_i)$ and $DVRL(L_i)$ are estimated with nonparametric smoothing from 12 data sets for timothy which contain sprouting date, heading date and daily mean air temperatures during the growth of first crop in 1981-1990 at Konsen Agricultural Experiment Station (Fig. 1). Daily mean air temperature at every 1km^2 plot in the Konsen district is estimated as follows. Raster data of monthly normal mean air temperature, which were supplied by the Japan Meteorological Agency, were converted by harmonic analysis to raster data of daily normal mean air temperature. Measured daily mean air temperature was taken from a network of meteorological observatories. Difference between measured and normal daily mean air temperature at each observatory was calculated. Difference at each 1km^2 plot was the weighted average of reciprocal of distance from nearby observatories. Difference added to normal data at each plot yielded the daily mean air temperature on the day. Day length can be calculated from latitude and calendar day. As mentioned above, heading date could be predicted using the daily mean air temperature and day length on every day from the sprouting date. However, it was impossible to give a unique sprouting date to every 1km^2 plot. Therefore, calculation for prediction at each plot was started from the sprouting date observed at Konsen Agricultural Experiment Station. The following data base and programs were used for the calculation mentioned above, with the permission of each organization: raster map for normal temperature from the Japan Meteorological Agency, altitude data base from the Geographic Survey Institute, measured daily mean air temperature from the Hokkaido Agricultural Research Information System, nonparametric *DVR* analysis programs by Tamura *et al*. (1989) and estimation program of raster data for daily mean air temperature in real time by Seino (1993).

2. Foreseeable prediction error of the system
At first, estimation error of daily mean air temperature was investigated by comparison with estimated data and measured data at 11 observation points. The points were not only those established by the authors but also observation points for road maintenance established by the Civil Engineering Research Institute of the Hokkaido Developement Bureau. The prediction errors due to the errors for estimation of daily mean air temperature and differneces of sprouting date dependent on districts were estimated.

RESULTS AND DISCUSSION
Differences between predicted and observed value of heading date were investigated for 12 years (Table 1). Prediction error with cross-varidation for heading date of timothy with *DVR*s was less than 2days. The errors in estimated daily mean air temperature increased with altitude (Fig.2). Because more than 90% of grasslands in the Konsen district are located at altitudes of less than 300m, the error was estimated to be ±0.5-1.0ºC. The change in prediction result of the heading date was estimated when the daily mean air temperature was 1ºC higher or lower than normal at Konsen Agricultural Experiment Station. It was ±5 days for ±1ºC. However, the differences of predicted heading dates using estimated daily mean air temperatures and those using observed daily mean air temperatures

were less than 5 days (Table 2). Actually, the estimated daily mean air temperature did not exceed or fall below the measured one for any long, continuous period. Therefore, this error was considered to be less than 5 days of prediction error for heading date. In this system, sprouting date at Konsen Agricultural Experiment Staion was used as regional common date for starting the calculation of prediction. However, the sprouting date differs by area. Therefore, the difference of predicted heading date was investigated with climate data of 1992 when the starting date was different. As a result, 5-day differences of sprouting date made less than ± 1 day of difference for prediction results in 80% of the Konsen district, because *DVRT* in sprouting period was too small to change the predcition result due to low temperature. Thus, the effect of change in sprouting date could be ignored. From these results, prediction drrors due to the net prediction process and the temperature estimation process were less than ±2 days and less than ±5 days, respectively. Therefore, when a difference between predicted heading date and the observed one exceeded 5 days, other local factors should be considered.

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Table 1
Difference between predicted and observed heading date at Konsen Agricultural Experiment Station.

Year		1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
Heading date	predicted (A)	6/27	7/11	6/30	7/10	6/26	7/1	7/2	6/26	6/28	7/8	6/20
	observed (B)	6/24	7/9	6/23	7/10	6/24	6/30	6/30	6/23	6/28	7/7	6/22
difference (A-B)		3	2	7	0	2	1	2	2	1	2	-2

Table 2
Difference of predicted heading date using estimated daily mean air temperatures and those using observed daily mean air temperature.

Observed plot for daily mean air temperature	altitude (m)	year	*RMSE* of daily mean air temperature (ºC)	Predicted heading date using day length and estimated daily mean (A)	Predicted heading date using day length and observed daily mean (B)	Difference (A-B)
Bihoro Pass	480	1990	1.3	6/29	6/30	-1
Chihoku Pass	390	1989	1.2	7/5	7/5	0
Nishishunmetsu	113	1989	1.0	7/8	7/9	-1
Rausu Pass	80	1989	1.0	7/11	7/15	-5

Figure 1
Relationship between daily mean air temperature, day length and *DVR* derived from timothy development data at Konsen Agricultural Experiment Station.

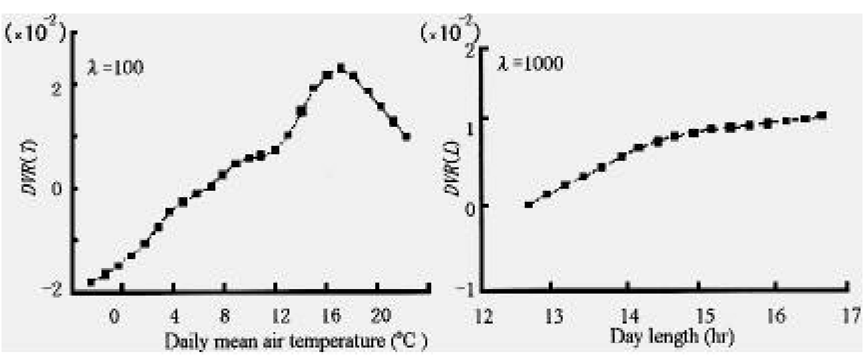
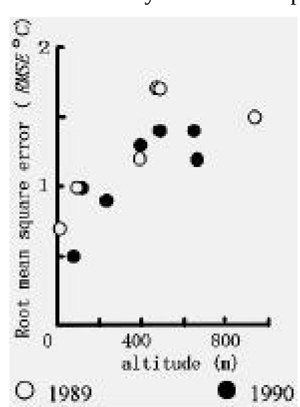


Figure 2
Relationship between altitudes and estimation errors for daily mean air temperature



$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}(D_i - R_i)^2}{n}}$$

where D_i is estimated daily mean air temperature, R_i is observed daily mean air temperature and n is number of data set.