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Monitoring Regional Rice Development and Cool-Summer Damage

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Abstract

Development Stage and Spikelet Sterility Models were used to develop a monitoring and forecasting system of rice development and spikelet sterility in the Tohoku district, Japan in 1993. Actual crop data were provided by the Ministry of Agriculture, Forestry and Fisheries (MAFF). Daily Meteorological data (real-time and at 1 km × 1 km grid-mesh) and land-use information of the monitored area were provided through the Automated Meteorological Data Acquisition System (AMeDAS) and the Geographic Information System (GIS), respectively. The mesh-weather data and crop data inputted into the 2 models led to the monitoring and forecasting of rice development stages across the Tohoku district under climatic normals and actual weather conditions. Based on the information on the rice varieties planted in the monitored area, spatial distribution of mean air temperatures, their deviation from climatic normals, and spikelet sterility due to cool temperature were determined. The initial results show the importance of the 2 models as tools for monitoring and forecasting the rice development stages and spikelet sterility on a wide scale.

Discipline: Agro-meteorology
Additional key words: GIS, AMeDAS

Introduction

Cool-summer damage to rice crop due to cool air temperature is manifested by high spikelet sterility when it occurs at the booting stage, or low grain ripening when it occurs during the grain-filling stage. Cool temperature during the rice booting stage sometimes results in a considerable reduction of yield. The farmers are very concerned since they cannot predict the severity of the damage because visual symptoms appear only at 10 – 14 days after heading, that is at least 20 days after the occurrence of the chilling injury. Some counter-measures to reduce the chilling injury include the appropriate control of the water depth in the paddies, and proper timing of irrigation. For the benefit of the farmers, information on the potential occurrence of cool weather in relation to the rice crop development stages is very important.

In 1988, cool-summer damage of rice crop occurred in Miyagi Prefecture. From this experience, a model to estimate the rice development stages and percentage of spikelet sterility based on available weather data was developed[5]. The method using GIS and real-time mesh data as inputs enabled to forecast the rice development stages and spikelet sterility at the regional level.

This paper intends to describe the initial results of wide-area monitoring of rice development stages and spikelet sterility using a rice crop model.

Materials and methods

The approach involved the use of the development stage and spikelet sterility models, and crop and geo-climatic data sets for the development of the prediction system.

1) Crop models

(1) Development stage model for rice

Based on the development stage (DVS) model designed by Prof. T. Horie (1987), values of 0, 1, and 2 are assigned to emergence (seed germination), heading and physiological maturity, respectively. The value of DVS at any point of crop development is calculated by integrating the developmental rate (DVR) with time:

$$DVS_{(t)} = \Sigma\, DVR_i \quad \text{.................................} \quad (1)$$

where $DVS_{(t)}$ is the developmental stage on the *i*th day, and DVR_i is the development rate on the *i*th day from emergence. Horie & Nakagawa[2], suggested that DVR from emergence to heading of rice plant could be expressed as a function of day length (L) and daily mean temperature (T) such as:

$$DVR = 1/G \cdot [1 - \exp\{B(L - L_c)\}] \; / \; [1 - \exp\{-A(T - T_h)\}] \quad \text{......} \quad (2)$$

or

$$DVR = a(T - T_o) \quad \text{................................} \quad (3)$$

where L_c, T_h, T_o, A and B are parameters (coefficients). Equation 3 is used when transplanting dates are fixed and when rice varieties planted are non or weakly photosensitive. This equation is only applicable when DVR increases linearly with the temperature.

(2) Spikelet sterility model for rice

The spikelet sterility model on the relationship between spikelet sterility and cool temperature sensitivity of rice plant at the panicle development stage was proposed by Yajima[3,5,6], with the following equation:

$$G = \sum_{DVS=0.72}^{1.2} (T_c - T_i)\; W(DVS) \quad \text{for } T_i < 18.9 \text{ and, } 1.20 > DVS > 0.72 \quad \text{.................} \quad (4)$$

where W(DVS) is the panicle sensitivity factor to cool temperature as a function of DVS. The value of W was based on the spikelet sterility data obtained by using the var. Sasanishiki in Miyagi Prefecture (1988). Rice shows 2 sensitivity peaks to cool temperature. The first is observed at $DVS = 0.88$ which corresponds to the meiosis of pollen mother cell, and the second is at $DVS = 1.07$ which corresponds to the mid-flowering stage (Fig. 1).

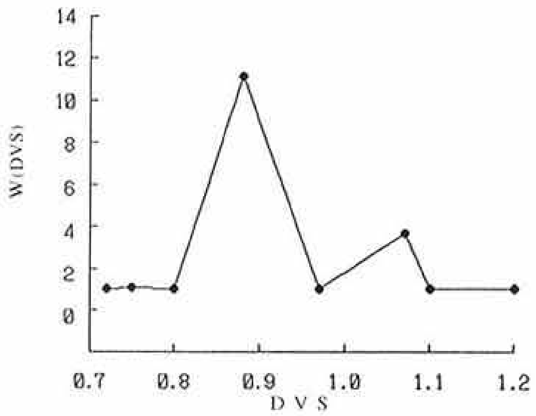


Fig. 1. Effect of cool temperature on sensitivity to spikelet sterility[5]

2) Crop and weather data

Crop data such as, variety planted, transplanting date, heading date and actual paddy yield were provided by the Dept. of Statistics, Ministry of Agriculture, Forestry and Fisheries (MAFF). Meteorological data such as, air temperature have been collected from 860 sites all over Japan since 1974. The Automated Meteorological Data Acquisition System (AMeDAS), provided the real-time weather information all over Japan. The Geographic Information System (GIS) in Japan also provided the information on land elevation, land use, and other geographical data on each rectangular grid-point 1 km × 1 km in dimension. With the AMeDAS and GIS data, climatic normals such as monthly air temperature were prepared for each grid-point covering Japan in the early 1990s. The mesh climatic data system gave the opportunity to estimate the daily mean temperature at each grid-point so that real-time weather information would be available at every mesh (1 km^2) all over Japan.

The investigation was focused on the Tohoku district involving the monitoring of Aomori, Iwate, Miyagi, Akita, Yamagata and Fukushima Prefectures in 1993. Each prefecture was divided into 3 to 5 subdivisions based on geographic and climatic conditions. Using the 2 above-mentioned models, crop development and percentage of sterility were estimated for the Tohoku district in 1993. The real-time mesh data on daily air temperature at 1 km × 1 km grid-point were estimated by using Seino's method[4] with daily AMeDAS data. On the other hand, crop data were provided by the MAFF.

Results and discussion

The rice varieties studied were Akihikari in Aomori Prefecture, Akitakomachi in Iwate and Akita Prefectures, Sasanishiki in Miyagi and Yamagata Prefectures, and Koshihikari in Fukushima Prefecture. Transplanting across the 6 prefectures was performed within the period May 7 – 23, 1993.

1) Actual air temperature and climatic normal temperature

Based on the real-time mesh data on air temperature recorded over the Tohoku district during the period August 1 – 10, 1993, prefectures on the Pacific Ocean side, generally showed a cooler air tempera-

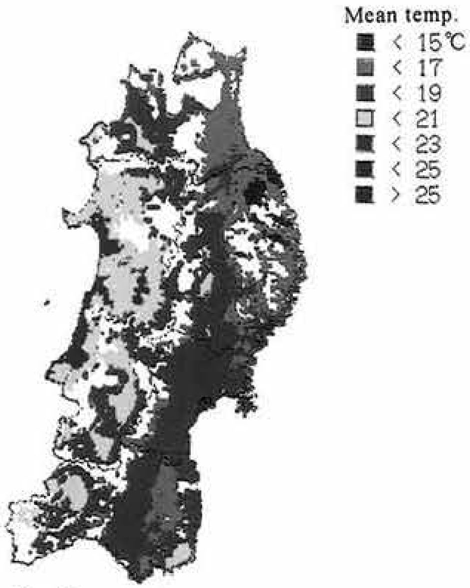
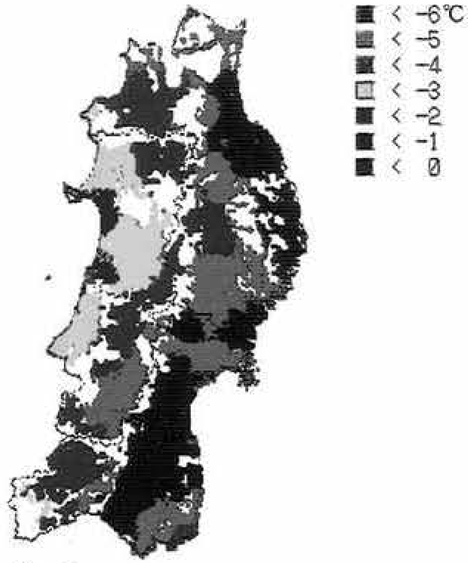


Fig. 2.



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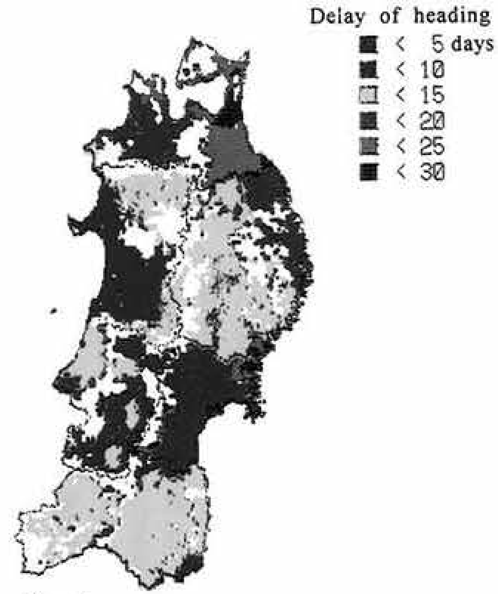

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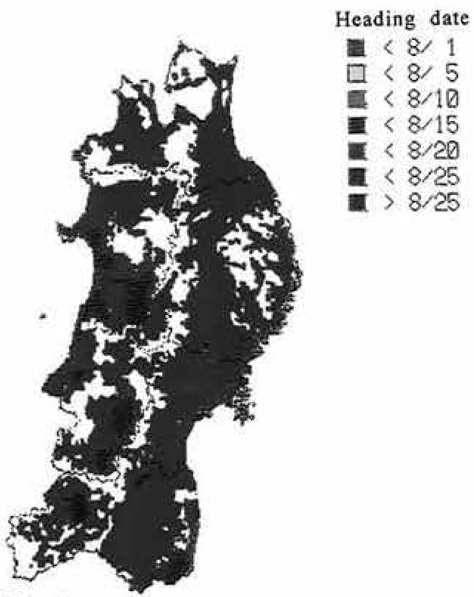

Fig. 5.

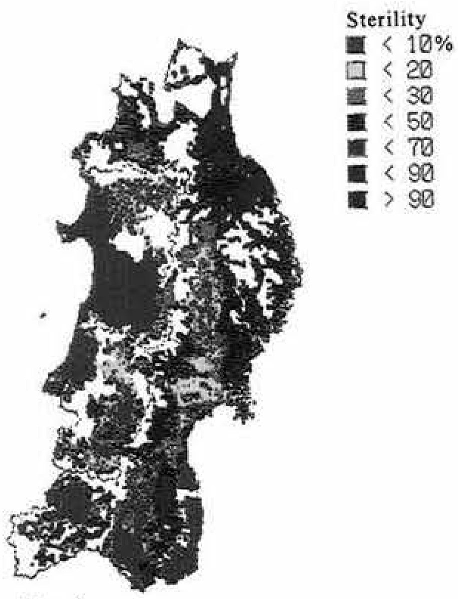

Fig. 6.

Fig. 2. Mesh data on air temperature over Tohoku district, August 1–10, 1993

Fig. 3. Deviation of air temperature from climatic normals in Tohoku district, August 1–10, 1993

Fig. 4. Estimated delay in heading (days) of rice cultivars in Tohoku district, 1993

Fig. 5. Estimated heading dates of rice cultivars across Tohoku district, 1993

Fig. 6. Spatial distribution of estimated spikelet sterility in Tohoku district, 1993

ture (below 17°C) than the prefectures on the Japan Sea side (19–21°C and in some areas above 21°C) (Fig. 2). The cool temperature in the northern part and most parts of the Pacific Ocean side of the Tohoku district is caused by the "Yamase", a cold anti-cyclone stationary on the Sea of Okhotsk that blows cold winds on the Pacific Ocean side of the Tohoku district.

The spatial distribution of the difference in climatic normal temperature and actual temperature (mean normal temperature minus the actual temperature during the period of abnormally cool weather) in this period is shown in Fig. 3. Prefectures on the Pacific Ocean side were in the range of below 3–5°C compared with the climatic normal temperature covering about 20,000 km^2. Relatively lower temperature differences (1–3°C) were observed in the Japan Sea side prefectures.

2) Heading dates

Using the real-time data on air temperature, the heading dates of rice cultivars across the Tohoku district were estimated. The estimated heading dates in about 70% of the Tohoku district corresponded to the period August 10–25. The heading dates in about 30% of the rice production area are likely to correspond to the period after August 26, and these areas are concentrated on the Pacific Ocean side particularly the northeastern parts (Fig. 4). Correspondingly, delays in heading dates were in the range of 5–20 days in most parts of the Tohoku district, while beyond 20 days in the northeastern parts (Hokubu and Shimokita) which usually experience severe cold wind during the reproductive stage of the rice crop (Fig. 5).

3) Spikelet sterility and yield index

Percentage of sterility due to cool temperature was estimated for the Tohoku district in 1993. Spikelet sterility estimates of 50–100% were obtained in the Pacific Ocean side prefectures, particularly in areas with large negative temperature deviations (3–5°C) from climatic normals. Spikelet sterility estimates for the prefectures on the Japan Sea side which ranged from 10–30% (Fig. 6) may be due to the negative deviation of air temperature from climatic normals by 1–3°C particularly during the meiosis of mother pollen cells until heading in these areas.

When the estimated spikelet sterility was plotted against the yield index (actual crop data), a highly significant negative linear relationship ($R = -0.92^{***}$) was obtained (Fig. 7), suggesting that the spikelet sterility model is suitable for prediction purposes. Based on the results, with the use of the real-time mesh data on temperature, spikelet sterility could be monitored on a daily basis, aside from the development stage of rice plant such as heading date with the utilization of the automated weather data transfer for immediate results.

Conclusion

Two components of a rice crop model, namely, Development Stage Model[1,2] and Spikelet Sterility

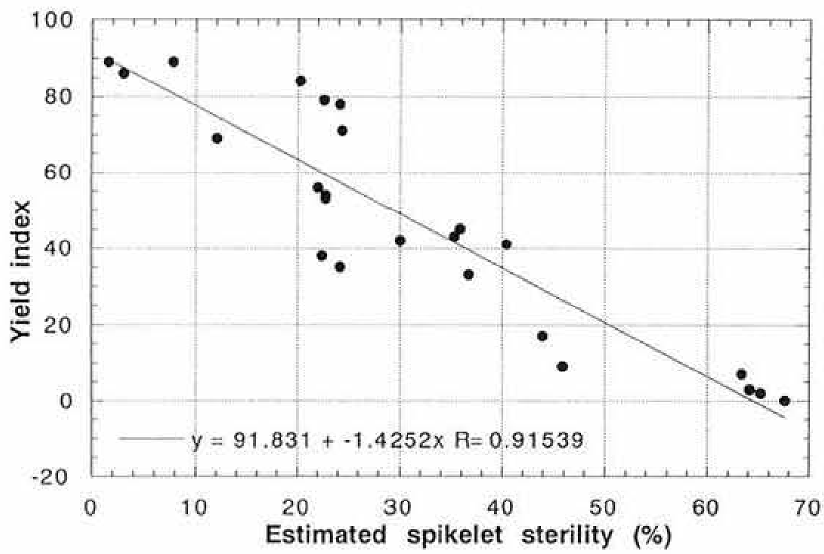

Fig. 7. Relationship between estimated spikelet sterility and actual yield index in Tohoku district, 1993

Model[5] were used to develop a monitoring and forecasting system of rice development and spikelet sterility in the Tohoku district, Japan in 1993. Actual crop data were provided by MAFF. Meteorological data (real-time weather data) and geographic information of the monitored area were provided through AMeDAS and GIS, respectively. With the use of mesh-weather data, rice models were developed and varietal characteristics of rice planted in the monitored area, spatial distribution of mean air temperatures and their deviation from climatic normals, as well as the spikelet sterility due to cool temperature were determined. A significant negative linear correlation was obtained between the estimated spikelet sterility and yield. The results suggest the importance of the use of crop model for the monitoring and forecasting of rice development stages and spikelet sterility at the regional level or in areas affected by cool temperature damage. With this method extension staff could easily provide information on the possible occurrence of spikelet sterility in particular areas which may enable the farmers to take the necessary measures to minimize the yield reduction due to cool temperature. This method could also be applied under tropical conditions such as in the cool elevated areas.

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