IRRIGATION WATER MANAGEMENT TO PROTECT RICE GRAINS FROM HEAT DAMAGE DURING RIPENING

GESTION DE L'EAU D'IRRIGATION POUR PROTEGER LES GRAINS DU RIZ CONTRE LES DEGATS CAUSES PAR LA CHALEUR PENDANT LE MURISSEMENT

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ABSTRACT

The reduced quality of rice caused by heat damage during ripening has become a major problem. On the agricultural extension side, various methods for preventing high-temperature injury have been recommended to farmers. Certain methods such as delayed planting or spill-over irrigation may change the irrigation period and irrigation water demand. However, in many cases, the agricultural irrigation water supply cannot sufficiently meet those demands due to the limitation of water rights and/or irrigation facilities. This study proposes adjustment methods for irrigation water management to prevent high-temperature injury to rice plants.

As part of this research, water temperatures were measured at the intake of irrigation water from a river, in the water channels within rice paddy irrigation areas, and in rice paddies; furthermore, a questionnaire survey on the occurrence of heat damage to rice was carried out in a rice paddy irrigation area of southeastern Miyagi Prefecture in northern Japan. The effect of water temperature on the occurrence of high-temperature damage to rice was found to be greater than that of the average air temperature for the 20 days after ears of rice began to sprout. From the questionnaire results, it was found that as the average water temperature rose, the frequency of occurrence of heat damage in the surrounding area tended to increase. Therefore, to avoid heat damage to wetland rice, it is important to obtain low-temperature water from rivers or water storage ponds.

Key words: *Rice, Heat damage, Delayed planting, Water temperature, Air temperature, Japan.*

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RESUME ET CONCLUSIONS

La baisse de la qualité du riz provoquée par des dégâts provoquées par la chaleur pendant le mûrissement est devenue un problème majeur. Sur le plan de la vulgarisation agricole, une variété de mesures ont été proposées aux agriculteurs des points de vue des variétés des graines de riz et de la technologie de la culture pour éviter des dommages liés à la haute température. Certaines méthodes, y compris la plantation tardive ou l'irrigation par le débordement peuvent changer la période d'irrigation ainsi que la demande d'eau irriguée. Cependant, dans la plupart des cas, l'offre d'eau irriguée pour l'usage agricole ne peut pas suffisamment répondre à ces demandes à cause des restrictions qui existent aux niveaux du droit à l'eau et/ou des installations d'irrigation. Notre recherche vise à proposer les méthodes d'adaptation pour la gestion de l'eau d'irrigation compatible avec les mesures prises contre les dommages aux plants de riz provoqués par la haute température afin d'aider les activités de la vulgarisation agricole et de l'alimentation en eau irriguée et de fournir des instructions agricoles appropriées tout en entretenant et utilisant au mieux de l'eau irriguée.

Dans le cadre de cette recherche, nous avons mesuré les températures aux points de prélèvement d'eau irriguée depuis une rivière, dans les canaux à l'intérieur des zones irriguées rizicoles et dans les rizières. De plus, nous avons effectué, après la saison de la récolte, une enquête basée sur les questionnaires concernant la fréquence des dommages provoqués par la chaleur auprès des agriculteurs dans les zones rizicoles irriguées situées dans le sud-est de la préfecture de Miyagi, dans le nord du Japon. À partir des résultats de la mesure des températures, nous avons constaté que, pendant les vingt jours suivant la pousse des épis du riz, l'effet de la température de l'eau sur l'apparition des dégâts au riz liés à la haute température est plus important que celui de la température moyenne de l'air. De plus, la température de l'eau dans les zones de recherche dépendait largement de la température de l'eau aux points de prélèvement, c'est-à-dire dans les rivières. Selon les résultats des questionnaires, nous avons trouvé que la fréquence des dégâts liés à la chaleur tend à augmenter au fur et à mesure que la température moyenne de l'eau s'élève. Par conséquent, afin d'éviter les dégâts au riz irrigué provoqués par la chaleur, il est important d'obtenir de l'eau à température basse depuis les rivières ou les réservoirs d'eau.

Cette étude a été menée afin d'examiner la relation entre la température de l'eau et l'apparition des dégâts liés à la haute température dans le sud-est de la préfecture de Miyagi, une région ayant subi en 2010 la haute température comparable à celle prévue dans les scénarios du réchauffement de la Terre. Les résultats montrent que quand la température dans les canaux d'irrigation ou dans les rizières est élevée, les dégâts au niveau de grains tendent à se produire sur les champs plus étendus. De surcroît, lorsque nous avons mesuré la température dans la rivière qui sert de la source d'irrigation d'eau pour les zones concernées dans l'étude, nous avons constaté que la température moyenne de l'eau pendant les 20 jours suivant la pousse des épis du riz dépendait largement de la température de l'eau de la rivière et que cette dépendance était beaucoup plus marquée que l'effet de la température moyenne de l'air observée aux points de mesure de la température de l'eau. Par conséquent, afin de fournir de l'eau d'irrigation et d'éviter des dégâts au riz occasionnés par la chaleur, il sera efficace de prélever de l'eau à partir d'un endroit où la température de l'eau est basse et durant une période de basse température.

Dans les activités réelles, il est nécessaire que les vulgarisateurs agricoles et les fournisseurs en eau irriguée échangent régulièrement des informations et des opinions. C'est pourquoi *les systèmes de consultation et de liaison entre eux sont importants. Cette méthode de consultation est applicable non seulement pour prendre des mesures contre les dégâts provoqués par la chaleur, mais aussi pour mettre en œuvre différents modèles de gestion de la culture touchant le contrôle de l'eau et ayant des effets importants sur la demande de l'eau d'irrigation, tels que les mesures contre les dommages provoqués par la basse température. Pour adopter ces mesures, il faut étudier à l'avance le changement de la période d'irrigation et de la demande d'eau.*

Mots clés : *Riz, dégât causé par la chaleur, plantation tardive, température de l'eau, température de l'air, Japon.*

1. INTRODUCTION

The summer of 2010 brought very high temperatures to areas from northern to western Japan. Extreme heat during the ripening period of rice lowers the quality and reduces the weight of the unpolished rice grains. This high-temperature ripening damage results in cloudiness and cracking of unpolished rice, and thus the rice is graded at a lower quality, which reduces farmers' incomes. Increasing occurrence of high-temperature ripening damage due to global warming is a major concern and the mechanisms of this type of damage have been researched by crop scientists. To avoid heat damage to rice, proposals have been made for developing heat-resistant varieties, as well as cultivation techniques with adjustments to the transplanting period, planting density, and fertilizer and water management.

In the present study, the distribution of water temperature was measured under the high-temperature conditions of 2010 over a large irrigation area, and its relationship to the occurrence of grain damage was determined. Parts of this paper were compiled from the report on this measurement and analysis to the International Symposium on Agricultural Meteorology (Sakata et al. 2011).

According to a survey by the Ministry of Agriculture, Forestry and Fisheries, among the 107 land improvement districts that encountered heat damage in 2007, 69 of those had difficulty supplying sufficient irrigation water for prevention due to the limitation of water rights and irrigation facilities. Therefore, this study examined adjustment methods for irrigation water management compatible with the measures against heat damage during ripening of rice grains in order to assist the agricultural extension side and the irrigation water supply side to provide appropriate farming instruction while managing and making the most of the irrigation water.

2. MATERIALS AND METHODS

2.1 Overview of the Study Area

The study was carried out in the towns of Watari and Yamamoto in southeastern Miyagi Prefecture. This area is located on the right bank of the downstream part of the Abukuma River, stretching about 20 km in the north-south direction and about 10 km in the east-west direction (the longest length in each case). Irrigation water is taken from the Abukuma River, and in 2010 about 3000 ha of paddy fields were irrigated within this area. Also, this area faces the Pacific Ocean and is flat, with a maximum elevation of about 4 m above sea level;

therefore, differences in temperature due to differences in elevation, and differences in sunlight due to differences in slope, are considered to be negligible.

2.2 Items Measured and Measurement Methods

Water temperature gauges (Hobo U22 Water Temp Pro v2) were installed at the intake from the Abukuma River (1 location), at 12 locations in the water channels, and in five paddy fields. Measurements were taken at 1-hour intervals, and the daily average value was calculated. In the paddy fields, the water temperature gauges were installed at three locations, and average values were obtained in the same way. The water channels are of two types: one in which only irrigation water taken in from the river is flowing (I1 to I7 in Figure 1) and the other in which irrigation water is mixed with water discharged from paddy fields (D1 to D4 in Figure 1). The water from the latter was used to re-irrigate paddy fields via a pumping station. Figure 1 shows a schematic diagram of the water system and the locations of the water temperature gauges.

A questionnaire survey was carried out among the farmers of the area in order to assess the occurrence of heat damage to rice. On maps that were distributed as part of the survey, the farmers indicated the locations where grain damage occurred. Of the locations with damaged grains, 87% had milky white kernels, immature kernels, and cracked kernels caused by high temperatures. The questionnaire was distributed to 500 people, and replies were received from 175 (response rate 35%).

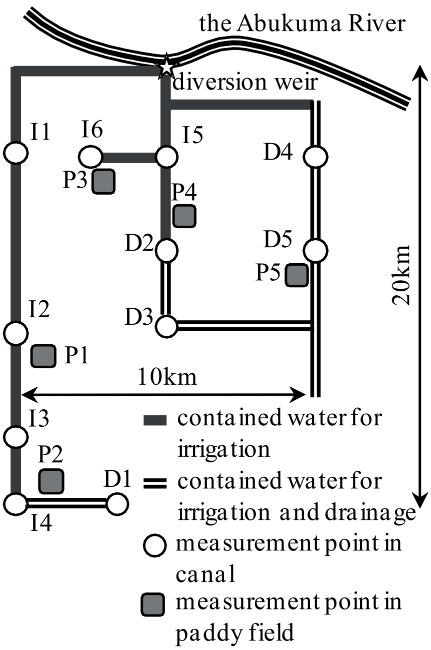

Fig. 1. Layout of water-temperature measurement points in the canal network (Plan des points pour la gestion de la temperature d’eau dans le réseau de canaux)

Also, the existing proposals for heat damage measures were reviewed and classified, and those having an effect on irrigation water demand were closely examined from the viewpoint of technical content and influence on the irrigation water demand. For example, spill-over irrigation, which is generally regarded as highly effective if sufficiently supplied with irrigation water of a temperature lower than that of the atmosphere, generates a huge demand for irrigation water.

3. RESULTS

3.1 Effect of River Water Temperature and Air Temperature on Water Temperatures within the Area

The river water temperature and the air temperature at the measurement points are expected to be important factors governing the water temperature at the measurement points. Therefore, multiple regression analysis was carried out for the heading period, with the average water temperature at each measurement point as a dependent variable and the average water temperature at the point of intake from the river (hereinafter referred to as the intake water temperature, *DW* and the average air temperature at each measurement point, *AT*, as explanatory variables. The relational expression is given by the following equation:

$$Y = a_{DW}x_1 + a_{AT}x_2 + b$$

where Y is the daily average water temperature at a measurement point, a_{DW} is the partial differential coefficient of the water temperature at the intake point (river), a_{AT} is the partial differential coefficient of the daily average air temperature at the measurement point, and b is a constant.

Table 1 lists the partial differential coefficients and coefficient of determination R^2 for each measurement point obtained from the multiple regression analysis. The table lists the values only of coefficients for which the significance level from the *t*-test is 5% or 1%. Also, air temperature data near point P2 could not be obtained, and thus this point was excluded from the analysis.

Table 1. Partial regression coefficient a and coefficient of determination R^2 in multiple linear regression analysis (Coefficient de régression partielle a et coefficient de détermination R^2 dans l'analyse de regression lineaire multiple)

	I1	I2	I3	I4	I5	I6	I7	
a_{DW}	0.959	0.936	0.902	0.685	0.907	0.784	0.921	
a_{AT}	-	-	-0.079*	0.084*	0.060	0.140	0.053*	
R^2	0.998	0.981	0.961	0.976	0.993	0.971	0.993	
	D1	**D2**	**D3**	**D4**	**P1**	**P3**	**P4**	**P5**
a_{DW}	0.649	0.719	0.586	0.658	0.872	0.460	0.571	0.584
a_{AT}	0.223	0.144	0.290	0.253	-	0.346*	0.430	0.468*
R^2	0.897	0.976	0.940	0.944	0.919	0.651*	0.862	0.712

a_{DW} and a_{AT} are the partial regression coefficients for the water temperature at the diversion weir and the calculated air temperature at each measurement point, respectively. "*" indicates that the t-test significant level is 5%; the significant level for the others is 1%. Multicollinearity is not observed between the a_{DW} and a_{AT} of each point.

From Table 1, a significant correlation with *DW* or *AT* was obtained for the average daily water temperature in all water channels and paddy fields. Comparing the coefficients of determination for the water channels and paddy fields, it can be seen that the values are higher for the water channels than for the paddy fields, and that the values are larger for the water channels with irrigation water only (I1 to I7) than for the water channels in which irrigation water is mixed with discharge water (D1 to D4). Comparing *DW* and *AT*, there are points in the paddy fields where the values of the partial differential coefficients are about the same, but in the case of the water channels, the influence of *DW* is much greater at all points. Therefore, it is considered that the water temperature depends greatly on the temperature of the river water up until the water flows into the paddy fields, and within the paddy fields this changes and the water temperature is influenced by the air temperature.

3.2 Effect of Water Temperature and Air Temperature within the Area on the Occurrence of Heat Damage

To determine the effect on the occurrence of heat damage in rice of the average water temperature at the measurement points during the heading period, the relationship between the number of fields where damaged grains occurred within a radius of 1 km of each measurement point, as extracted from the results of the questionnaire survey, and the average water temperature, is shown in Figure 2. Regarding the relationship between the prevalence of grain damage and the average water temperature, although it was not possible to dismiss the null hypothesis at the 5% significance level in either case, the following trends could be observed.

In Figure 2, a trend is seen where the frequency of occurrence of damaged grains becomes higher as the average water temperature increases in water channels with irrigation water only (I1 to I7) and in paddy fields (P1 to P5). In this study, average temperatures greater than 25°C were recorded, but there was no large difference between the daily average air temperature and the daily minimum air temperature, and, although small, differences were seen in the frequency of occurrence of damaged grains in the experimental paddy fields. At least in flat areas, such as those in this study where there is almost no difference in elevation, differences in air temperature due to geographical effects do not occur, and therefore differences in water temperature are considered to affect the occurrence of damaged grains.

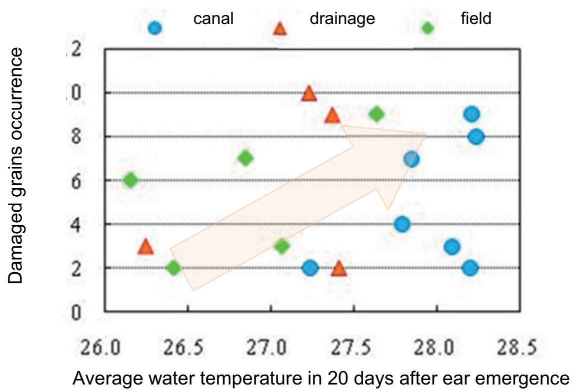

Fig. 2. Relationship between water temperature and damage occurrence (La relation entre la temperature de l’eau et l’apparition des dégâts)

3.3 Coordination Method

This study also examined adjustment methods for irrigation water management, intended for use by the agricultural extension side in coordination with the irrigation water supply side and compatible with measures against heat damage. Among those measures examined, the agricultural extension side proposes measures that are suitable for the region concerned, and then the irrigation water supply side explores the feasibility of providing the irrigation water. In cases where the provision of irrigation water is judged impossible, the agricultural extension side proposes an alternative measure that can be achieved within the limitation of water availability.

As for preventive measures, irrigation water management should be examined before the planting season and should be incorporated into the instruction provided by the agricultural extension side and also into the water supply plan prepared by the irrigation water supply side. On the other hand, the stakeholders will be consulted about support measures based on the meteorological conditions at the ripening period, and specific measures such as the period of implementation will also be discussed.

4. CONCLUSIONS

This study was carried out to investigate the relationship between water temperature and occurrence of grain damage due to high temperatures in southeastern Miyagi Prefecture, where high temperatures, such as those expected under global warming scenarios, occurred in 2010. The results showed that when the water temperature in the irrigation channel or in the paddy fields was high, there was a trend toward grain damage occurring in more fields. Also, when the water temperature was measured in the river that served as the source of irrigation water for the study area, the irrigation water channels flowing through the area, and the paddy fields within the area, it was found that the average water temperature in the 20 days after the ears of rice sprouted was highly dependent on the river water temperature, and this dependence was much greater than the effect of the average air temperature at the points of measurement for the water temperature. Therefore, to provide irrigation water and avoid heat damage to rice, taking water from a location where the water temperature is low and taking water during a period when the temperature is low should be effective.

In actual operation, it is necessary for the agricultural extension side and the irrigation water supply side to regularly exchange information and opinions; therefore, the consultation and liaison systems between them are important. This consulting method is applicable not only to heat damage countermeasures but also to the various types of cultivation management related to the water controls that have a great effect on irrigation water demand, such as low-temperature damage countermeasures. For those measures, it is necessary to study the change in irrigation period and water demand in advance.

REFERENCE

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