Mem. Fac. Agr. Kagoshima Univ., 41, 9-18, 2006

Effects of Temperature and Depth of Irrigation Water on Growth and Development in Paddy Rice (*Oryza sativa* L.)

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Received for Publication, September 10, 2005

Summary

Koshihikari and Hinohikari sown at three different times were grown under running and stagnant irrigation and in two water depth systems. The number of days required for transplanting to heading (DTH) was shortened as the date of sowing was put back. Rises in water temperature during the daytime were strictly checked under running irrigation and at 22cm depth, though the water temperature during nights was not different from surface to 22cm depth. Running irrigation extends DTH, while stagnant irrigation remarkably reduced DTH under high temperatures. A high water temperature induced by stagnant irrigation and deep flood irrigation accelerated elongation growth, and low temperature due to running irrigation reduced the rate of leaf emergence and final leaf number on the main stem. The effects of running and stagnant irrigation on dry matter production depended on the temperature environment during growing period, and running irrigation under high temperature and stagnant irrigation under low temperature acted positively on dry matter production. From those results, it was concluded that it is possible to control the growth and development of rice by changing irrigation type.

Key words: growth and development, irrigation type, paddy rice, water depth, water temperature

Introduction

An accurate prediction of the developmental process in rice is the basis of proper growing management. Although the leaf number index built up by Matsushima [7] or the cumulative temperature from transplanting proposed by Samoto et al. [10] and Hanyu [3] have often been used for this purpose, they both tend to induce a large prediction error in cool weather damage years when the developmental process is largely different from normal years. These errors cause cultivators to miss the timing of proper growing management, and as a result, to promote more severe damages.

The prediction model of developmental process in rice plants established by Horie and Nakagawa [4] hold a comparatively high accuracy by considering both the effects of air temperature and day length. However, it has been assumed that water temperature directly affects rice develop-

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ment in comparison with air temperature because its growing point is under the water for a long time [8]. The importance of water temperature on rice growth and development can be understood through the roles of water warming ponds and canals in frequent districts of cool summer and cold water damages; of windbreak nets being used to raise water temperatures on the leeward side; and of deep flood irrigation which reduces cool summer damage due to floral impotency [6]. On the contrary, in warm regions where excess high water temperatures appear frequently, cultivation management that keeps a check on rises in water temperature are related to increased yield [14, 17, 19].

The facts also indicate the importance of water temperature upon growth and development in rice. In spite of these, there is little information about effects of water temperature on growth and development in rice. In order to investigate the effects of water temperature upon growth and development in rice, the authors changed both irrigation type and water depth, giving a wide variation of water temperature surrounding the growing point of rice. Whether the effects of different treatments differ by shifting the cultivation season or not will be also discussed in this paper.

Materials and Methods

The experiment was done inside the vinyl greenhouses at the farm of the Faculty of Agriculture, Kagoshima University, in 2003. Two rice cultivars, Koshihikari and Hinohikari, which are the main early-season and normal-season cultivars in Kagoshima Prefecture, respectively, were examined. Seeds were disinfected by 500 times of Benrate (Sumitomo-Kagaku Ltd.) for 12 hours, sowed at the rate of 1 seed per 1 hole in 200 holes-trays, on 25 May, 30 June, and 26 July, respectively, and grown until transplanting. 13 seedlings were transplanted at the rate of one plant per hill and 13 hills per pot, in a container of 8L pot^{-1} filled with uniform soil that was passed through a sieve. 0.24g pot^{-1} and 0.32 g pot^{-1} of N, P_2O_5 and K_2O were given as basal dressing and top dressing, respectively. Each 8L-pot was transferred to a 400cm×110cm×39cm pool 1 week after transplanting. The pool was divided into running irrigation and stagnant irrigation sections. Although the water depth in the beginning of the experiment was kept at 11cm from the bottom of the hills by spreading blocks of 11cm thick all over the bottom of pool, the water depth for half pots in each section after panicle formation was changed to 22cm by removing those blocks. Therefore, the experiment consists of 4 treatments, that is, [running irrigation+ shallow flood], [running irrigation + deep flood], [stagnant irrigation + shallow flood], and [stagnant irrigation + deep flood]. In addition, the remnant pots put in out of pools were regarded as [control]. After this, these will be mentioned as RS, RD, SS, SD, and C. Four pots were prepared for each treatment. Air temperature and relative humidity in the vinyl greenhouse was measured continuously every one hour, by hygro-thermometer (SK-L200TH, Sato meter factory Ltd.), and water temperature at surface and 22cm depth, by a logger (SK-200T, Sato meter factory Ltd.) connected with waterproof sensors (LT-34, Sato meter factory Ltd.). Plant height, stem length and leaf number on the main stem was measured every week, and the day when more than 50% of the rice plants eared and the primary branch became yellow was recorded as heading and harvesting date, respectively. On the harvesting date, all the plants were harvested from the 8L-containers. All the hills were divided into main stem and tillers, and the former were further separated into leaf blades, leaf sheaths and culms, roots and dead parts. Each weight dried at 80℃ for 72hours or more were measured.

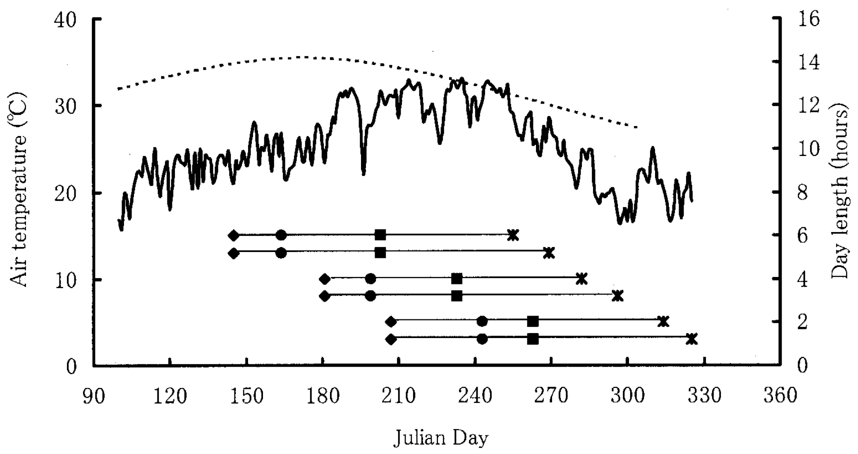

Figure 1. Changes in day length, air temperature in the vinyl greenhouse through investigation and the outline of treatments.
Solid and broken lines indicate air temperature and day length, respectively.
◆, sowing; ●, transplanting; ■,deep flooding; * harvesting

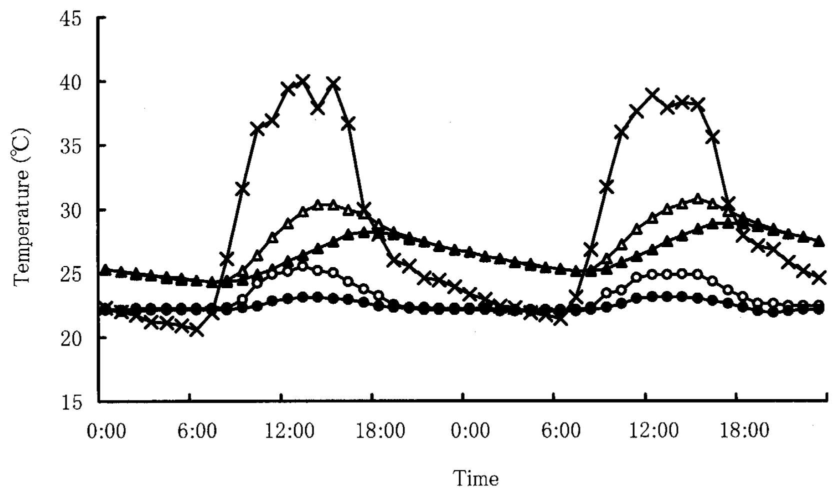

Figure 2. Changes in air temperature and water temperature (17-18, Sep. 2003). Crosses show air temperature, and triangles and circles indicate stagnant and running irrigation, respectively. Open and solid symbols are water temperature at surface and 22cm depth, respectively.

Results and Discussion

1. Characteristics of changes in weather and water temperature

Fig.1 shows the changes of mean air temperature in the vinyl greenhouse and day length (hours from sunrise to sunset) in Kagoshima City. The weather in 2003 was characterized by the small amount of solar radiation from mid to late May and from mid to late June in Kagoshima Prefecture [18]. The rise in air temperature during these periods was remarkably slow, but then because of the large amount of solar radiation from mid August to mid September, high temperatures above 32℃ were recorded on the basis of daily mean temperature. Day length in Kagoshima City from late May to mid July was above 14 hours and the maximum was 14.2 hours. However, it was shorter than critical day length for each cultivar [2,9].

Fig.2 shows an example of the diurnal change of air and water temperature measured. In both days, maximum air temperature reached around 40℃. At both surface and 22cm depth, the water

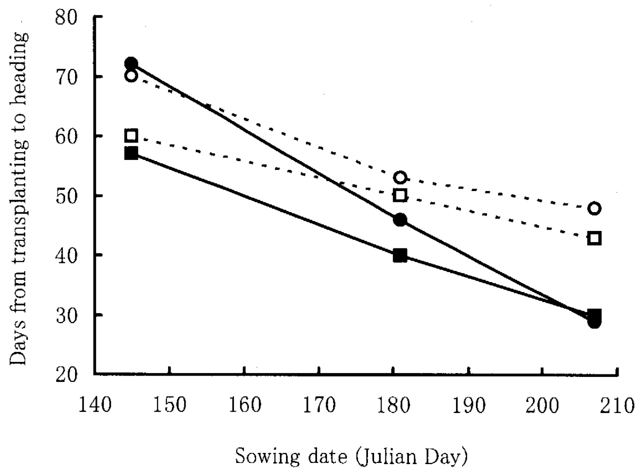

Figure 3. Changes in days from transplanting to heading with delayed sowing (Control). Circles and squares indicate Hinohikari and Koshihikari, and open and solid symbols show calculated values based on SIMRIW and observed values, respectively.

temperature was lower in running irrigation than in stagnant irrigation. The difference of water temperature between each treatment was observed regardless of day and night, but it was especially conspicuous in the maximum water temperature. In addition, it was found that the time when the maximum water temperature appears tended to be later in stagnant irrigation than in running irrigation. This suggests that the heat produced in the pool was discharged efficiently from that place in accordance with drained water. Although a rise in water temperature in the daytime was still more conspicuous at the surface than at 22cm depth, the difference disappeared around sunset. Consequently, daily mean temperature was high at the surface, and the diurnal range was small at the 22cm depth. The characteristics detected in Fig.2 tended to be reducing toward late autumn, but observed consistently until middle of October, to say the least of it (not shown).

2. Effects of sowing date and irrigation type on heading date

The number of days required from transplanting to heading (DTH) was shorter the later the sowing date was (Fig.3). It is well known that the higher the temperatures or the shorter the day length, the larger the development rate in rice [4]. The early growing stage after sowing in May experienced long days and not higher air temperatures, as already shown in Fig.1. On the other hand, plants sown in July grew under short-days and high temperatures from the early growing stage. It is presumed that the result shown in Fig. 3 reflects the differences between growing environments. This hypothesis is also supported by the tendency introduced from the simulation model predicting development process in Koshihikari and Hinohikari established by Nakagawa and Horie [9] and Hasegawa [2], respectively. In connection to this, the error between calculated and actual values grew, but this seems to be due to the large difference in leaf number on the main stem, being 3.5, 4.5 and 6.0 in May-, June- and July-sowing, respectively.

Fig.4 is a summary showing the effect of different irrigation types on DTH. With running irrigation which promotes lower water temperature, the heading date was 2-6 days behind the control. This suggests that running irrigation increased by 5-14% as compared to DTH in control. On the other hand, the heading was accelerated under stagnant irrigation which promotes a higher water temperature in July sowing where the plant encountered high air temperatures frequently after transplanting, though this was not found in plants sown in June. The result suggests that DTH will

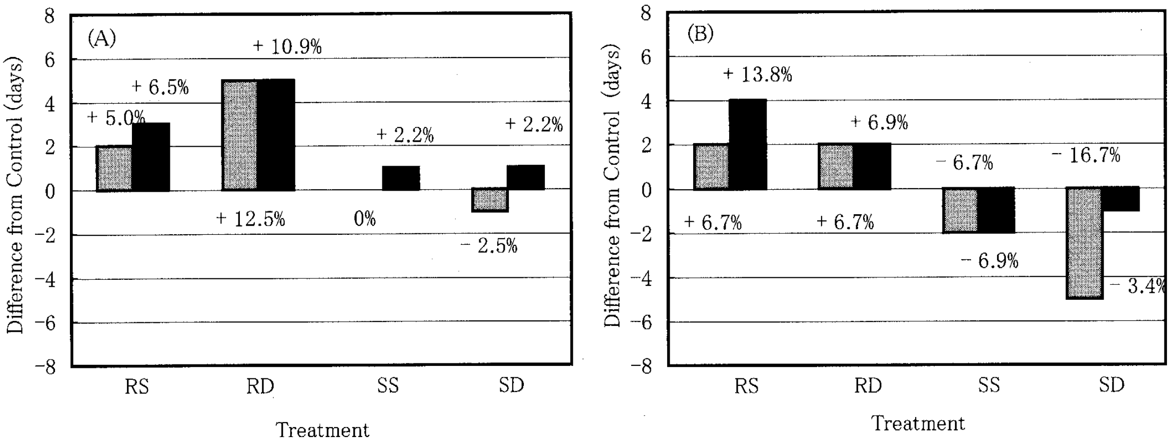

Figure 4. Effects of different irrigation types upon heading date (difference from heading date in control). (A) and (B) are the results sown in June and July, respectively. Gray and black bars indicate Koshihikari and Hinohikari. The numerals show the percentage of variation from days between transplanting and heading (DTH) in control. DTHs in Koshihikari and Hinohikari are 40 and 46 when sown in June, and 30 and 29 when sown July.

be shortened as water temperatures exceed a critical temperature. In addition, in June sowing, the increase in DTH under running irrigation was more conspicuous in RD than in RS. On the whole, it is regarded that high temperatures accelerated reproductive growth in common with both cultivars. It is also shown in Fig.4 that DTH in SD of Koshihikari was shortened remarkably when sown in July. Judging from the water temperature was lower at 22cm depth as mentioned before (Fig.2), a stimulative effect of deep flood toward reproductive growth can not be attributed to the difference of water temperature between SS and SD. Although rice plants, in appearance, begin conspicuous vertical or internodes elongation as they switch from vegetative growth to reproductive growth, the similar internodes elongation was also promoted by deep flood irrigation after panicle formation. In fact, in Koshihikari where the DTH became remarkably short at SD, prompt internodes elongation was begun from the beginning of deep flood irrigation as later mentioned. Therefore, it can not negate the possibility that the effect of deep flood irrigation on internodes elongation is connected with short DTH. We note that deep flood treatment conducted after panicle formation affected DTH in through either temperature or physical stimulus, though further investigation why only Koshihikari was peculiar will be required. That development rate from panicle formation to heading is influenced by air temperature and day length had been already suggested in the rice development prediction model [2,9]. These results are of absorbing interest in suggesting a possibility that development can be, to an extent, controlled even through water management after panicle formation.

3. Effects of different irrigation types on growth in rice

Fig.5 shows the changes in stem length under different irrigation types and sowing dates. By the way, the characteristics in Fig.5 were also found in plant height. Firstly, the final plant height and stem length of both cultivars tended to were smaller the later the sowing date. This agrees with the results of Samoto et al [12] who observed that final plant height or stem length in late season culture is inferior to those in normal season culture. We support the view of Samoto et al [12] that a difference in the duration of elongation growth induces such a difference in plant height or stem length (See Fig.3). Secondly, considering the effect of irrigation types, both plant height and stem length tended to be higher in stagnant irrigation than in running irrigation. Judging from the

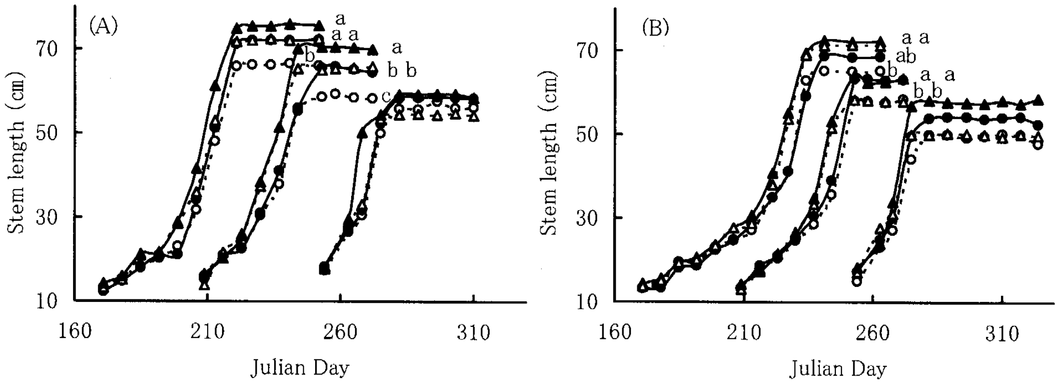

Figure 5. Changes in stem length.
(A) and (B) indicate Koshihikari and Hinohikari, respectively.
△, ▲, ○, and ● show SS, SD, RS, and RD, respectively.
Two mean values not belonging to the same letter significantly differ at 5% level (by ANOVA test).

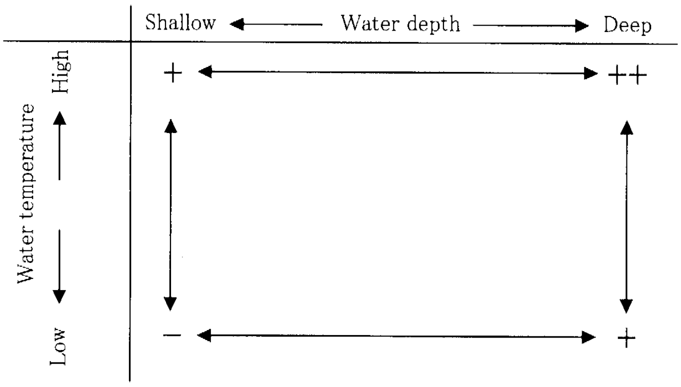

Figure 6. Diagram showing the effects of water temperature and depth on elongation growth.
+, positive; -, negative.

observations of Samoto et al. [13] that elongation growth accelerates under high temperature condition, it is assumed that this is due to the difference in water temperature. On the other hand, plant height and stem length became longer in RD and SD than in RS and SS, respectively, from the beginning of deep flood treatment. Because the water temperature is lower at 22cm depth that at the surface as shown in Fig.2, the differences between RD and RS and between SD and SS can not be attributed to water temperature. It was also reported by Goto et al. [1] and Ohe and Mimoto [10] that plant height became higher, and leaf blade and leaf sheath became longer under deep flood conditions. According to Suge [15] who investigated 5 native varieties originating from certain area of Gifu Prefecture, those have the ability to develop internodes under submergence although the ability was extremely low as compared with the true floating varieties in tropical Asia. He supposed that an endogenous gibberellin concentration may play an important role also in the internodal elongation because GA3 increased the rate of elongation and almost no elongation was detected when the inhibitor of gibberellin biosynthesis was applied before the submergence. It is estimated that the differences in stem length between RD and RS and between SD and SS reflect such a direct effect of water depth on elongation.

The effects of different irrigation types on plant height and stem length can be summarized as

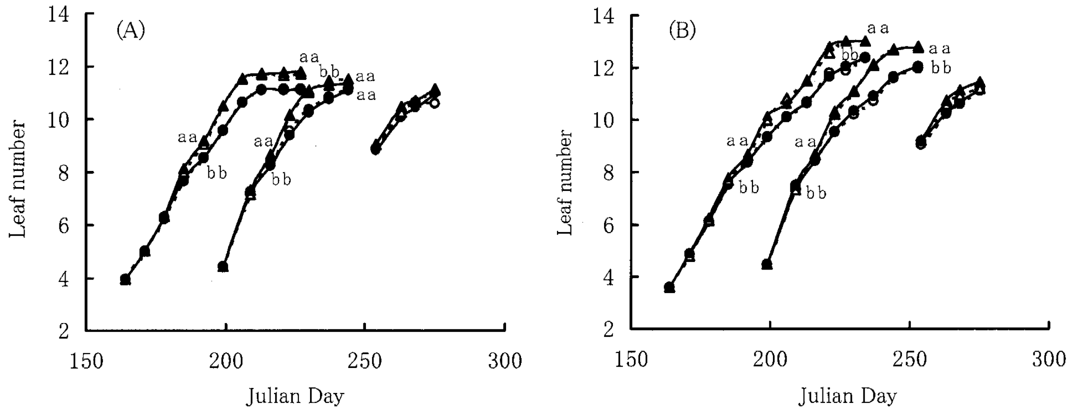

Figure 7. Changes in leaf number on the main stem.
(A) and (B) indicate Koshihikari and Hinohikari, respectively.
△, ▲, ○, and ● show SS, SD, RS, and RD, respectively.
Two mean values not belonging to the same letter significantly differ at 5% level (by ANOVA test).

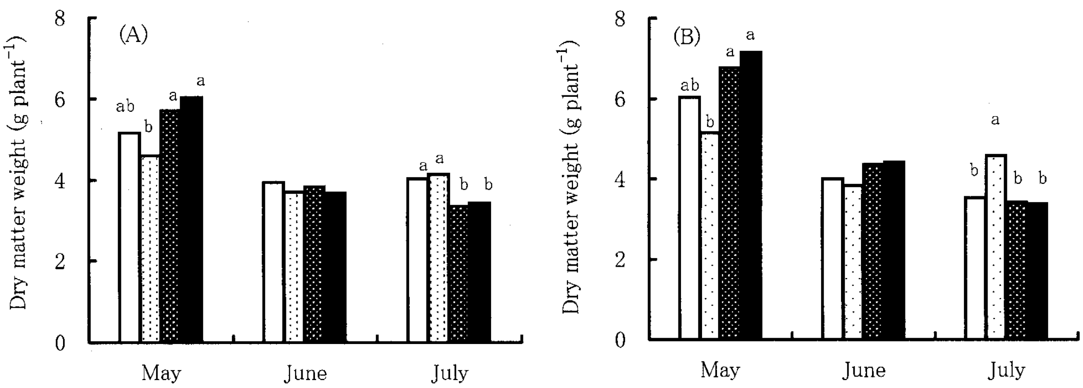

Figure 8. Effects of different irrigation types and sowing season on dry matter weight.
(A) and (B) indicate Koshihikari and Hinohikari, respectively.
Each bar shows RS, RD, SS, and SD from left, respectively.
Two mean values not belonging to the same letter significantly differ at 5% level (by ANOVA test).

shown in Fig.6. That is, the effects of irrigation type used in the experiment can be resolved into effects of water temperature and depth, and high temperature and deep flood accelerated the elongation growth. Hence, stem length often was in the order of SD>RD≒SS≧RS. However, this can not be always generalized because the effect of water depth tended to become more evident as the later the sowing date became.

Fig.7 shows the effects of difference in irrigation type and sowing date on changes in leaf number on the main stem (L_N). Final L_N of Hinohikari tended to decrease the later the sowing date was, Koshihikari remained stable around 11. It is assumed that this corresponds with the results of Fig.3 which show that a decrease in DTH was more conspicuous in Hinohikari. The results that running irrigation reduced the rate of leaf emergence are also shown in Fig.7. This indicates that the water temperature, one of the environmental factors surrounding leaf primordia, considerably affected their differentiation and development. The effect of water depth on changes in L_N was not detected as reported by Ohe [11].

Fig.8 shows the effects of differences in irrigation types and sowing date on the total dry weight

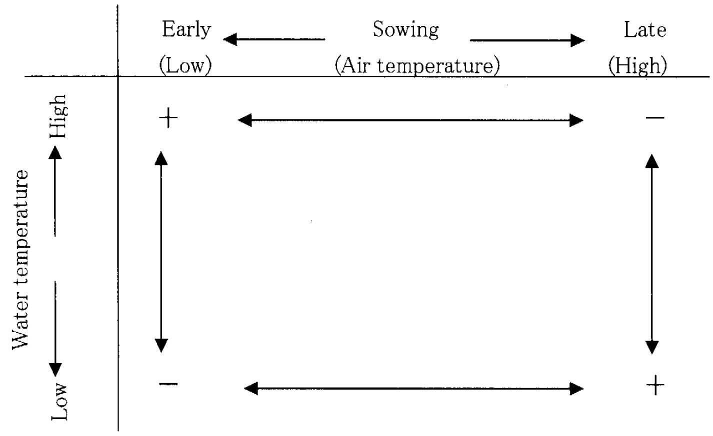

Figure 9. Diagram showing the effects of water temperature and sowing date on dry matter matter production. +, positive ; -, negative.

at harvested date (DW_H). DW_H tended to decrease the later the sowing date was. This is related partly to the growing duration being shorter with later sowing dates (Koshihikari, r = 0.76; Hinohikari, r = 0.81). However, the difference in DW_H between irrigation types is also great. In particular, the tendency that late sowing reduced DW_H was evident in both stagnant irrigation treatments, while the difference in DW_H between sowing dates was relatively small in both running irrigation treatments. DW_H, in May sowing, tended to be larger in SS and SD than in RS and RD, and it was the opposite in July. On the other hand, a significant difference was not detected between treatments in June sowing. Generally speaking, the dry matter partitioning ratio to the leaf blade was larger [16] and the leaf emergence was faster (Fig.7) under higher temperature conditions. In May sowing where the rice plant was grown under relatively low temperature, it is supposed that high water temperatures produced under stagnant irrigation (Fig.2) accelerated increases in leaf area. On the other hand, high temperatures have the effects of increasing developmental rate, and as a result shorten vegetative and all growth duration, and accelerating the aging of leaf. The result in July sowing that the reduction in leaf blade weight, as compared to other organ weights, was conspicuous in SS and SD (unshown) may be related to the two effects.

The effects of different irrigation types on dry weight production can be summarized as shown in Fig.9. The fact that the effects of irrigation types on dry matter production were different between sowing dates (Fig.8) indicates that respective treatments which increase or decrease water temperature can have negative or positive effects depending on the growing season. And, a main factor which decides the direction of the effect is probably the difference in air temperature. In May sowing where plants grew under relatively low temperatures, running irrigation treatments which induced lower water temperatures checked and stagnant irrigation which raise the temperature of water surrounding leaf primordia accelerated the growth and dry matter production, respectively. However, in July sowing, where plants encountered high temperatures from an early growth stage, the growing duration was easily shortened and the aging of leaf accelerated. Under such a high temperature environment, running irrigation which reduces the water temperature acts positively on dry matter production.

It is understood from the present study that the growth and development of rice plants can be, to some extent, controlled by changing irrigation types. The conclusion indicates again that water control should be assessed as a basic technique for rice growth management.

Acknowledgement

The authors are much indebted to T.C. Katayama, honorary professor of Kagoshima University, for his kindness in reading and advice on the papers and for his constant encouragement.

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