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Studies on Agronomic Traits of African Rice (*Oryza glaberrima* Steud.)

II. Dry matter increase and water use efficiency*

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Abstract : To compare the time courses of dry matter increase and water consumption in the two cultivated rice species, *Oryza sativa* L. and *O. glaberrima* Steud., six strains each of *O. glaberrima* and *O. sativa* collected in West Africa and Nipponbare, a Japanese leading cultivar, were examined. The six strains of *O. glaberrima* showed a vigorous growth around the heading time but afterward the dry matter increase stopped promptly, while all strains of *O. sativa* showed a slower but longer dry matter increase. The decline of leaf area after heading was slower in strains of *O. sativa* than in those of *O. glaberrima*. The root/top weight ratio increased after ripening again in *O. sativa*, but no such phenomenon was observed in *O. glaberrima*. These differences between the two species are presumed to be caused by the genetic differences in their progenitors, *i.e.*, whether they are perennial or annual. The water use efficiency (WUE) estimated on the basis of dry matter was smaller in *O. glaberrima* than in *O. sativa*, and decreased with the advance of growth stages. The decline was closely correlated with the decrease in the leaf area ratio (LAR) which accompanies the advanced growth stages. Although vigorous leaf development is one of the characteristics of *O. glaberrima*, and this is resulted in a large water consumption, the leafy posture seemed to be beneficial for WUE. The ratio of panicle dry weight to total transpiration was equal both in *O. glaberrima* and *O. sativa*.
Key words : Annual, Dry matter increase, Leaf area ratio, *Oryza glaberrima*, *Oryza sativa*, Perennial, Water consumption, Water use efficiency.

アフリカイネ（*Oryza glaberrima* Steud.）の農学的形質に関する研究　第2報　乾物増加と水利用効率：
角　明夫・片山忠夫・縣　和一**（鹿児島大学農学部・**九州大学農学部）
要　旨：西アフリカで収集した栽培稲 *Oryza glaberrima* と *Oryza sativa* の中から選んだ6系統ずつに日本晴（*O. sativa*）を加えた計13系統をポット栽培し，両栽培稲の乾物増加と水消費の経過を比較検討した．*O. glaberrima* の各系統の乾物増加は出穂期前後に高い反面登熟完了後急激に停止したが，*O. sativa* の各系統は緩やかであるがより後期まで乾物増加が継続した．*O. sativa* は，出穂後の葉面積減少が *O. glaberrima* より緩やかであり，また根/地上部重比が登熟完了後再度微増した．このような差異は，*O. glaberrima* の直接祖先種が一年生であるのに対して，*O. sativa* はその祖先種である *O. perennis* の多年生形質を多分に残していることを反映していると推察した．水利用効率（WUE）は，*O. glaberrima* より *O. sativa* のほうで高く，また WUE は供試した全系統とも生育経過に伴って低下した．この WUE の低下は生育に伴う葉面積比（LAR）の低下と密接に関連していた．*O. glaberrima* の特性である旺盛な葉面積生長は，消費水量の増大をもたらす一方で，この種の特性である低い光合成/蒸散比を幾分か高く維持することに寄与していると考えられた．*O. glaberrima* は穂重/全乾物重比が高く，結果として穂重/蒸散比には差異は認められなかった．
キーワード：一年生，*Oryza glaberrima*, *Oryza sativa*, 乾物増加，多年生，水消費，水利用効率，葉面積比．

Previously, we pointed out that no difference was detected between *O. glaberrima* and *O. sativa* in dry matter productivity and yielding ability, suggesting enough grounds for controversy on the culture of *O. glaberrima*[12]. Usuallly, rice plants are grown as an annual crop. *O. glaberrima* derived from *O. breviligulata*[8], is a pure annual species, whereas *O. sativa*, related to *O. perennis*[8], is potentially perennial[7]. To what extent has such a difference in the cycle of growth and development influenced the patterns of dry matter increase and water consumption ? To answer this question, the time courses of dry matter increase and water consumption should be compared between the two cultivated species.

Frequently, *O. glaberrima* is said to be inferior to *O. sativa* in water use efficiency (WUE) : assimilation rate/transpiration rate ratio or total dry matter increment/transpiration ratio[1,12]. Although this confers no special

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advantages, to what extent does it pose a problem ? We intend to begin to answer that question by considering the relationship between WUE and plant posture and the panicle weight/transpiration ratio.

Materials and Methods

Six strains each from *O. glaberrima* and *O. sativa* were collected in West Africa by the authors[5] and used with *O. sativa* cv. Nipponbare, a Japanese cultivar. The experiment was carried out in a vinyl plastic house in the Experimental Farm of Kagoshima University, from May 21 to Nov. 10, 1992. Seeds were sown on May 21, at the rates of 3 grains per hill and 3 hills per pot in the 15 liter plastic containers filled with 9.42 kg of dried sandy loam soil passed through a sieve of 5 mm width. On June 15, plants were thinned at the rate of one plant per hill and grown under submerged conditions from that time. Compound fertilizer (8-8-8) was applied 4 times at the rate of 4.5 g per pot. Heading times varied from 14 to 24 (average ; 20) in *O. sativa*, 17 to 29 (average ; 22) in *O. glaberrima*, and Aug. 17 in Nipponbare. After heading, plants were supported with a stick to prevent lodging. Three plants were harvested 4 times from July 30 to Nov. 10, from each strain. The samples were separated into leaf blades, stems including leaf sheaths, panicles, dead parts and roots, and then leaf area was measured with an automatic area meter (Hayashi Denko, AAM-5). The dry weight of each part were determined after drying at 85°C for 72 hours or more. The water consumption in each pot was assessed by the total amounts of water supplied to hold the pot weight constant. Water use efficiency was determined by the following equation[11,12].

$$\mathrm{WUE}i=\frac{\Delta \mathrm{W}i}{\mathrm{ET}i-\mathrm{E}i} \qquad (1)$$

where WUEi, ΔWi, ETi and Ei are water use efficiency, total dry matter increment (g/pot), total evapotranspiration (= the amount of water supplied to keep the pot weight constant + the increment on total fresh weight, kg/pot), and evaporation (kg/pot) from bare ground until the ith days after measurement was commenced. For excluding the effect of the difference in mean potential evaporation on WUE at each stage, the corrected WUE (WUE′) was calculated by the following equation[2].

$$\mathrm{WUE}'i=\frac{\mathrm{WUE}i\times \mathrm{E}i}{100} \qquad (2)$$

Containers were arranged sparsely and transposed at the time of water supply to avoid the light effects.

Results

The time courses of total and panicle dry weights, leaf area and root/top weight ratio (R/T) are shown in Figs. 1, 2 and 3, respectively. The values indicated are the average of 6 strains. Panicle weight was the greatest in *O. glaberrima*, and higher in *O. sativa* from West Africa than in a Japanese variety, Nipponbare. Both rice species from West Africa were also higher in total dry matter weight than Nipponbare. No clear difference was observed in total dry matter weight between two species from West Africa in the whole growth stages. However, all 6 strains of *O. glaberrima* showed vigorous growth around the heading time but thereafter the dry matter increase stopped promptly, whereas strains of *O. sativa*, including Nipponbare, showed a slower but longer dry matter increase (Fig. 1). All strains of *O. glaberrima* showed more conspicuous leaf development until heading, as well as a decline of leaf area after heading than that of *O. sativa*. In the maintenance ability of leaf area after heading, Nipponbare surpassed all strains from West Africa (Fig. 2). R/T increased rapidly toward the maximum value around 30 days after the beginning of measurement and then declined. Mean R/T of *O. glaberrima* was less than or nearly equal to that of *O. sativa* from West Africa, but was greater than that of Nipponbare. There was no considerable difference in R/T between both species, but they showed two marked changes. Firstly, *O. glaberrima* showed more evidence of R/T decline after reaching the maximum. Secondly, the R/T of *O. sativa* tended to increase again after ripening, whereas no such secondary increase was observed in *O. glaberrima* (Fig. 3).

The changes in total accumulated (A) and daily mean (B) evapotranspiration are shown in Fig. 4. The values for *O. glaberrima* and *O. sativa* from West Africa are shown as the average of 6 strains. The accumulated evapotranspiration was larger in *O. glaberrima*

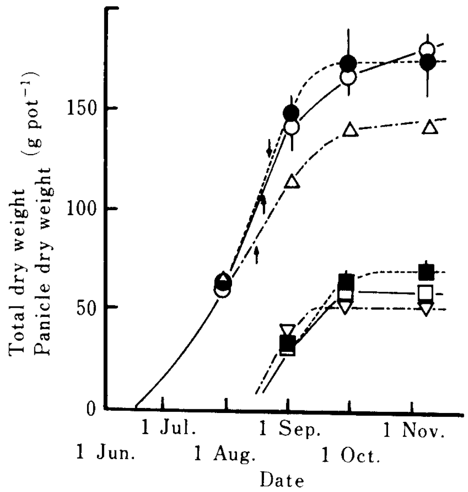

Fig. 1. Time course of total and panicle dry weights. Each symbol of —○— and —□—, ---●--- and ---■---, and △—·— and ▼—·— shows total and panicle dry weights of *O. sativa* and *O. glaberrima* from West Africa and Nipponbare, respectively. Values of *O. sativa* and *O. glaberrima* from West Africa show means of the respective six strains, and bars in the figure are standard deviations.

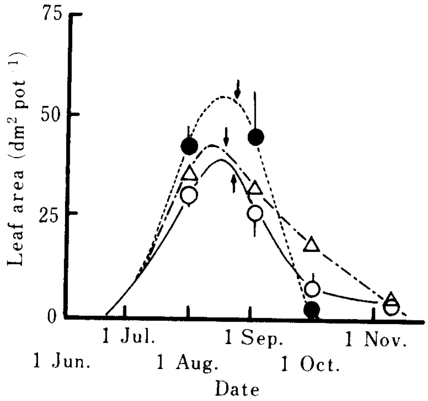

Fig. 2. Time course of leaf area. Each symbol of —○—, ---●--- and △—·— shows *O. sativa* and *O. glaberrima* from West Africa, and Nipponbare, respectively. Bars in the figure are standard deviations.

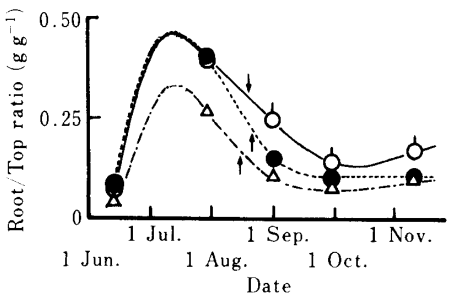

Fig. 3. Time course of the ratio of root weight to top weight. Symbols are the same as those shown in Fig. 2.

than in *O. sativa*, and was the smallest in Nipponbare. All strains showed higher daily evapotranspiration through August to September, when the mean air temperature was higher and all strains had a larger leaf area, and the differences in total integrated evapotranspiration among strains arose principally from the differences in evapotranspiration during the above period. In this connection, a drop in daily evapotranspiration in mid-August was due to the fact that all pots were carried into a room for 3 days for escaping from the damage by typhoon No. 10 and there were a lot of rainy or cloudy days around that period.

Fig. 5 shows the time course of water use efficiency (WUE). WUE tended to decrease with the advance of growth stages in all strains examined. Mean WUE of *O. glaberrima* was smaller than that of *O. sativa*. The corresponding relationship between WUEs obtained here and that obtained previously (1990) is shown in Fig. 6. WUEs in both years related considerably to each other, though WUEs in 1990, when potential evapotranspiration was much larger, were considerably smaller than those in the present experiment. This result shows that quantitative relationships between the WUEs of each strain were comparatively stable from year to year. However, the correlation coefficients between WUEs obtained here and those obtained in 1990 decreased with increasing time lag between the determined times. The decline of WUE with time was closely related to the decline of the leaf area ratio (LAR) with the advance of growth stages (Fig. 7). The ratio of panicle dry weight to transpiration was 1.23 and 1.24 g kg^{-1} on average in *O. sativa* and *O. glaberrima* at the end of the experiment, respectively.

Discussion

Sumi and Katayama[11] found that a strain of *O. glaberrima* had vigorous growth around heading time but that dry matter increase stopped promptly after ripening, while a strain of *O. sativa* had a slower but longer increase in dy matter. The present results agree. Mori-

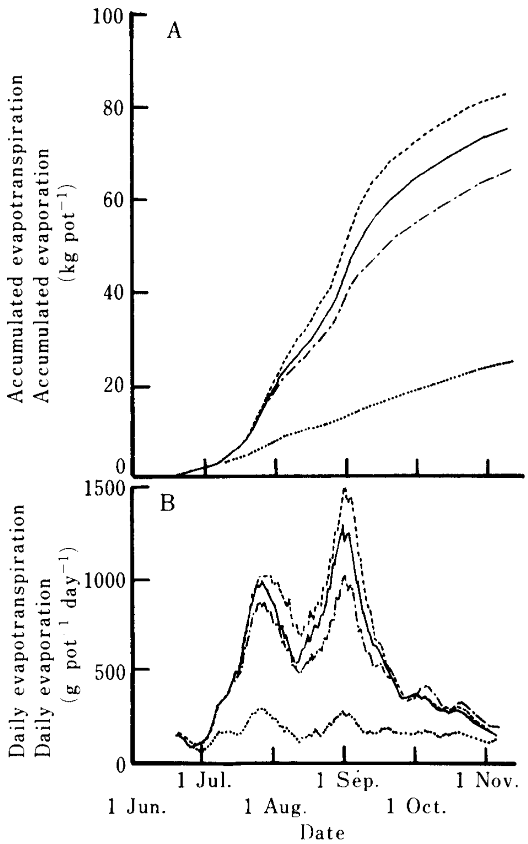

Fig. 4. Time course of accumulated-(A) and daily-(B) evapotranspiration and evaporation. Daily evapotranspiration and evaporation show in the running mean of every 10 days. Each line of -- and ---, and · , and ··· shows evapotranspiration of *O. sativa* and *O. glaberrima* from West Africa, and Nipponbare, and evaporation, respectively.

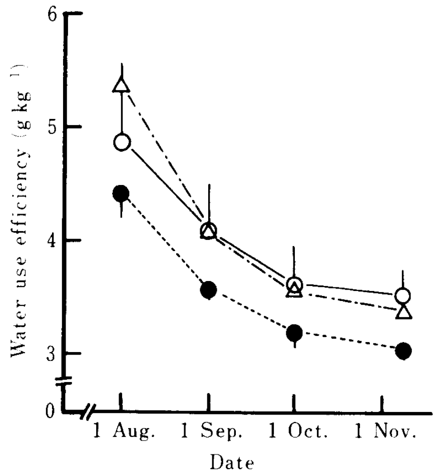

Fig. 5. Time course of water use efficiency obtained in each determined time. Symbols are the same as those shown in Fig. 2.

shima and Oka[9] pointed out that annual wild rice strains showed vigorous growth around heading time but the growth rate declined rapidly, whereas perennial wild rice strains showed a considerably large weight increase after heading although their seed productivity was low. Because *O. sativa* is cultivating as an annual plant even though it is genetically in close relationship to perennial wild species, *O. perennis*, the difference in growth pattern between two cultivated species was not so significant as in annual and perennial wild species. However, it could be generally concluded that strains of *O. glaberrima* derived from annual wild species, *O. breviligulata*, followed the growth pattern in annual wild species and that strains of *O. sativa* derived from *O. perennis*, followed the growth pattern of perennial wild species. Vigorous growth around heading time may contribute to the high seed productivity of *O. glaberrima*. Sumi and Katayama[11] concluded that *O. glaberrima* was characterized by the larger leaf development and leaf decline before and after heading, whereas *O. sativa* was characterized by slower declines of leaf area and photosynthetic activity after heading. These differences could also be caused by the genetic differences between whether or not their progenitors are perennial or annual[4]. The rate of decline of R/T after arriving at the maximum was more evident in *O. glaberrima* than in *O. sativa*, indicating the rapid top growth in the former around heading time as compared to root development. And, the secondary R/T increase in *O. sativa* is caused by late tiller development after ripening.

Ratio between net CO_2 assimilation rate and transpiration rate (A/T ratio) is significantly higher in *O. sativa* than in *O. glaberrima*[1]. Although the values of the WUE and A/T ratio are differently obtained in the method and in object, the two results agreed each other. The present experiment also showed that WUE is variable depending on the growth time. The decline of WUE with time was closely correlated with the decrease in LAR which accompanies the advanced growth stages. This indicates that WUE depends not only on meteorological[2] and genetic[1,3] factors but also on the ratio of leaf area to total dry matter weight. The positive relationship between WUE and LAR might

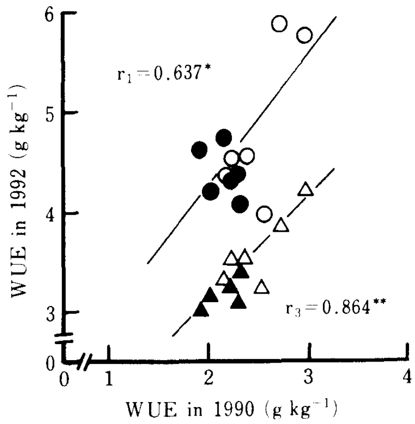

Fig. 6. Relationship between water use effeciency (WUE) in early October, 1990 and WUEs in early August and in late September, 1992. Each symbol of ○ and ●, and △ and ▲ shows *O. sativa* and *O. glaberrima* in early August, and in late September, respectively. r_1 and r_3 show the correlation coefficients between WUE in early October, 1990, and WUEs in early August and in late September, 1992, respectively. * and ** indicate that r is significant at 5% and 1% levels, respectively. Correlation coefficients between WUE in early October, 1990, and WUEs in early September and November, 1992 were 0.794** and 0.780**, respectively.

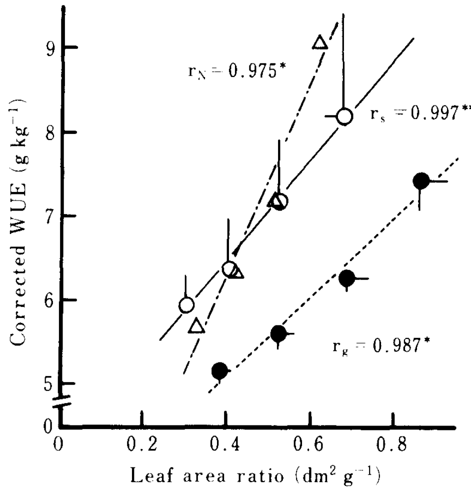

Fig. 7. Relationship between leaf area ratio and corrected water use efficiency. Changes in both leaf area ratio and water use efficiency are based on the progress of growth. r_S, r_g and r_N show correlation coefficients in *O. sativa* and *O. glaberrima* from West Africa, and Nipponbare, respectively. * and ** indicate that r is significant at 5% and 1% levels, respectively. The other symbols are the same as those shown in Fig. 2.

arise partly because the larger the LAR was, the easier the A/T ratio measured in leaves was to be reflected in WUE calculated on dry matter basis, and partly because the percentage of the water loss from stems including leaf sheath and panicles for total transpiration increase with a decline in LAR[10,11]. On the other hand, the result suggests that the A/E ratio measured in a single leaf is not always a good predictor of WUE on a dry matter basis[3], when the LAR is very different between strains.

Total evapotranspiration is larger in *O. glaberrima* than in *O. sativa*[12], suggesting that *O. glaberrima* is a more-water consumptive species. That is mainly due to a larger leaf area during the period when the evapotranspiration rate is higher in *O. glaberrima*. However, leaf development is more vigorous in *O. glaberrima*[6], then this makes WUE value large on a dry matter basis. It other words, the disadvantage of the lower A/E ratio in a single leaf was concealed to some extent through the higher LARs. It is worth noting that no difference was detected between the two rice species in the ratio of panicle dry weight to total transpiration at the end of the experiment.

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