Jpn. J. Crop Sci. 63(1) : 96—104 (1994)

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

I. Growth, yielding ability and water consumption*

Akio SUMI and Tadao C. KATAYAMA
(*Faculty of Agriculture, Kagoshima University, Korimoto, Kagoshima 890, Japan*)
Received March 30, 1993

Abstract : To compare the growth, yielding ability and water consumption in the two cultivated rice species, *Oryza sativa* L. and *O. glaberrima* Steud., the respective six strains of *O. sativa* and *O. glaberrima* collected in West Africa were examined. *O. glaberrima* tended to be larger in leaf area at heading time than *O. sativa*. In some strains of *O. glaberrima*, the vegetative growth was expanded notably under manuring, and also the panicle number per hill was significantly larger and the one-grain weight significantly smaller than in *O. sativa*. These two significant differences are correlated with the fact that many strains of *O. sativa* had long culm and that all strains of *O. sativa* belong to the *javanica* type with a large grain. No difference was observed in the grain number per head and the percentage of ripened grains between the two species. The grain yield tended to be larger in *O. glaberrima* than in *O. sativa*. On the other hand, *O. glaberrima* was found to have smaller water use efficiency with greater water consumption.
Key words : Growth and development, Manuring, *Oryza glaberrima*, *Oryza sativa*, Water consumption, Water use efficiency, Yielding ability.

アフリカイネ (*Oryza glaberrima* Steud.) の農学的形質に関する研究　第1報　生育，収量性および水消費：角　明夫・片山忠夫（鹿児島大学農学部）

要　旨：西アフリカで収集した栽培稲 *O. glaberrima* と *O. sativa* の中から選んだ6系統ずつを供試し，両栽培稲の生育，収量性および水消費を比較した．*O. glaberrima* は，*O. sativa* より有意に出穂期の葉面積が大きかった．また，*O. glaberrima* の中には施肥によって栄養生長期間が顕著に延長されるいくつかの系統が認められた．本実験に供試した系統の範囲内において，*O. glaberrima* は穂数が多く，一籾重が小さい傾向にあった．この差異は供試した *O. sativa* 系統の中に長稈少げつの系統が多かったこと，またその全系統が大粒のジャワ型であったことに関係した結果である．一穂籾数と登熟歩合には種間差異は認められなかった．収量は *O. sativa* よりむしろ *O. glaberrima* で大きい傾向にあった．その一方で，*O. glaberrima* は水利用効率が低く，より多水分消費型の種である傾向が認められた．
キーワード：*Oryza glaberrima*, *Oryza sativa*, 収量性，生育，施肥，水消費，水利用効率．

Recently, in West African countries, rice cultivating areas have been increasing rapidly with an increase in demand for rice[19,20]. Although such a phenomenon is not particular to these countries, it is especially significant in this region, probably due to the historical backgrounds that *O. glaberrima* derived from annual wild species, *O. breviligulata*, in a upper basin of the Niger River, and that the species has been cultivated since B. C. 1,500 at the latest[13,24]. On the other hand, the cultivating area of *O. glaberrima* has decreased with the introduction of cultivars of *O. sativa*[5,31], and this is frequently cited as an evidence that *O. glaberrima* is inferior to *O. sativa*. According to our field observation and others, however, *O. glaberrima* has still filled an important position under several growing environments such as upland, inland swamp and deepwater field[4,5,6,30], although it has been regarded as a 'weed' under irrigated conditions in some cases[31].

In the West African region, rice plants have been grown under various climatic environments[27], and their cultivation under irrigation is dominant only in the northern part of the region, where precipitation is particularly small[27]. In the other larger parts, rice is grown in upland, inland swamp and deepwater field, etc.[5,19,20,27], and the rice-growing area has increased even now on a large scale in inland swamp and upland without irrigation[20,27,31]. Judging from this situation, the importance of *O. glaberrima* will not disappear even in the future. Moreover, because genetic erosion has continuously taken place, a wide-ranging survey on the unknown eco-

* Outline of this paper was presented at the 194th meeting of the Crop Science Society of Japan in October, 1992.

physiological characters of this species is urgently required.

In this paper, the growth, yielding ability and water consumption are discussed for *O. glaberrima*, comparing it with *O. sativa*.

Materials and Methods

Six strains, each from *O. glaberrima* and *O. sativa*, close in heading time, were used from the samples collected by us in four West African countries[4]. The places of collection and habitats of those twelve strains were listed in Table 1.

Experiment 1. The experiment was done inside a glasshouse in the Experimental Farm of the Faculty of Agriculture, Kagoshima University, from May 17 to Oct. 18, 1988. The seedlings sown on May 17 and grown for a month were transplanted at the rate of one plant per container (8 liter plastic baskets) filled with 5.2 kg sandy loam (on dried soil basis), which passed through a sieve of 5 mm width, on June 17. But, for C180 and C194, which had an extremely low germination percentage, the seedlings resown on May 30 were transplanted on June 17. In addition, two kinds of seedling, sown on May 17 and May 30, were transplanted for C150 and C170. Compound fertilizer (8-8-8) was applied at the rate of 3.1, 3.1 and 3.0 g per pot on June 16, July 11, Aug, 10. To prevent lodging, all plants were grown with a stick support after heading. Five plants were sampled twice from each strain at the times of heading and harvesting. After measuring the plant height, culm length, culm number and leaf number on the main stem, the plants were separated into leaf blades, stems including leaf sheaths, panicles, dead parts and roots, and the dry weight was determined after 72 hours desiccation at 80°C. At the heading time, the chlorophyll content of the upper three leaves and total leaf area was determined by a chlorophyll meter (Minolta, SPAD-501) and an automatic area meter (Hayashi Denko, AAM-5), respectively. Both yield and yield component were determined for all plants at the harvesting time. In C180 and C194, late in sowing, the values were obtained without correction in almost all cases, however, estimated value

Table 1. Strains used in the experiments, places collected and their habitats

Strain No.	Species	Place, habitats and remarks
C103	S	Birnin Kebbi, NIGERIA. River flood plain. Mixed-growing with *O. glaberrima*. Javanica type.
C106	S	Argungu, NIGERIA. River flood plain. Mixed-growing with *O. glaberrima*. Javanica type.
C110	S	Rabah, NIGERIA. River flood plain. Javanica type.
C115	S	Talata Mafara, NIGERIA. Paddy field. Mixed-growing with *O. glaberrima*. Javanica type.
C138	S	Palala, Bong County, LIBERIA. Shifting field on hill slope. Javanica type.
C150	G	Near Ziguinchor, SENEGAL. Rainfed paddy field.
C170	G	Amdoulaye Village, SENEGAL. Upland field . A few plants remaining in the field where *O. sativa* was already harvested.
C173	S	Banbatou Village, SENEGAL. Rainfed paddy field. Javanica type.
C174	G	Dar es Salaam Village, SENEGAL. Rainfed paddy field. Mixed-growing with *O. sativa*.
C180	G	Kilidio Saboly Village, SENEGAL. Rainfed paddy field. Mixed-growing with *O. sativa*.
C189	G	Bandiana Village, SENEGAL. Rainfed paddy field. Growing as weed in *O. sativa* field.
C194	G	Pirang Village, GAMBIA. Rainfed paddy field. Growing as weed in *O. sativa* field.

S and G indicate *Oryza sativa* and *Oryza glaberrima*, respectively.

(W) was also calculated by the following equations:

$$W = \varepsilon \times W' \quad (1)$$

$$\varepsilon = (W_{C150} + W_{C170}) / (W'_{C150} + W'_{C170}) \quad (2)$$

where, W′ and ε are observed value obtained in case sown on May 30 and correction coefficient, respectively. W_{C150} and W_{C170}, and W'_{C150} and W'_{C170} are observed values of C150 and C170 in the case sown on May 17, and observed values in the case sown on 30 May, respectively. ε varied between 1.00 and 1.31 with determined elements and times. According to calculation, days from transplanting to heading in C180 and C194 would be shortened by 4 days if they were sown on May 17 without any accidents.

Experiment 2. The experiment was carried out in a vinyl plastic house in the Experimental Farm of Faculty of Agriculture, Kagoshima University, from May 20 to Oct. 4, 1990. The seedlings sown on May 20 and grown for three weeks were transplanted at the rate of one plant in a container (8 liter plastic baskets) filled with 4.9 kg sandy loam soil (on dried soil basis), which passed through a sieve of 5 mm across, on June 10. After transplanting, 5 plants for each strain were grown under two sets of conditions, with and without fertilizer, respectively. For fertilizer conditions, compound fertilizer (8-8-8) was applied at the rate of 3.0, 6.0 and 6.0 g on June 10, July 10 and Aug. 9, respectively. In order to prevent lodging, plants were supported with a stick after heading. In this year when the violent heat hit around heading stage, and, lots of steriles were observed. On 3 and 4 October, all plants were harvested and each traits, as in Experiment 1, was examined. In addition, the water consumption in each pot was assessed by accumulating the total amount of water supplied during the growing period and determined the increased total fresh weight.

In both experiments, containers were arranged sparsely and transposed at water supply in order to reduce the effect of light conditions upon both dry matter increase and water consumption.

Results

Mean measurements with standard deviation in various traits, found for each species, are given in Tables 2 and 3.

No difference was detected in days required from sowing to heading (DSH) between *O. sativa* and *O. glaberrima* within the strains used here. However, DSH was increased with fertilizer in some strains of *O. glaberrima*, while DSH of *O. sativa* were rather stable even with or without fertilizer (Fig. 1).

Although both plant height and culm length tended to be longer in *O. sativa* than in *O. glaberrima*, both the highest and the shortest strains belonged to *O. sativa*, indicating *O. glaberrima* was less variable in these two traits than *O. sativa*. No difference was also found in the total leaf number on the main stem.

Although no difference was seen in the total dry matter weight at heading time between the two species, it varied greatly from 47.0 g plant^{-1} in C173 (*O. sativa*) to 98.1 g plant^{-1} in C189 (*O. glaberrima*). This large difference between those two strains was closely related to the difference in days from transplanting to heading (Fig. 2). *O. glaberrima* was significantly larger in leaf area, and significantly smaller in mean chlorophyll content of upper three leaves at heading time than *O. sativa*. The larger the leaf area at heading time became, the smaller the mean chlorophyll content at the same time became (Fig. 3). No difference was detected also in total dry matter weight at the harvesting time, however, a significant difference in root/top ratio (R/T) was found between the two species, although the difference was not detected at the heading time.

At the heading time, the panicle number of *O. glaberrima* was more than of *O. sativa*, and this significant difference became more conspicuous in the harvesting time because of a difference in late-emerging heads. The number of grains per head was less in *O. glaberrima* than in *O. sativa*, although the difference was not significant. The same tendency was also observed in the percentage of ripened grains, except with fertilizer condition in the Experiment 2, where *O. glaberrima* tended to be higher. One unhusked grain weight was significantly larger in *O. sativa* than in *O. glaberrima*. No evidence that *O. glaberrima* was inferior to *O. sativa* in yield was found. That is, in the Experiment 1, the yield was more or less high in *O. glaberrima* even including C180 and C194, which were behind in sowing 13 days, and with fertilizer in Experiment 2, it was significantly higher in *O. glaberrima*.

Table 2. Growth and yield components

		Heading Time		Harvesting Time	
		O. sativa	*O. glaberrima*	*O. sativa*	*O. glaberrima*
DSH	(days)	96.83±5.23	96.83± 9.26		
P. H.	(×10 cm)	14.90±1.99	13.90± 1.43	15.50± 2.59	13.71± 1.65
C. L.	(×10 cm)	10.03±1.00	8.96± 0.80	11.70± 2.36	9.85± 1.01
L. N.	(no.)	15.00±0.65	14.38± 0.77		
D. W.	(g $plant^{-1}$)	60.27±7.78	68.70±15.96	93.63±13.86	99.34±16.17
R/T	(g g^{-1})	0.22±0.05	0.21± 0.04	0.15± 0.03	0.10± 0.01**
L. A.	(dm^2 $plant^{-1}$)	34.35±8.87	47.63± 6.92*		
Chl.	(mg dm^{-2})	4.28±0.19	3.67± 0.27**		
P. N.	(no. $plant^{-1}$)	12.30±2.86	17.47± 2.82*	18.55±10.29	31.78± 3.47**
G. N.	(no. $head^{-1}$)			89.56±30.15	70.37±12.40
Percent.	of R. G. (%)			83.85± 9.63	74.81± 5.71
G. W.	(mg $grain^{-1}$)			28.18± 2.29	20.50± 2.43**
G. Y.	(g $plant^{-1}$)			33.78± 2.32	34.18± 7.30

Data indicated are Mean±S. D. Data are different significantly between *O. sativa* and *O. glaberrima* at 5(*) and 1%(**) levels, respectively. The values of *O. glaberrima* contain the measurements of C180 and C194 which were late in sowing. DSH, days required from sowing to heading ; P. H., plant height ; C. L., culm length ; L. N., total leaf number on the main stem ; D. W., total dry weight ; R/T, root/top ratio ; L. A., leaf area ; Chl., chlorophyll weight in the unit leaf area ; P. N., panicle number including late-emerging head per plant ; G. N., grain number per head ; Percent. of R. G., percentage of ripened grains ; G. W., one unhusked grain weight ; G. Y., unhusked grain yield. Chlorophyll content was determined in upper three leaves by SPAD-501.

Table 3. Growth, yield components and water consumption

		No-manuring		Manuring	
		O. sativa	*O. glaberrima*	*O. sativa*	*O. glaberrima*
DSH	(days)	92.67± 7.42	82.17± 7.96	90.50± 5.47	85.83± 8.50
P. H.	(×10 cm)	13.42± 1.24	12.47± 0.43	17.25± 2.07	16.71± 1.12
C. L.	(×10 cm)	11.05± 1.19	10.14± 0.41	14.05± 2.23	13.50± 1.05
L. N.	(no.)	13.90± 0.44	13.87± 0.89	15.10± 0.55	14.87± 1.05
D. W.	(g $plant^{-1}$)	48.80± 4.20	46.84± 3.96	98.70± 8.29	102.08± 8.46
R/T	(g g^{-1})	0.36± 0.05	0.23± 0.04**	0.17± 0.02	0.12± 0.01**
P. N.	(no. $plant^{-1}$)	8.93± 4.21	16.37± 3.11**	19.30±15.55	42.13±10.47*
G. N.	(no. $head^{-1}$)	87.87±33.11	70.94±10.66	92.69±41.89	60.32± 9.65
Percent.	of R.G. (%)	59.38±18.18	50.11± 9.52	31.69±15.01	35.53± 8.52
G. W.	(mg $grain^{-1}$)	27.93± 2.09	22.73± 1.89**	25.75± 2.76	20.19± 1.95**
G. Y.	(g $plant^{-1}$)	10.96± 2.66	12.60± 1.27	10.41± 3.81	17.49± 3.89**
ET	(kg $plant^{-1}$)	24.29± 2.11	26.24± 1.24	45.15± 4.70	51.88± 2.69*
WUE	(g kg^{-1})			2.48± 0.31	2.13± 0.15*

Data indicated are Mean±S. D. ET, accumulated evapotranspiration from transplanting to harvesting times per plant ; WUE, water use efficiency. WUE was estimated as slope of regression line between evapotranspiration and inceased dry matter weight from transplanting to harvesting times. The other symbols and abbreviations are the same as those in Table 2.

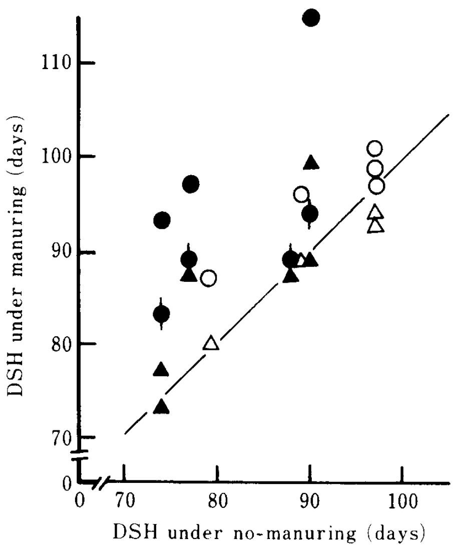

Fig. 1. Comparison between days required from sowing to heading (DSH) with (1988 and 1990) and without (1990) fertilizer. ○ and △ show DSH of *O. sativa*, while ● and ▲ show DSH of *O. glaberrima* in 1988 and 1990, respectively. ⧳ shows that of *O. glaberrima* resown on 30 May in 1988. Straight line shows Y= X.

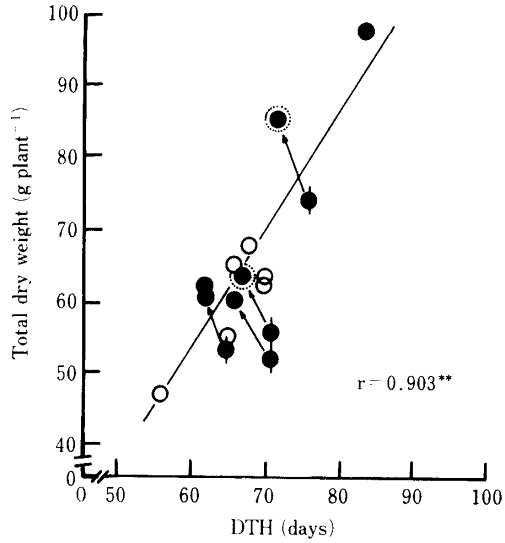

Fig. 2. Relationship between days required from transplanting to heading (DTH) and total dry weight at heading time. ○ and ● show *O. sativa* and *O. glaberrima*, respectively. ⧳ shows *O. glaberrima* resown on May 30. Dotted circles indicate the estimated values of C180 and C194 which were late in sowing, in case sown on May 17. r shows correlation coefficient on the assumption that all strains would be sown on May 17, and ** indicates that r is significant at 1% level.

Water consumption was larger in *O. glaberrima*, though the difference was small without fertilizer. Between total evapotranspiration (ET) and the increased total dry matter weight ($\varDelta W$), the relationship expressed by the following equation was found, for each strain (Fig. 4).

$$\varDelta W = \varkappa(ET - E_0) \quad (3)$$

In Eq, (3), $\varkappa$ and E_0 indicated the water use efficiency dependent on each strain and unavailable evapotranspiration or evaporation, respectively. The water use efficiency was lower in *O. glaberrima* than in *O. sativa*.

Disussion

Sumi *et al.*[26] pointed out that the heading of C174 (*O. glaberrima*) was late with an increase of fertilizer application, while one of C173 (*O. sativa*) was constant regardless of the amount of fertilizer. Although rice plant has been known as a nitro-negative crop, heading and flowering are related negatively to nitrogen content[2], such a character was more conspicuous even in *O. glaberrima* in the present experiments. Rice breeders have been intended to increase the adaptability to heavy manuring ; a character that fertilizer increase doesn't provoke the over-luxuriant growth and lodging[1,22,29]. In this sense, *O. glaberrima* is more primitive than *O. sativa* since vegetative growth and leaf development were easy to induce by giving fertilizer and also the species has pronounced seed dormancy[13,14]. In West African region, the cultivation of *O. glaberrima* has begun to drive out first from mangrove swamp and irrigated field, where large nutrients have been supplied naturally or artificially might be partly attributable to expression of such a character.

Morishima *et al.*[14], compared the modes of evolution of cultivated forms from two wild rice species, have observed that *O. glaberrima* and its progenitor, *O. breviligulata*, were shorter in averages of plant height than *O. sativa* and its progenitor, *O. perennis*, though the latter showed wider range of variation on plant height than the former. Although the number of strains used here were limited, our results agreed with the results of Morishima *et al.*[14]. Moreover, this difference might has affected largely the difference in yield component

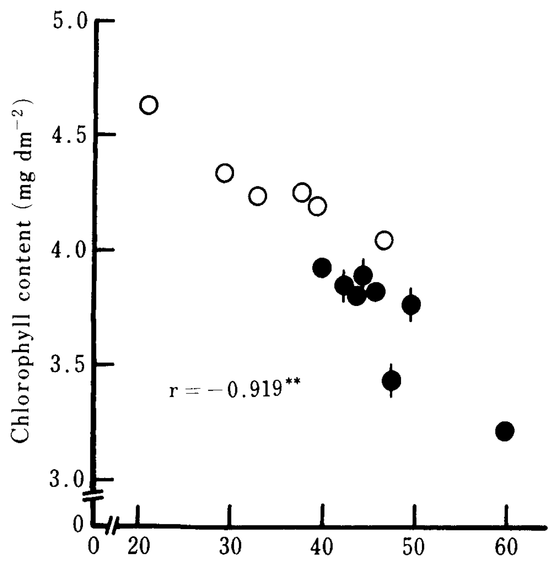

Fig. 3. Relationship between leaf area at heading time and mean chlorophyll content of upper three leaves at the same time. Symbols are the same as those shown in Fig. 2.

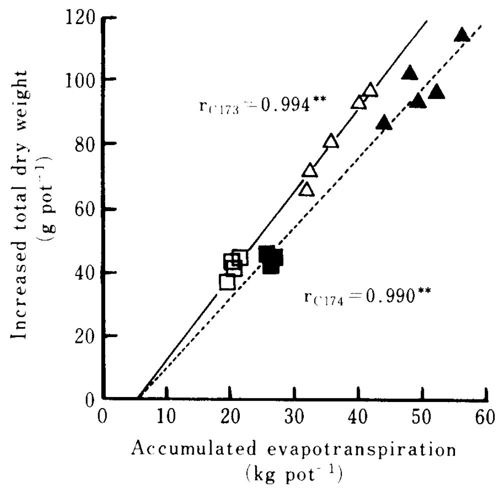

Fig. 4, Relationship between increased total dry weight and accumulated evapotranspiration from transplanting to harvesting. Each symbol of □ and △, and ■ and ▲ shows C173 (*O. sativa*) under no-manuring and manuring, and C174 (*O. glaberrima*) under the two conditions, respectively. r_{C173} and r_{C174} show correlation coefficients in C173 and in C174, respectively, and ** indicates that r is significant at 1% level. The other strains also showed r greater than 0.990.

between the two species. Omura[21] found a significant negative correlation between culm length and panicle number and interpreted this as a kind of correlated character. The same result was observed in the present experiments, regardless of difference in species (Fig. 5). Therefore, the collateral fact that short culm strains existed more in *O. glaberrima* than in *O. sativa* seems to produce the result that *O. glaberrima* was superior to *O. sativa* in panicle number. In fact, C173 (*O. sativa*) with shorter culm than other strains of *O. sativa* produced a large number of panicle also adds the weight for such supposition. At present, although long-culm varieties of *O. sativa* are practically used in West African countries, however, no accident will happen if the present level of fertilizer application is practiced[25], as we can infer from the historical transition of rice varieties in Japan accompanying with the change of amount of fertilizer[29].

A negative correlation between panicle number and grain number per head[28] is known to exist, and the same relationship was also observed here (Fig. 6). In the decrease in grain number per head with an increase in panicle number, however, *O. glaberrima* was not so conspicuous as *O. sativa*, and consequently, the former produced more number of grain per plant than the latter. In addition, the total grain number was correlated negatively with the percentage of ripened grains[11,32] and such a relationship was also found here (Fig. 7). That is a reason why the percentage of ripened grains was low in *O. glaberrima*. But, the percentage of ripened grains under the same grain number per plant tended to be higher in strains of *O. glaberrima*. And, such a tendency was conspicuous especially with fertilizer in the Experiment 2, where high temperature induced sterility. In this connection, the result that *O. glaberrima* showed less incidence of sterility than *O. sativa* is worth noting because high temperature beyond 36°C where sterility begins to occur[7] often happens in the tropics. Weight of one unhusked grain was significantly smaller in *O. glaberrima* than in *O. sativa*, but, Morishima *et al.*[13,14] examined the spikelet length and spikelet width of many strains on *O. glaberrima* and *O. sativa*, and reported that ranges of variation in two species overlapped in those characters. That also agreed with the result examined on all strains collected by the authors[18]. However, *O. sativa* collected in West Africa contains many strains of *javanica* type, which was characterized by

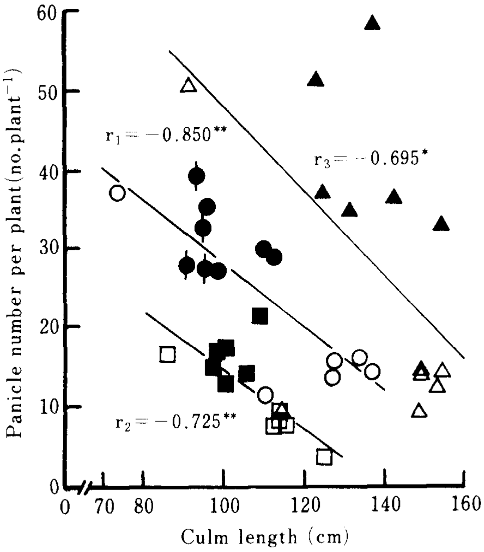

Fig. 5. Relationship between culm length and panicle number per plant. Each symbol of □ and ■ shows *O. sativa* and *O. glaberrima* under no-manuring in 1990, respectively. r_1, r_2 and r_3 show correlation coefficients in 1988, under no-manuring and manuring conditions in 1990, respectively. * and ** indicate that r is significant at 5% and 1% levels, respectively. The other symbols are the same as those shown in Fig. 2.

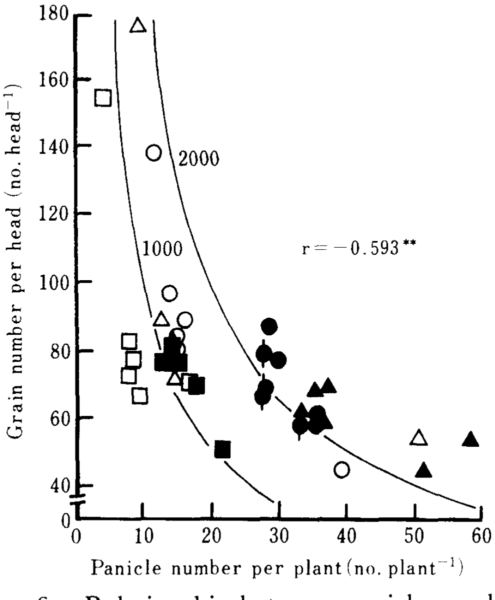

Fig. 6. Relationship between panicle number per plant and grain number per head. Two curved lines show isoquants of 1000 and 2000 in grain number per plant. The other symbols are the same as those shown in Fig. 5.

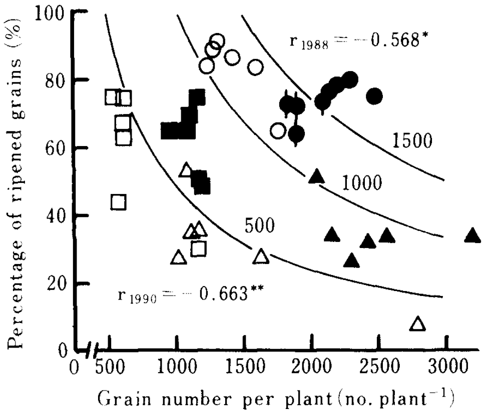

Fig. 7. Relationship between grain number per plant and the percentage of ripened grains. Three curved lines show isoquants of 500, 1000 and 1500 in ripened grains number per plant. r_{1988} and r_{1990} are correlation coefficients in 1988 and in 1990, respectively. The other symbols are the same as those shown in Fig. 5.

large grains[15,16,17], so the difference observed here is not due to the species difference. No evidence that *O. glaberrima* is inferior to *O. sativa* was found in grain yield, too.

The results obtained under isolated conditions such as in the present experiment do not always agree with those under community, because the photosynthesis of a community are easily influenced by the community structure[3,12]. However, Morishima *et al.*[13] also drew the same conclusion that *O. glaberrima* is not different in grain-yielding ability from *O. sativa*, from the field experiment. We also support their view[13]. Although *O. glaberrima* has a tendency that fertilizer is easy to promote vegetative growth[8], such a character is also observed in *indica* type of *O. sativa*[9,10,23]. Since *O. glaberrima* might have escaped from selection pressure for high-yielding ability during the long history as compared with *O. sativa*, and since the great diversity of rice growing environments exist in West Africa, there is enough ground for controversy on the agronomic potentiality of *O. glaberrima*. *O. glaberrima* was found to have smaller water use efficiency and R/T ratio at the harvesting time than *O. sativa*. These points will be discussed in the following paper.

Acknowledgement

We are much indebted to Prof. W. Agata of Kyushu Unversity for his careful reading of

the manuscripts.

References

1. Baba, I. 1954. Studies on rice breeding. Extra Issue of Japan. J. Breed. Vol. 4 : 167—184.
2. Ehara, K. 1980. General principles of crop production. Yokendo, Tokyo. 176—177***.
3. Horie, T. 1981. System ecological studies on crop -weather relationships in photosynthesis, transpiration and growth. Bull. Natl. Inst. Agric. Sci. A28 : 1—181*.
4. Katayama, T.C. 1987. General remarks on cultivated rice in Africa concerned. Kagoshima Univ. Res. Center S. Pac., Occasional Papers No. 10 : pp. 91—102.
5. ——— 1989. Current status of African rice culture -mainly, from the technological aspect. Internatl. Coop. Agric. For. 12(2) : 2—12**.
6. ——— 1990. Considerations on distribution of cultivated rice in Africa. Kagoshima Univ. Res. Center S. Pac., Occasional Papers No. 18 : pp. 193—200.
7. Kim, H.Y., T. Horie, H. Nakagawa, K. Wada, and Y. Nakano. 1993. Effects of elevated CO_2 concentration and high temperature on growth and yield of rice. 4. Effects on yield and its component. Jpn. J. Crop Sci. 62(Extra 1) : 188—189**.
8. Kubota, F., S. Okano, W. Agata and T.C. Katayama 1992. Responses of dry matter production and photosynthesis in *Oryza glaberrima* Steud. and *Oryza sativa* L. introduced from West Africa to the concentrations of culture solution. Jpn. J. Crop Sci. 61 : 207—212*.
9. Maruyama, S., N. Kabaki and K. Tajima 1988. Growth response to nitrogen in Japonica and Indica rice varieties. I. Varietal differences in the rate of increase in straw weight and number of spikelet due to nitrogen fertilization. Jpn. J. Crop Sci. 57 : 470—475*.
10. ——— and K. Tajima 1988. ———. II. Differences in the rate of increase in culm length and leaf area due to nitrogen fertilization. Jpn. J. Crop Sci. 57 : 692—698*.
11. Matsushima, S. 1957. Analysis of developmental factors determining yield and yield prediction in lowland rice. Bull. Natl. Inst. Agric. Sci. A5 : 1—271*.
12. Monsi, M. und Saeki, T. 1953. Über den Lichtfaktor in den Pflanzengesellschaften und seine Bedeutung für die Stoffproduktion. Jpn. J. Bot. 14 : 22—52.
13. Morishima, H., K. Hinata and H.I. Oka 1962. Comparison between two cultivated rice species, *Oryza sativa* L. and *O. glaberrima* Steud. Jpn. J. Breed. 12 : 153—164.
14. ———, ——— and ——— 1963. Comparison of modes of evolution of cultivated forms from two wild rice species, *Oryza breviligulata* and *O. perennis*. Evolution 17 : 170—181.
15. Nakagama, A., A. Sumi and T.C. Katayama 1988. On distribution and morphology of cultivated rice in Nigeria. Bull. Exp. Farm Fac. Agric. Kagoshima Univ. 13 : 29—39.
16. ———, ——— and ——— 1988. On distribution and morphology of cultivated rice in Liberia. Bull. Exp. Farm Fac. Agric. Kagoshima Univ. 13 : 41—50.
17. ——— , M. Ngning, A. Sumi and T.C. Katayama 1988. On distribution and morphology of cultivated rice in Senegal. Bull. Exp. Farm Fac. Agric. Kagoshima Univ. 13 : 51—63
18. ——— and T.C. Katayama 1990. Geographical distribution and grain-type of cultivated rice, *Oryza sativa* L. and *Oryza glaberrima* Steud., in Africa. Kagoshima Univ. Res. Center S. Pac., Occasional Papers No. 18 : pp. 201—209.
19. Nozaki, M. 1989. Rice culture in West Africa. Internatl. Coop. Agric. For. 12(2) : 13—31**.
20. Nyanteng, V.K. 1987. Rice in West Africa ; Consumption, Imports and Production with Projections to the Year 2000. WARDA, Monrovia. 1—40.
21. Omura, T. 1970. Correlations between characters of local rice varieties, the characteristics of local varieties in Japan. Agriculture, Forestry & Fisheries Research Council Secretariat, Tokyo. 135—136***.
22. Osada, A. 1966. Relationship between photosynthetic activity and dry matter production in rice varieties, especially as influenced by nitrogen supply. Bull. Natl. Inst. Agric. Sci. D14 : 117—188*.
23. Otoo, E. and A. Osada 1984. Different response between Indica and Japonica rice varieties to nitrogen fertilizer as expressed by physiological and morphological characters. Jpn. J. Trop. Agric. 28 : 13—24.
24. Portères, R. 1956. Taxonomie agrobotanique des riz cultives *O. sativa* Linnē. et *O. glaberrima* Steudel. J. Agr. Trop. Bot. Appl. 3 : 341—856.
25. Sumi, A. and T.C. Katayama 1989. A role of fertilizer application to yield increase in Central and West African countries. Mem. Fac. Kagoshima Univ. 25 : 65—73.
26. ———, ——— and A. Nakagama 1990. Effect of fertilizer application on dry matter and yield productions of *Oryza sativa* L. and *Oryza glaberrima* Steud. collected in west Africa (prediction). Rep. Kyushu Br. Crop Sci. Soc. Japan 57 : 78—82**.
27. ———, ——— and T. Takeda 1992. Rice culture and climate in West African countries. Kishoriyou-Kenkyu (Applied Meteorology) 5 :

35—39***.
28. Suzuki, M. 1980. Studies on the growth characteristics of rice plants in warmer regions of Japan viewed from the aspect of dry matter production. Bull. Kyushu Natl. Agric. Exp. Stn. 20 : 429—494*.
29. Takeda, T., M. Oka and W. Agata 1984. Characteristics of dry matter and grain production of rice cultivars in the warmer part of Japan. II. Comparison of grain production between old and new types of rice cultivars. Jpn. J. Crop Sci. 53 : 12—21*.
30. Takezawa, S. 1984. Rice in Africa. Q. Anthropol. 15(1) : 66—116***
31. Wakatsuki, T. 1991. Rice culture under non-paddy field and small-plot quasi-paddy field in inland valley swamps in monsoon West Africa. Agric. Tech. 13 : 31—67***.
32. Wada, G. 1969. The effect of nitrogenous nutrition on the yield-determining process of rice plant. Bull. Natl. Inst. Agric. Sci. A5 : 27—167*.

* In Japanese with English abstract.
** In Japanese.
*** Translated from Japanese by the present authors.