Competitiveness of Four Rice Cultivars against Barnyardgrass,
Echinochloa oryzicola Vasing, with Reference to Root and Shoot Competition

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Abstract: Four cultivars of rice (Oryza sativa L.) different in plant stature were grown on a paddy field, fairly fertile without nitrogen application, with or without barnyard grass, Echinochloa oryzicola Vasing, in the middle of the rice rows. The reduction of the growth variables of the four cultivars by competition with E. oryzicola was examined. The effect of a veneer board inserted in the soil between the rice and barnyardgrass rows was also examined to evaluate the growth reduction by shoot competition (WCc) and root competition (WCr) separately. On the average, the reduction of top dry weight (DWtop) by competition with weed (full competition, WCc) and by WCr increased with the time during the early growth period. Thereafter, the reduction of DWtop by WCr decreased steeply and instead the reduction by WCc increased and became a primary factor of the reduction by WCc in the late growth period. Nitrogen accumulation in the top (Ntop) tended to be reduced at a higher rate than DWtop by WCc. The cultivar difference in the rate of DWtop reduction by WCc was largest at maturity ranging from 0.22 in Ch86 (very tall indica) to 0.45 in Taichung65d47 (short japonica), and was intermediate in Taichung65 (moderately tall japonica) and Takanari (moderately short indica). The reduction of DWtop and Ntop by WCc in all cultivars almost fully accounted for that by WCc at maturity and closely correlated with the height of rice plant. Although the rate of DWtop reduction by WCc before heading significantly differed among cultivars (0.13 0.28), it did not contribute to the rate of DWtop reduction by WCc at maturity (0.01 0.06). These results indicated that shoot competition was a more important factor to cause cultivar difference in the reduction of final biomass by competition with E. oryzicola. Considering its great contribution to WCc during the early growth period especially for Ntop, WCc might be an important factor in the competition with weed of rice cultivars under crucially nitrogen-limited conditions.

Key words: Competitive ability, Echinochloa oryzicola Vasing., Nitrogen accumulation, Rice, Root competition.

Competition with weeds is an important constraint of rice production, where chemical control of weeds can not be readily practiced due to either economical reasons or the environmental concern of the society.

A substantial difference in competitiveness against weeds is known to exist among genotypes of Oryza sativa (Jennings and Aquino, 1968; Garrity et al., 1992; Fischer et al., 1995; Fischer et al., 1997; Tachibana and Watanabe, 1998; Tachibana et al., 1999) and between O. sativa and O. glaberrima (Fofana, et al., 1995; Johnson et al., 1998). In general, tall and leafy genotypes are considered to be more competitive than short genotypes and the competitiveness is attributed to the plant traits that reduce light absorption by weed plants. However, root separation experiments showed great contribution of root competition to the whole plant competition between rice and Echinochloa species (Assemat et al., 1981; Perera, et al., 1992; Gibson et al., 1999). Fofana et al. (1995) also suggested that the extensive root system might be attributed partly to the high competitiveness of glaberrima rice. In fact, root competition has been considered to be a more important process than that of shoot competition in the interaction between various plant species (Wilson, 1988). The ability of rice genotypes to suppress weeds, therefore, would be better evaluated by considering both the root and shoot competitions.

In lowland paddies, root and shoot competition in the field would be the competition for soil nutrients and light, respectively. Among soil nutrients, nitrogen is usually the most growth-limiting factor. In the field with an extremely infertile soil, we found that a cultivar with vigorous canopy development exhibited superior growth than an improved cultivar through both greater light interception and nitrogen accumulation (Suzuki et al. 2000). Such a cultivar is normally expected to show high competitiveness against weeds, but the relative contribution of shoot and root competition is yet to be examined.

This study was conducted to determine the plant traits of rice for competitiveness against weeds. Special attention was paid for the contribution of root and shoot
competitions to the whole competition, and for the difference in the competitiveness against weeds among rice cultivars with different plant statures.

**Materials and Methods**

Four cultivars of rice (*Oryza sativa*) with different plant heights were used; namely Ch86, a very tall indica; Takanari, an improved cultivar of moderately short indica; Taichung65, a moderately tall japonica; and Taichung65d47, a short isogenic line of Taichung65. Ch86 is a local variety from Jiangsu province, China, and exhibited markedly fast canopy development under the crucially nitrogen–limited environment in Northeast Thailand (Suzuki et al. 2000). An inbred strain of *Echinochloa oryzicola*, which is an obligate weed in paddy rice production, was used as the competitor of rice.

The experiment was conducted on a paddy field of sandy loam fluvial soil at Kyoto University, Japan. In view of the performance of rice in the previous year, the soil of this field was fairly fertile in N, producing at most 1300 g m⁻² of rice biomass (Suzuki et al., 2000). Thus the field was not fertilized with nitrogen but with 10 g m⁻² of phosphate (P₂O₅) and potassium (K₂O) before planting, to make the experimental condition be within the ordinary range of nitrogen supply.

Competitive interactions between different plant species would normally be analyzed by the replacement experiment with at least the one versus zero and the opposite controls and the one-versus-one plant mixed culture (Loomis and Connor, 1992). But the replacement design was not employed in this study, because this study focused on competitive ability of rice cultivars against *E. oryzicola* rather than full feature of inter–specific interaction. To detect how much rice cultivars were affected by the existence of *E. oryzicola* as neighboring competitor, simple treatments with and without insertion of *E. oryzicola* row between rice rows were laid out as described below.

Twenty-seven-day-old rice seedlings were transplanted on 24 May, 2000, at one plant per hill in rows 30 cm apart with 20 cm intra-row spacing and 6 m in length. Four plots were established for weed competition (WC), non-competition (NC), WC with root separation (WC₀) and NC with root separation (NC₀). They were arranged by the split plot design with two replications with cultivar and competition / board treatment as main and sub plots, respectively. In the WC and WC₀ plots, seedlings of *E. oryzicola* at the same age were intercropped in the middle of rice rows (Fig. 1) on the same date with rice. Thus, the distance between rows of rice and *E. oryzicola* was 15 cm. The intra-row spacing of *E. oryzicola* was also the same as that of rice. The root separation was achieved by 5 mm–thick vencer boards inserted vertically to a 24 cm–depth in soil at the middle of rice and *E. oryzicola* rows in WC₀ plot. NC and NC₀ plots consisted of two rice rows, and WC and WC₀ plots two rows of rice and a single row of *E. oryzicola*. One week after planting, the field was treated with a herbicide to suppress weeds carefully, except for WC and WC₀ plots, where the emerging weeds were hand–removed.

Six and three plants of rice and *E. oryzicola*, respectively, were harvested from each replicate at mid–tillering, panicle initiation, mid–reproductive growth and heading stages, and eight rice and four *E. oryzicola* plants were harvested at maturity. The plant material was divided into the organs of leaf blade, leaf sheath + culm and grain, if existed, for which leaf area and dry weight were determined. The plant samples were then ground and subjected to the analysis of nitrogen content by the Kjeldahl method.

The rate of growth reduction caused by full competition with weed (WC₀) and that by shoot competition (WC) were calculated as follows.

![Fig. 1. Layout of mono cropping of rice (NC and NC₀) and intercropping of rice and *Echinochloa oryzicola* (WC and WC₀). I and V represent rice and *E. oryzicola* plants, respectively. NC, no competition; NC₀, no competition but with board; WC, competition with weed; WC₀, competition with weed but separated with board.](image)

1) Collected by Y. Satoh, Faculty of Agriculture, Shizuoka Univ., Japan and its name is from the registration code in his collection.
2) Provided by Y. Yamasue, Graduate School of Agriculture, Kyoto Univ. Japan, for which the growth characteristics were described in detail by Yamasue et al. (1997a, b).
Table 1. Plant traits and DW and N content in the top at maturity of the four rice cultivars under no competition (NC) and full competition with *Echinochloa oryzicola* (WC). The values for the four neighboring *E. oryzicola* also are presented.

<table>
<thead>
<tr>
<th>Cultivar</th>
<th>Days to heading</th>
<th>Plant length at heading</th>
<th>DW in the top at maturity</th>
<th>N content in the top at maturity</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>d</td>
<td>cm</td>
<td>NC, WC, <em>E. oryzicola</em> under WC</td>
<td>NC, WC, <em>E. oryzicola</em> under WC</td>
</tr>
<tr>
<td>Takanari</td>
<td>76</td>
<td>96 96 105</td>
<td>1302 778 588</td>
<td>8.91 6.16 1.41</td>
</tr>
<tr>
<td>Ch86</td>
<td>78</td>
<td>149 144 123</td>
<td>1273 995 348</td>
<td>9.60 6.72 1.29</td>
</tr>
<tr>
<td>Taichung65d47</td>
<td>78</td>
<td>84 84 101</td>
<td>1282 700 555</td>
<td>10.62 5.98 1.41</td>
</tr>
<tr>
<td>Taichung65</td>
<td>79</td>
<td>112 117 116</td>
<td>1383 866 763</td>
<td>10.39 6.76 2.41</td>
</tr>
</tbody>
</table>

LSD (0.05) - 14 20 15 ns 151 220 ns ns ns

Table 2. Grain yield and harvest index (HI) of the four rice cultivars under no competition (NC) and full competition (WC) with *Echinochloa oryzicola*.

<table>
<thead>
<tr>
<th>Cultivar</th>
<th>Grain DW* g m⁻²</th>
<th>HI</th>
<th>Rate of reduction**</th>
<th>NC</th>
<th>WC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Takanari</td>
<td>738 459</td>
<td>0.38 0.566 0.590</td>
<td>0.16 0.413 0.445</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ch86</td>
<td>527 443</td>
<td>0.47 0.495 0.452</td>
<td>0.45 0.489 0.457</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Taichung65d47</td>
<td>600 317</td>
<td>0.23 0.103 0.021</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Taichung65</td>
<td>676 395</td>
<td>0.23 0.103 0.021</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

LSD (0.05) 151 84 0.23 0.103 0.021

*Rough grain. **Rate of reduction of grain DW by WCf (full competition).

Results

Days to heading was similar among the four rice cultivars (Table 1), and *E. oryzicola* began heading 81 days after planting (DAP). The plant height of rice was in the order of Ch86 > Taichung65 > Takanari > Taichung65d47, with a 65 cm difference between the highest and the lowest. The plant height of *E. oryzicola* at heading varied from 101 to 123 cm depending on neighboring rice cultivars and was higher than the rice cultivars except for Ch86. On the other hand, the plant height of rice cultivars was not affected by the presence of *E. oryzicola*.

Neither dry weight of the top (DWₜₐₜ) nor nitrogen accumulated in the top (Nₜₐₜ) at maturity significantly varied among cultivars under NC (Table 1). However, under full competition with *E. oryzicola* (WCₜ), there was a significant cultivar difference in DWₜₐₜ and Ch86 had the heaviest DWₜₐₜ. Nₜₐₜ under WCₜ did not vary among cultivars.

The grain DW under NC was heaviest in Takanari (738 g m⁻²) and lightest in Ch86 (527 g m⁻²), and harvest index (HI) also was highest in Takanari and lowest in Ch86 (Table 2). Due to WCₜ, grain yield was reduced by 16% in Ch86 and by 47% in Taichung65d47. Under WC, Takanari and Ch86 exhibited higher yields than Taichung65d47, but the grain yield was not related to HI.

The rates of reductions of biomass accumulation by WCₜ, WCₕ and WCₘ at various stages in the four rice cultivars are shown in Fig. 2. In all cultivars, the rate of DWₜₐₜ reduction by WCₜ rapidly increased up to around 0.4 within the first 50 DAP (Fig. 2A). During this period, the reduction by WCₕ showed larger contribution than WCₜ except for Taichung65d47 (Figs. 2B, 2C). The rate of reduction by WCₜ rapidly declined after 50 DAP. By contrast, the reduction of DWₜₐₜ by WCₜ increased slowly but consistently during the growth period, and it became a primary factor of the reduction by WCₜ at the late growth stage (Fig. 2C). The values shown in Fig. 2 are the integrated values for the period from planting to each measurement time. Therefore, the reduction by WCₕ and WCₘ at maturity (the last measurement) represents the reduction by them for the whole growing period. The mean rate of DWₜₐₜ reduction by WCₕ at maturity (0.34) in four cultivars was far greater than that by WCₜ (0.04) and close to that by WCₘ (0.36).

Although the reductions of DWₜₐₜ and Nₜₐₜ by WCₜ, WCₕ and WCₘ were more or less similar in all the cultivars, significant difference was detected in some measurements. The rates of DWₜₐₜ reduction by WCₜ at
50 DAP and maturity varied with the cultivar, and the rate of the reduction at maturity was more evident ranging from 0.22 in Ch86 to 0.45 in Taichung65d47 (Fig. 2A). The cultivar difference in \(\text{DW}_{\text{top}}\) reduction by WC\(_{t}\) was detected at the two measurements before heading (Fig. 2B). In these cases, Ch86 was most affected by WC\(_{t}\) (0.28) and Taichung65d47 least affected (0.13) (mean of 50 and 63 DAP). The rate of \(\text{DW}_{\text{top}}\) reduction by WC\(_{t}\) at maturity was small ranging from 0.01 to 0.06 with no cultivar difference. The cultivar difference in the reduction by WC\(_{s}\) was largest at maturity ranging from 0.21 to 0.43 (Fig. 2C).

As shown in Fig. 3, the rate of \(\text{N}_{\text{top}}\) reduction by WC\(_{t}\) did not largely change throughout the growing period, and was around 0.4. The rate of \(\text{N}_{\text{top}}\) reduction by WC\(_{t}\) tended to decline after 50 DAP, and instead the rate of reduction by WC\(_{s}\) gradually increased up to the level similar to that by WC\(_{t}\) at maturity. Thus, the relative contribution of WC\(_{t}\) to WC\(_{t}\) was greater than that of WC\(_{s}\) until 50 – 63 DAP, but was similar to that of WC\(_{s}\) at maturity.

Although the rate of \(\text{N}_{\text{top}}\) reduction by WC\(_{t}\) varied with the cultivar, the cultivar difference at different growth stages was not consistent (Fig. 3A). At maturity, the rate of \(\text{N}_{\text{top}}\) reduction by WC\(_{t}\) was largest in Taichung65d47, but before heading, it was larger in Ch86 and Taichung65 than in Taichung65d47. The reduction of \(\text{N}_{\text{top}}\) by WC\(_{t}\) tended to be larger in Takanari than in the other cultivars, but the difference was significant only at heading.

The difference between plant heights of *E. oryzae* and the neighboring rice cultivars is shown in Fig. 4. The difference varied with the cultivar, but only Ch86
was higher than *E. oryzicola* from 60 to 120 DAP, the difference being largest at the heading stage. This may be why the reduction of DW<sub>top</sub> by WC<sub>T</sub> and WC<sub>S</sub> was smaller in Ch86 than in other cultivars during this period (see Fig. 2A, C).

**Discussion**

The rate of the reduction of DW<sub>top</sub> and grain DW by competition with *E. oryzicola* varied among cultivars from 0.22 to 0.45 (Fig. 2) and from 0.16 to 0.47 (Table 2), respectively. Although significant cultivar differences in the reduction of DW<sub>top</sub> by WC<sub>T</sub> were observed in the early growth stage, these differences were not reflected in the reduction of either DW<sub>top</sub> or grain DW at maturity. Ch86 that showed the largest reduction of DW<sub>top</sub> by WC<sub>T</sub> before heading showed the highest final yield under WC<sub>T</sub>. Perera et al. (1992) who studied three genotypes with root separation experiments indicated that the reduction of rice biomass by the presence of *E. crus-galli* was evidently increased by root competition more than by shoot competition in all rice genotypes, and that the genotypes most affected by competition with weeds exhibited least root competition. The results of the present study, however, indicated that the shoot competition was a more important factor in the differential yield reduction by weed competition in rice cultivars.

The reason for this inconsistency between the two studies could be the difference in the traits of competitor weeds used in the early growing period. Under the one-versus-one mixed planting rate, the strain of *E. crus-galli* observed by Perera et al. (1992) exhibited more vigorous growth than neighboring rice throughout the whole growing period, while, under a similar planting pattern, *E. oryzicola* showed more vigorous growth only in the latter half of growing period (Yamasue et al., 1997b). The nitrogen accumulation pattern also varies among weed species and genotypes and this may also affect the relative importance of root and shoot competition. A strain of *E. oryzicola* observed in Kyushu continued to accumulate more nitrogen than the neighboring rice plants (Noda et al., 1968). In contrast, the strain of *E. oryzicola* used in this study ceased nitrogen accumulation after heading stage in all the plots while the neighboring rice plants continued (data not shown). This might have caused the narrower variation among cultivars in the reduction of N<sub>top</sub> than that of DW<sub>top</sub> (Figs. 2 and 3). In addition, although no nitrogen fertilizer was applied, the amount of soil nitrogen accumulated in rice plants (NC) was as large as 10 g m<sup>-2</sup> in the present experiment (Table 1). This is a value nearly equivalent to that for rice fertilized with 10 g m<sup>-2</sup> nitrogen on the ordinary paddy soil in the same region (Shiraiwa et al., 1997), indicating that this experiment was conducted on a soil quite fertile especially in nitrogen. This also may have mitigated the competition for nitrogen resource in the soil and/or accelerated shoot competition due to the large amount of leaves produced by the adequate supply of nitrogen. Referring to various competition studies, Wilson (1988) noted that competition for the soil resources, mainly N, tended to lose its importance as the supply of resources increased. Therefore, the result of this experiment, particularly the greater contribution of shoot competition than root competition, is associated with the experimental condition and the traits of the weed plant used.

Both the cultivar difference and seasonal change of the growth of Ch86 under WC<sub>S</sub> were closely correlated with the difference in plant height of rice and *E. oryzicola*. The correlation between plant length and LAI at heading of four cultivars in NC also was high (r = 0.95, n = 4). Thus differential light interception by the canopy is no doubt an important factor for the shoot competition, as has been frequently documented and recently examined in detail by Tachibana and Watanabe (1998) and Tachibana et al. (1999).

Although the shoot competition was a primary factor in the reduction of the final yield of rice, the major contribution of root competition in the full competition during the early growth period is not negligible. During early growth period, WC<sub>T</sub> in almost cultivars showed a greater contribution to DW reduction by full competition than WC<sub>S</sub> did and this was further evident for N<sub>top</sub> reduction. As discussed above, the root competition may become a dominant factor when soil nitrogen resource is crucially limited or when the rice competes with a weed that explores soil resources more aggressively. The cultivar variation in the reduction of DW<sub>top</sub> and N<sub>top</sub> by WC<sub>T</sub> (Figs. 2B and 3B) was not related to plant height, suggesting that the tall and leafy traits do not necessarily participate in root competition. There have been some studies showing that some semidwarf cultivars were notably competitive against weeds (Fischer et al., 1997; Tachibana and Watanabe, 1998). Although the mecha-
nisms have not been fully elucidated, this fact implies the involvement of root characteristics in the cultivar difference in competitiveness. In a hydroponic culture of divergent 63 cultivars, one of the authors observed a wide variation of the early root growth (Shiraiwa and Watatsu, 2001). In that study, Ch86 was ranked relatively inferior in root growth, which is consistent with the large reduction of DW of by WC in this cultivar before heading in the field. Thus, it is suggested that there would be an opportunity to improve the competitiveness of rice through exploring traits related to root competition.

In conclusion, the competitiveness of rice cultivars against E. oryzicola in terms of final DW and yield was primarily related to shoot competition under the fairly fertile soil condition. However, considering its large contribution during the early growth period, root competition may also be an important factor in competitions under more nitrogen-limited environment and/or in competition with more aggressively root-growing weeds.

Acknowledgments

The authors wish to thank Drs. Yuji Yamase of Kyoto University and Yoichiro Sato of Shizuoka University for providing the materials. They are also grateful to Dr. Yamase and Dr. Tatsu Tominaga of Kyoto Prefectural University for valuable comments for conducting this study.

References


*In Japanese.