Using Computers to Design Weed-Competitive Rice Plants for the Sahel

WEEDS ARE a major factor in reducing rice yields in West and Central Africa. Now that new rice plant types are available through the interspecific breeding activities, WARDA has adapted a weed-competition model to learn more about what makes rice plants good competitors.

Total rice consumption in the Sahel has grown tremendously in recent decades as a result of population growth and increased per-capita consumption, especially in urban centers. Senegal has the largest share of rice consumption among the Sahelian countries, and about 75% of the rice consumed there is imported. Major investments have been made to help meet demand, yet yields remain relatively low (about 4 tonnes/ha). Inadequate weed management is one of the most important factors reducing rice yields in Senegal (*see*, for example, point 5 of Figure 1, page 00: not weeding a field of a popular improved variety results in 50% yield loss).

Relatively good soil, intense sunlight, high temperatures throughout most of the year, and the assured availability of water from irrigation, create ideal conditions for weeds to grow in abundance. As irrigated rice in the Sahel is mostly direct-seeded rather than transplanted, weeds and rice start competing as seedlings and yield losses tend to be greater than in transplanted systems. Studies conducted by WARDA on farmers' fields in 1998 demonstrated that the benefits from improved weed control were in the order of 1 t/ha, or almost 25% above farmers' practice (*see* 'Soil Nutrients and Fertilization in Irrigated Rice in the Sahel,' *Annual Report 1998*, pages 16–22). Yet, farmers tend to wait until weeds are clearly visible and competing with rice before they control them. When herbicides are applied late, weed control is less effective as the weeds become less sensitive to herbicides as they grow. The extended periods of competition—both before weed control and afterwards because of reduced efficiency of control measures—cause increased crop losses.

Rice cultivars that are more competitive with weeds would be appropriate in all the rice ecologies of the region, including the Sahel irrigated systems. Access to the *Oryza glaberrima* gene-pool through the development of progeny of interspecific hybrids (the NERICA rices) has increased the scope for the development of low-management (low input) rice plant types. "One of the most important features of the NERICAs," explains WARDA Deputy Director for Research Monty Jones, "is the weed competitiveness that they have inherited from the *Oryza glaberrima* parent. In fact, that was one of the main targets of the whole interspecific breeding program." Studies have shown that, compared with traditional *Oryza sativa* varieties, *O. glaberrima* produces more biomass and tillers, has higher leaf indices (for definitions of indices, *see* Box), and puts more of its increasing biomass into leaves in the earlier stages of growth. Subsequently,

Plant growth indices used in INTERCOM

This story refers to three indices related to plant growth characteristics, and that are used in WARDA's weed-competitiveness studies and in the INTERCOM model adapted for Sahel irrigated systems.

Leaf Area Index, LAI is the total leaf area of a plant divided by the amount of ground it occupies; it is therefore a direct function of plant-spacing in the field. LAI was already known to be a good indicator of weed-competitiveness before WARDA started these studies.

Specific Leaf Area, SLA is leaf area per unit leaf weight. Thus, a thin leaf has a high SLA, and a thick leaf has a lower SLA. A thin leaf (high SLA) presents a bigger area to absorb sunlight than a thicker leaf (low SLA) of the same weight does. So, for the same weight, a thin-leaved plant provides more shading to smother weeds than a thick-leaved one does. This index is measured (or simulated) for each leaf on the plant for the purposes of INTERCOM modeling. Like LAI, SLA was known to be a good indicator of weed-competitiveness before these studies commenced.

Relative Growth Rate of Leaves, RGRL is the daily growth rate of a plants' leaves expressed as a percentage, in the early growth stages (until LAI = 1).

it was shown that, in a wider range of cultivars, leaf indices and tillering capacity were predictive of weed-competitiveness. The early NERICA lines were better adapted to upland conditions, but recent developments have generated plant material likely to be suited to lowland conditions. With these materials now available, it is appropriate to examine the impact that different plant types could have on losses due to weed competition.

Mathematical crop simulation models can be valuable in giving us better insight into the complex mechanisms of crop–weed interactions. Furthermore, these models can be used as a tool to guide plant breeders in the design and evaluation of new plants.

"Our starting point," explains Weed Scientist David Johnson, "was INTERCOM, a computer model—developed by the International Rice Research Institute (IRRI) and Wageningen Agricultural University—that uses ecological and physiological parameters to simulate competition between a crop and weeds in the field." The model was already in use at WARDA headquarters, and being adapted for upland rice (*see* 'Donor Country Profile: Canada,' in this Report, page 47). "What was needed," Johnson continues, "was to reconfigure the model for Sahelian irrigated rice conditions with suitable varieties and weeds, so that we could then manipulate the plant type as required."

In the second half of 1999, Dutch MSc student Petra Hogervorst, visited the Sahel Station from Wageningen Agricultural University. Her task was to collect the data necessary to configure INTERCOM for irrigated rice in the Sahel. To study the effect of weed competition on rice growth, rice and weeds were grown in mixed populations at different densities of weed infestation. The rice variety used was the now-popular Sahel 108 (*see* Box 'Sahel 108 and other Sahel rice varieties,' page 11), while two common weeds were chosen to represent the main weed groups that infest irrigated rice fields in the Sahel—*Echinochloa colona* for the typical grass weeds, and *Cyperus difformis* for the perennial sedges. Hogervorst determined growth and development parameters of the two weed species and the rice variety—including plant height and the leaf indices. The data were then 'plugged' into INTERCOM to provide the model for rice–weed competition in irrigated systems in the Sahel.

In order to validate the newly-configured model, rice–weed competition experiments were conducted in farmers' fields in the Senegal River delta (actually within a 1-km radius of WARDA's Sahel Station, at N'diaye, Senegal) in the 1999 wet season and the 2000 dry season. These experiments were conducted by Senegalese MSc student Daouda M'Bodj, from the *Ecole nationale des cadres ruraux de Bambey* (ENCR). The experimental treatments consisted of different periods of competition to which the rice crop was exposed to identify critical periods of competition. More precisely, weeds were allowed to grow from the day the rice was sown for a certain period

Souleymane Diallo (ISRA, far right), Marco Wopereis (WARDA, center right) and Yaya Sané (WARDA, far left) discuss weed–rice competition trials with Daouda M'Bodj at WARDA's Sahel Station, N'diaye, Senegal

(14, 28, 42, 56, 70 days), after which the field was kept free of weeds by hand-weeding. In addition, two 'controls' were maintained: one that was kept weed-free throughout the growing season, and one that was not weeded at all. The experiments were conducted on five farmers' fields in the wet season, and on seven farmers' fields in the dry season. Again, fields were direct-seeded with pre-germinated seed of Sahel 108.

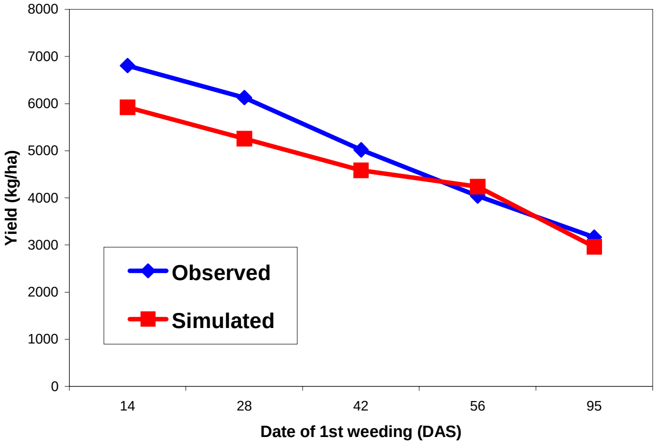
When the field data were plotted in comparison with the data simulated by the model, the two lines were very close together (Figure 6). Thus, INTERCOM is able to predict the essential features of rice–weed competition in the Sahelian context. With no weed control, yields dropped to 3.2 t/ha, or 50% of those kept weed-free from 14 days after sowing. As the date of first weeding is delayed, there is a steady decline in yield; in other words, the later weeding is started in the cropping cycle the greater the yield loss. This serves to illustrate the importance of early weeding. Increasing periods of weed competition also decreased the numbers of tillers and panicles per unit area. Deviations between simulated and observed yields occurred where weeding started earlier in the crop cycle—early weeding had a greater influence on crop performance than the model predicted. The accurate simulation of the field-trial results validated the use of the model for the subsequent modeling studies.

Modeling

INTERCOM was then used to analyze how the rice crop would have reacted had a different rice plant type been grown. "This is the beauty of modeling!" enthuses Agronomist Marco Wopereis. "It allows experimenting using the computer—once the model is properly validated." The objectives were to obtain a better understanding of weed competition in irrigated rice cropping systems in the Senegal River valley through the use of a computer model and to evaluate how new plant types would be affected by competition from weeds.

"We know that *Oryza glaberrima* competes better with weeds than does *O. sativa*," says Wopereis. "Given what we know about the *O. glaberrima* plant type, and

Figure 6. Validation of the calibrated INTERCOM model: Effect of weed competition on rice yield (actual data from wet season 1999 v INTERCOM-simulated data)



Note: 95 DAS (days after sowing) = no weeding.

our theories of what factors influence weed-competitiveness, plant height and the leaf indices were the obvious targets for manipulation within INTERCOM to assess the value of different plant types."

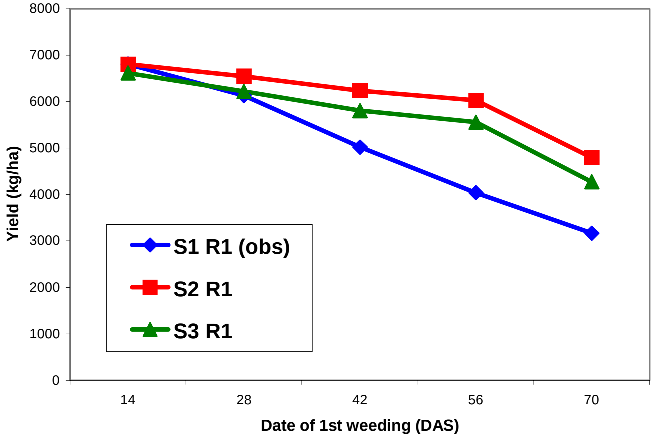
"Higher values of specific leaf area (SLA) [*see* Box, page 40] enable a plant to produce a greater leaf area with a given biomass," continues Wopereis, "and this is an advantage during the early stages of growth when competition for light is important." However, high values of SLA become a disadvantage later in the crop's development as plants 'over-produce' leaves. Once there are about four layers of leaves (i.e. LAI reaches 4), about 95% of solar radiation is intercepted by leaves. After that, having more leaves does not help! So, the ideal situation is to have high SLA early in the growth cycle, but low SLA later on.

Results—what INTERCOM tells us

When we compare only SLA differences between the three plant types, the model predicts that both the *glaberrima* and the intermediate plant types are more weed-competitive than the *sativa* type (Figure 7), with the difference becoming more marked as first weeding is delayed later in the season. If we then modify the *glaberrima* and 'interspecific' types so that they have faster-growing leaves in the early growth phase (Figure 8), the improvement in weed-competitiveness is even more marked—the interspecific giving yields 70% higher than Sahel 108 when left unweeded for the first 70 days after seeding.

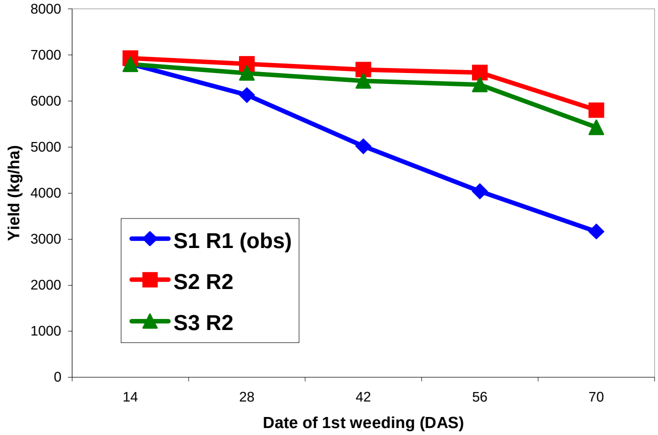
Finally, we compared the three plant types (as represented by SLA figures) at low plant density typical of farmers' fields in the Senegal River valley and delta (Figure 9). Such low plant density may be a result of low seeding rate, or poor germination or crop establishment. All three plant types suffer serious yield losses from competition with weeds, mainly as a result of the rice crop being unable to close the canopy and shade the weeds from the sunlight. Once again, however, when first weeding was delayed, the interspecific (S3) and *glaberrima* (S2) plant types gave more yield than the *sativa* type.

Figure 7. Simulated effect of SLA on yield, as a direct result of its effect on weed competitiveness



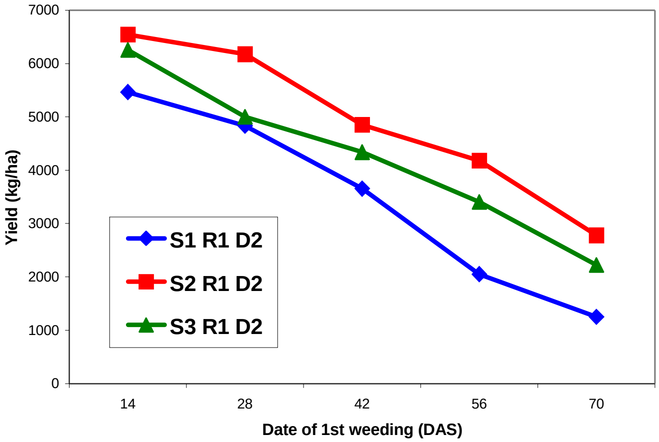
Notes: S1, S2, S3 = SLA type: *O. sativa* (Sahel 108), *O. glaberrima*, interspecific; R1 = RGRL of *O. sativa* (Sahel 108) type.

Figure 8. Simulated combined effect of SLA and increased RGRL on yield, as a direct result of their effect on weed competitiveness



Notes: As Fig. 2; R2 = RGRL of hypothetical plant type with high RGRL.

Figure 9. Simulated effect of reduced plant stand (120 plants/m^2) on yield (as a direct result of its effect on weed competitiveness) of 3 plant types: note almost uniform yield reduction regardless of plant type.



Notes: As Fig. 2; D2 = planting density of 120 plants/m^2.

"When we tested the effect of plant height," says Wopereis, "the results were not spectacular." The simulated plant that was 10% taller than 'normal' was not significantly more weed-competitive than the 'normal' height plant.

Conclusions—the value of modeling

The simulations showed the importance of weed competitiveness in fields with heavy weed infestation. INTERCOM can be used to predict what an increase in leaf indices or other parameters (compared to a 'standard' variety like Sahel 108) would mean given a certain weed pressure in the farmer's field. Thus, those parameters that directly affect weed-competitiveness and yield can be targeted in breeding activities.

"The indices are relatively easy to measure—and that is the exciting bit!" enthuses Wopereis. "However, they change with location and sowing date as a result of climatic factors (mainly minimum air temperature)." WARDA has started to measure these parameters in 'rice-garden trials' to obtain year-round figures for these important traits.

Johnson is also happy: "Our study showed the strength of modeling in testing new plant types," he says. "It allowed quantification of yield gains from improved crop management"—better quality seed, higher seeding density, timing of weeding—"and from better plant types. To do such analyses experimentally would be almost impossible."