Yields at IRRI research farm are still close to the climatic potential level

M.J. Kropff, Department of Plant Sciences, Wageningen University, The Netherlands; K.G. Cassman, University of Nebraska, USA; S. Peng, IRRI; and H.H. van Laar, Department of Plant Sciences, Wageningen University, The Netherlands.
E-mail: m.j.kropff@plant.wag-ur.nl

Highest dry-season yields obtained at the IRRI Research Farm declined from 9-10 t ha^{-1} in the late 1960s and early 1970s to less than 7 t ha^{-1} in the late 1980s; the comparable yield decline in the wet season was from about 6 to 4 t ha^{-1} during the same period (Cassman et al 1995). In 1991, research teams led by Cassman, Kropff, and Peng initiated investigations into the cause of the yield decline at IRRI. In the wet season of 1991, wet-season yields of 6 t ha^{-1} were achieved with modified N management to improve the congruence between N supply and crop demand (Cassman et al 1994), and these yields were comparable with wet-season yield levels achieved in the 1960s and early 1970s. Based on these results, Kropff et al (1994a) developed, parameterized, and evaluated the ORYZA1 simulation model for yield potential in rice. Based on simulations from this model, Kropff, Cassman, and van Laar (Kropff et al 1994a, b) predicted that, in most years, dry-season yields could be increased substantially with improved N management. Using a historical weather database from the IRRI Climate Unit, the model predicted that the dry-season yield potential would range from 8.5 to 10 t ha^{-1} in 8 of 10 years with a mean potential yield of about 9.3 t ha^{-1}, when the crop was transplanted in early January, which is the optimal transplanting date to achieve maximum yield at this site (Kropff et al 1993, 1994b). In the dry season of 1992, a yield of 9.5 t ha^{-1} was obtained with IR72, and a hybrid variety yielded 10.7 t ha^{-1} under improved N management (Kropff et al 1994b). In a subsequent study, Dobermann et al (2000) confirmed the role of improved N management in restoring yields close to yield potential levels at the IRRI Research Farm.

Since 1992, maximum dry-season rice yields of IR72 at the IRRI Farm have ranged from 9.03 to 9.58 t ha^{-1} under the optimum crop management systems (Peng et al 2003). In the dry seasons from 1998 to 2001, however, highest yields of IR72 were 17% lower than that in the 1992-98 period. Regression of yield on several climate variables was used to help identify the causes of this decline. It was concluded that the most likely causes for the reduction in maximum yield obtained in the 1999-2001 period, compared with yield levels achieved in 1992-98, were lower solar radiation and higher nighttime temperature. Both higher night temperature and less solar radiation would result in a reduction in net C assimilation rates: the former because of increased rates of maintenance respiration and the latter because of a decrease in photosynthetic rates. Pathak et al (2003) also reported that the decrease in solar radiation and increase in minimum temperature were responsible for the negative yield trends of the rice crop from 1985 to 2000 in the Indo-Gangetic Plain. The objectives of this paper were to demonstrate the effect of improved crop management since 1992 on yield potential at the IRRI Research Farm and to determine if the observed yield decline during 1998-2001 can be explained by changes in solar radiation and nighttime temperature using a well-validated ecophysiological simulation model.

Methods

The ORYZA1 model (Kropff et al 1994a) was used to estimate rice yield potential in the dry season at the IRRI Research Farm from 1980 to 2001 based on actual climate data from planting to maturity. Here, we define yield potential as the yield that can be achieved with an adapted rice cultivar when grown without limitations from water, nutrients, or pests. Parameter values used in these simulations were based on values derived for IR72 from the 1992 dry-season experiments as described by Kropff et al (1994a, b). Comparisons of simulated and actual yields were based on the yield of best entry in a long-term continuous cropping experiment from 1979 to 2001 at the IRRI Research Farm (Dobermann et al 2000) and the highest recorded yields of IR72 in replicated agronomic trials under the optimum crop management systems at the IRRI Research Farm for the 1992-2001 period as reported by Peng et al (2003).

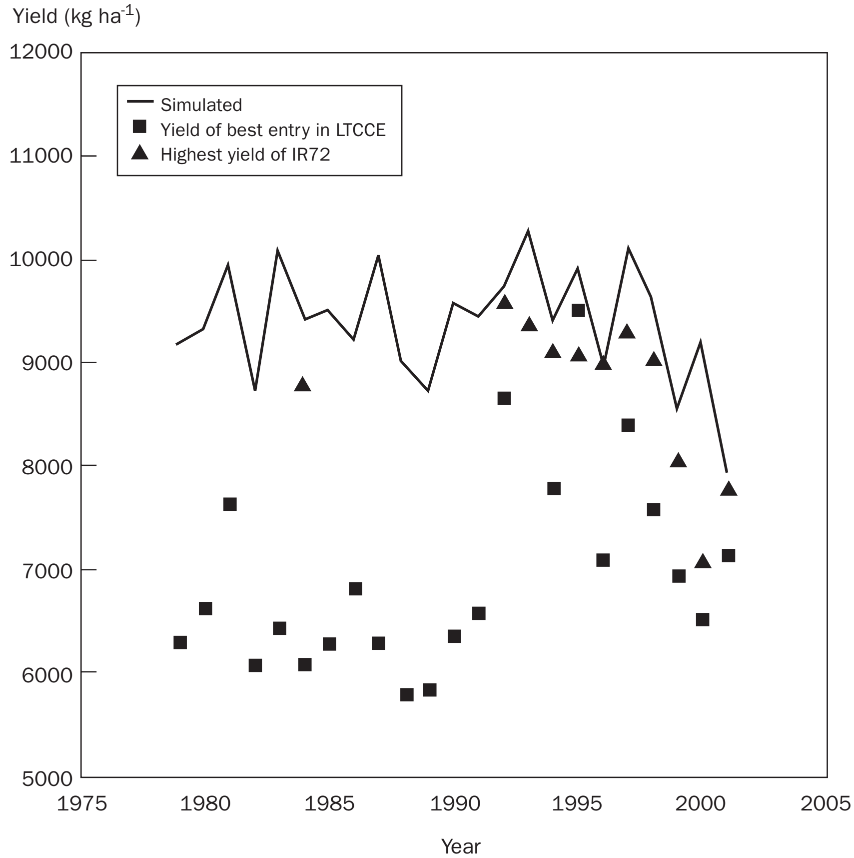
Results

The simulation results based on the actual data of solar radiation and temperature for the period 1979-2001 clearly indicate the large yield gap of about 3 t ha^{-1} between potential dry-season yield and the yield of the best entry in the long-term continuous cropping experiment at the IRRI Research Farm before 1992 (see figure). In contrast, the simulated yield potential is much closer to the best entry yield in the long-term continuous cropping experiment from 1992 to 2001. The average difference between simulated potential yield and the yield of best entry in the long-term continuous cropping experiment was about 1.5 t ha^{-1} from 1992 to 2001. However, the average difference between simulated potential yield and the highest recorded yields of IR72 grown in replicated agronomic trials under optimum crop management systems at the IRRI Research Farm was about 0.6 t ha^{-1} for 1992-2001 (see figure). These results suggest that improved crop managment has effectively closed the yield gap between simulated potential yield and actual yield. In 1992, 1994, 1996, and 2001, the model estimated the yield potential of IR72 very accurately. The model also simulates the variation in yield over years very well.

The smaller yield potential in the 1998-2001 period is also evident in the simulations (see figure). The highest yield of IR72 in the 1998-2001 period was reduced by 17% compared with the highest yield of IR72 in the 1992-97 period. The simulation model estimated that the climatic yield potential in 1998-2001 was, on average, 12% lower than the yield potential in 1992-97. Therefore, the recent decline trend in grain yield at the IRRI Research Farm was not related to crop management or varietal performance. Reduced solar radiation and increased nighttime temperature were mainly responsible for the yield decline. Furthermore, yields at the IRRI Research Farm are still close to the climatic potential level.

Conclusion

The trends in the highest actual yield of irrigated rice obtained at the IRRI Farm since 1992 can be well explained by the ecophysiological model ORYZA1 for potential production. Before 1992, there was an obvious yield gap of 3 t ha^{-1} between potential and actual yields, which apparently resulted from N limitation (Cassman et al 1993, Kropff et al 1993, Dobermann et al 2000). A much smaller yield gap was observed in recent 10 years after 1992, which apparently resulted from the effects of yield-reduc-



Observed and simulated yields at IRRI for the best entry in the long-term continuous cropping experiment (LTCCE) (Dobermann et al 2000) and for the highest yield recorded in IR72 in the dry season from 1992 to 2001 (Peng et al 2003).

ing factors such as pests and diseases. We believe it is useful to use the ORYZA1 model (or other well-validated rice simulation models) as a useful research tool to estimate the yield gap in experiments at IRRI and at other locations where strategic research is conducted on the effects of crop management practices and environmental conditions on rice yields.

References

Cassman KG, De Datta SK, Olk DC, Alcantara JM, Samson MI, Descalsota JP, Dizon MA. 1995. Yield decline and the nitrogen economy of long-term experiments on continuous, irrigated rice systems in the tropics. In: Lal R, Stewart BA, editors. Soil management: experimental basis for sustainability and environmental quality. Boca Raton: Lewis/CRC Publishers. p 181-222.

Cassman KG, Kropff MJ, Gaunt J, Peng S. 1993. Nitrogen use efficiency of irrigated rice: what are the key constraints? Plant Soil 155/156:359-362.

Cassman KG, Kropff MJ, Yan Z. 1994. A conceptual framework for nitrogen management of irrigated rice in high-yield environments. In: Virmani SS, editor. Hybrid rice technology: new developments and future prospects. Manila (Philippines): International Rice Research Institute. p 81-96.

Dobermann A, Dawe D, Roetter RP, Cassman KG. 2000. Reversal of rice yield decline in a long-term continuous cropping experiment. Agron. J. 92:633-643.

Kropff MJ, Cassman KG, van Laar HH, Peng S. 1993. Nitrogen and yield potential of irrigated rice. Plant Soil 155/156:391-394.

Kropff MJ, van Laar HH, Matthews RB. 1994a. ORYZA1: an ecophysiological model for irrigated rice production. SARP Research Proceedings. Wageningen (The Netherlands): DLO. 110 p.

Kropff MJ, Cassman KG, van Laar HH. 1994b. Quantitative understanding of the irrigated rice ecosystem and yield potential. In: Virmani SS, editor. Hybrid rice technology: new developments and future prospects. Manila (Philippines): International Rice Research Institute. p 97-113.

Pathak H, Ladha JK, Aggarwal PK, Peng S, Das S, Yadvinder Singh, Bijay Singh, Kamra SK, Mishra B, Sastri ASRAS, Aggarwal HP, Das DK, Gupta RK. 2003. Trends of climatic potential and on-farm yields of rice and wheat in the Indo-Gangetic Plains. Field Crops Res. 80(3): 223-234.

Peng S, Huang J, Sheehy JE, Laza RC, Visperas RM, Zhong X, Centeno GS, Khush GS, Cassman KG. 2003. Rice yields decline with higher nighttime temperature from global warming. (in press)