Simulation and systems analysis for rice production (SARP)

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Simulation of the effect of bacterial blight disease on crop growth and yield of rice

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Introduction

Bacterial blight disease in rice caused by *Xanthomonas campestris* pv. *oryzae* has been occurring in various degrees of severity in different rice cultivars. The disease manifests in three different forms viz., kresek, pale yellow leaf and leaf blight. The most common symptom of the disease is the blighting of leaves from tip downwards. Bacterial leaf blight has formed one of the major limiting factors in increasing rice production. In India, the losses in yield have been estimated in the range of 6 - 60% (Srivastava et al., 1966) and 2 - 74% (Reddy, 1976). Exconde et al. (1973) have reported an average yield loss of 22.5% in the wet season and 7.2% in the dry season. The level of disease severity, the stage of the crop at which the initial infection occurs, and the subsequent spread of the disease in a plant population have been reported to determine the yield loss. However, clear quantitative information on the extent of losses in yield due to the disease is lacking. Therefore, systems analysis and simulation were used to increase the quantitative understanding of the disease. In this approach, effects of the disease on physiological processes of the plant are quantified and introduced in a crop growth model. The model is used to integrate the effect of the various damage mechanisms and to establish the effect on crop growth and yield.

In this study, photosynthesis measurements were conducted to determine the effect of the disease on leaf photosynthesis. Further an effect on photosynthesis and respiration were introduced in a crop growth model. A field experiment was carried out to validate model performance.

Materials and methods

Pot experiment

Twenty-days-old seedlings of the cultivar MW10 raised separately, were uprooted and planted in 20 cm diameter earthen pots which were previously filled and puddled with 5 kg of soil. Bacterial suspension of *X. campestris* pv. *oryzae* was prepared by suspending the 48-h-old growth in sterile distilled water and it was adjusted to concentration of about 109 cells ml^{-1}. Leaves of 45-days-old plants were used to inoculate by clipping method of inoculation (Kauffman et al., 1973). Care was taken to clip only a small portion of the leaf tips. Separate controls were maintained with one in which the leaves were cut with a pair of

scissors dipped in sterile distilled water and another as normal uncut healthy leaves.

Measurements on the rate of photosynthesis were carried out with ADC MK II equipment (Analytical Development Co., UK), starting four days after inoculation, and repeated at 7 and 12 days after inoculation. Observations were made at the visibly diseased leaf tip and at the neighbouring completely green part of the leaf. For the first type of observation, the leaf chamber was put at 0.5 cm from the end of the completely dead leaf portion, to include the visibly diseased leaf portion. For the second type of observation, the leaf chamber was put between 7.5 to 12.5 cm from the end of the dead leaf portion, to include leaf area without disease symptoms.

Field experiment

A field experiment was conducted during the wet season (June - September) of 1990 at Central Rice Research Institute, Cuttack, India. A susceptible rice cultivar MW10 was used. The nursery was grown in the raised seed beds and 30-days-old seedlings were uprooted and transplanted in a well puddled field. The spacing between plants and lines was 20 x 20 cm by which the plant density becomes 250,000 plants ha^{-1}. The lay out was a randomized block design with four replications and three treatments viz., no inoculation (A), inoculation at tillering stage (B) and flag leaf inoculation (C). The size of the single plot was 42.24 m^2 (8.80 x 4.80 m). Nitrogenous fertilizer in the form of urea was applied in four split doses totalling to 120 kg N ha^{-1}. Adjacent plots were separated by open space of two meters.

For inoculation with bacterial blight pathogen, the clipping method was used (Kauffman et al., 1973). In treatment B, bacterial blight disease was initiated on all the plants one month after transplanting, at the tillering stage and continued throughout the crop growth period. In treatment C, only flag leaves were inoculated. Inoculation was conducted at the booting stage to coincide the disease appearance with ear emergence. Weekly observations of the disease development were recorded on 30 randomly marked hills. Of each hill two tillers were used. All the leaves of these tillers were observed, to obtain disease intensity. A leaf was classified as healthy when it was completely green without disease symptoms. Completely killed leaves were classified as dead, while those with blighted leaf tips were classified as diseased. For diseased leaves, the fraction of leaf area covered by the dead leaf tip was used as a measure for disease intensity.

Periodical harvests were conducted at 15-days intervals starting from 20 days after transplanting. It included two adjacent rows of five plants each. Leaf area and dry weight of leaves, stems and panicles were measured. Further nitrogen content of the leaves was determined by micro-Kjeldahl method.

Crop growth model

Simulation of the effect of bacterial blight disease was carried out using a slightly adapted version of the MACROS model (Penning de Vries et al., 1989). This model simulates the time course of dry matter production of a crop in dependence of daily total irradiation and air temperature. The dry matter produced is divided into roots, leaves, stems and storage organs. Partitioning factors are introduced as a function of the phenological state of the crop.

Leaf area was given as input to the model. Measured leaf nitrogen content was introduced in the model to estimate the assimilation rate at light saturation according to Penning de Vries et al. (1990).

To account for the effect of the disease on crop production, three types of leaf area were distinguished in the model; healthy, diseased and dead leaf area. Healthy leaf area, or leaf area of completely green leaves, was assumed to function normally with respect to photosynthesis and respiration. Dead leaf area, consisting of the area of completely dead leaves and dead leaf tips of diseased leaves, was assumed to be inactive. Diseased leaf area, or the green part of leaves with disease symptoms, was assumed to have a reduced photosynthetic rate and an increased rate of respiration. The reduction in leaf photosynthetic rate of diseased leaf area was made identical to the average dead leaf fraction of diseased leaves. This assumption was made since actual measurements showed a clear effect of the presence of the disease on photosynthesis of the remaining green leaf area. Rate of respiration was calculated as 1.7 times the respiration of healthy leaf area, based upon the report of Watanabe & Asaumi (1975). Three layers of equal leaf area were distinguished in the model, to account for the vertical distribution of the disease in the canopy. The disease observations on individual leaves were used to calculate the fraction of healthy, diseased and dead leaf area within each layer. Thus, three types of damage mechanisms were introduced into the model. They are a reduced rate of photosynthesis, an increased respiration, and shading of dead leaf area.

Results

Effect of bacterial blight on leaf photosynthesis

The rate of reduction in leaf photosynthetic rate at different time intervals after inoculation is depicted in Figure 1. Here it is shown that leaves respond initially to the shock of cutting

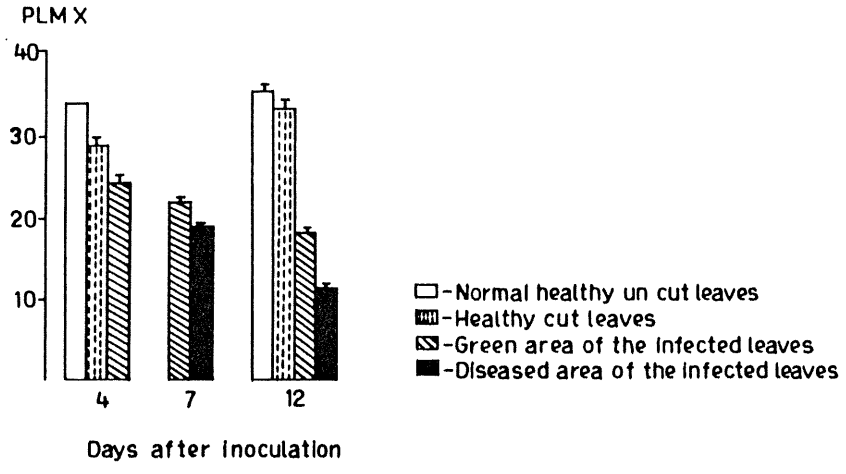

Figure 1. Maximum rate of leaf photosynthesis (PLMX, kg CO_2 ha^{-1} h^{-1}) measured at periodical intervals during the development of bacterial blight disease on cultivar MW10.

with a reduction in leaf photosynthetic rate. Later on, the leaves recover from this shock almost completely. At four days after inoculation, even before symptoms appeared, the photosynthetic rate of infected leaves was already considerably reduced. After appearance of the first disease symptoms and further development of the affected leaf tip, this reduction increased. The reduction in leaf photosynthetic rate appeared to depend upon the distance of the measured leaf part to the point of disease development.

Observed effect of bacterial leaf blight on crop growth and yield

Actual observations on the disease progress have shown that the disease development increased gradually in different leaves inoculated with *X. campestris* pv. *oryzae*. During kernel filling the fraction of leaf area covered with the dead leaf tip and other disease symptoms ranged from 10% in recently inoculated leaves to 70% in early inoculated lower leaves. The increase in the fraction diseased and dead leaf area is shown in Table 1, where layer 1 refers to the top layer of the canopy. Highest disease levels were found in plots were leaves were inoculated from tillering stage onwards. In the treatment where flag leaves were inoculated, a high incidence of infected flag leaves was found during kernel filling. Even in the uninoculated plots, low levels of disease incidence of flag leaves were recorded after flowering.

In all treatments, a gradual increase in leaf area was observed with a maximum around the time of flowering (Julian day 220, Figure 2). After flowering a rapid decline in leaf area was observed, especially in the treatment with inoculation from tillering stage onwards. Up to flowering the increase in leaf and stem dry weight was almost identical for the three treatments (Table 2). Small differences were observed from flowering onwards. Actual grain yields were reduced with 24% and 9% for the inoculation from tillering onwards and flag leaf inoculation, respectively (Table 3).

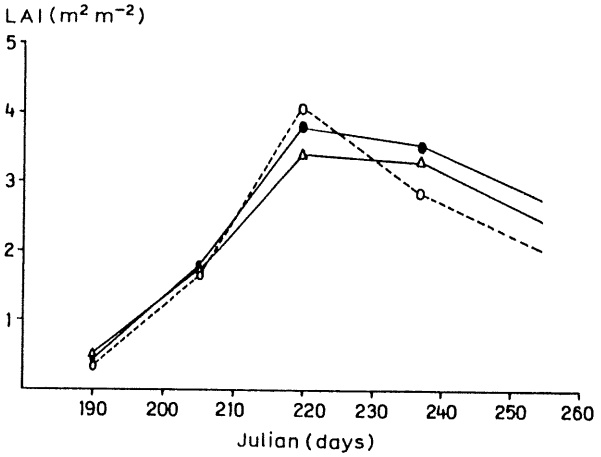

Figure 2. Leaf area development as observed in the field, and as introduced in the crop growth model (lines); control-uninoculated (•), tillering stage inoculation (o) and flag leaf inoculation (Δ).

Table 1. Observed fraction of dead and diseased leaf area at periodical intervals distributed in three equal leaf layers in the treatments of uninoculated (A), tillering (B) and flag leaf inoculation (C).

Julian days	Treatment A fraction dead+diseased leaf area				Treatment B fraction dead+diseased leaf area				Treatment C fraction dead+diseased leaf area			
	LAI	layer 1	layer 2	layer 3	LAI	layer 1	layer 2	layer 3	LAI	layer 1	layer 2	layer 3
211	2.6	0	0	0	2.63	0	0.58	0.70	2.4	0	0	0
218	3.6	0	0	0	4.1	1.0	0.68	0	3.1	0	0	0
225	3.75	0	0	0	3.45	1.0	1.0	0.4	3.36	0.76	0.15	0
232	3.6	0.11	0.02	0	3.25	1.0	1.0	0.44	3.3	0.76	0.15	0
241	3.39	0.24	0.04	0	2.7	1.0	1.0	0.61	3.15	0.78	0.23	0
258	2.58	0.3	0.15	0	1.9	1.0	1.0	1.0	2.28	0.88	0.43	0

Table 2. Dry weight of leaves, stem and panicles (kg ha^{-1}) on four sampling days (Days After Transplanting, DAT) during the crop growth period of rice cv. MW10.

	Date of sampling (Julian days)			
	190 (20 DAT)	205 (35 DAT)	220 (50 DAT)	237 (67 DAT)
Uninoculated treatment (A):				
Weight leaves	133.7	597.5	1405.0	1307.0
Weight stem	128.7	596.9	2881.2	4137.5
Weight panicles	-	-	266.2	2300.0
Tillering stage inoculation (B):				
Weight leaves	145.0	601.2	1465.0	1020.0
Weight stem	126.2	650.0	2937.5	4090.0
Weight panicles	-	-	305.0	1960.0
Flag leaf inoculation (C):				
Weight leaves	135.0	598.1	1283.7	1121.2
Weight stem	135.6	646.9	2943.7	4126.2
Weight panicles	-	-	278.7	2256.2

Table 3. Observed and simulated grain yield as affected through inoculation with bacterial blight. For treatments see Table 1.

Treatment	Observed (t ha^{-1})	Relative	Simulated (t ha^{-1})	Relative
A	3.4	100%	4.5	100%
B	2.6	76%	2.7	60%
C	3.1	91%	3.6	80%

Simulation

The model underestimates the total weight of leaves, stems and panicles when compared to the weight obtained through periodic harvesting (Figure 3). However, the differences between treatments are appropriately simulated. Contradictory to this, the model overestimates the grain yield. For the uninoculated plot a difference of 1000 kg ha^{-1} was found between field observation and model calculation. The model overestimated the effect of an infection on grain yield, even if the reduction was expressed as a percentage of the uninoculated plot.

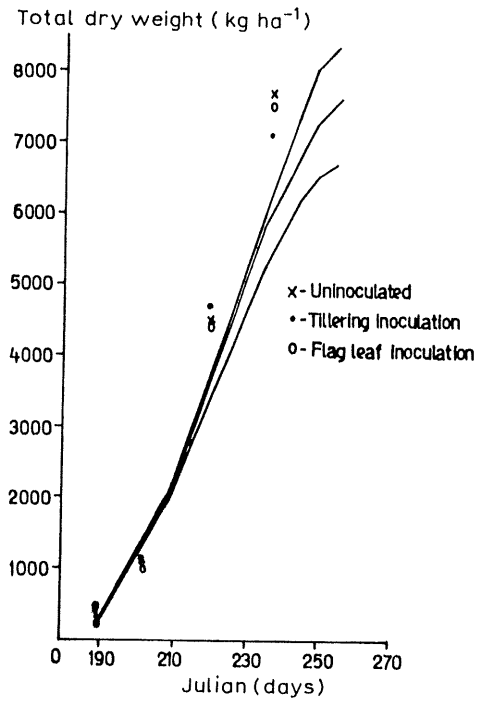

Figure 3. Observed and simulated increase (kg ha^{-1}) in total shoot dry weight for the treatments A, B and C (see Table 1).

Discussion

A significant reduction in the rate of photosynthesis was observed in the visibly healthy part of rice leaves infected with the bacterial blight pathogen. Even before symptom development, a reduction in leaf photosynthetic rate was found. The reduction was larger if the distance to the visibly affected leaf tip was smaller. However, the data obtained in this experiment are not sufficient to give a reliable quantitative description of the effect of bacterial blight on leaf photosynthetic rate. More experiments to quantify the effect of bacterial blight disease on basic processes as photosynthesis and respiration are needed.

In the field experiment, an effect of the disease on total shoot dry weight and grain yield was found. The differences between the treatments were as expected. The highest reduction was observed in the plots were leaves were inoculated from tillering stage onwards. A smaller reduction was observed if only flag leaves were inoculated.

With simulation, the increase in dry matter throughout the season was underestimated for all treatments. However, the differences between treatments were appropriately simulated. Contradictory to total dry weight, simulated grain yield was higher than grain yield obtained in the field. An explanation for this phenomenon is difficult to give. Leaf area development between dough ripe and crop maturity is the main determinant for the production of the crop after dough ripe. In this experiment, the leaf area development after dough ripe was not determined and an extrapolation was made. This lack of information hampers a good analysis of the effect of the disease and especially a thorough validation of the model. Therefore, the main conclusion from this study is that an appropriate validation of the model can only be achieved through field experiments with more frequent periodic harvests.

References

Exconde, O.R., O.S. Opina & K. Phanomsawaran, 1973. Yield losses due to bacterial leaf blight of rice. Philippine Agriculturist Vol. LVII, No. 3 and 4.

Kauffman, H.E., A.P.K. Reddy, S.P.Y. Hsieh & S.D. Merca, 1973. An improved technique for evaluating resistance of rice varieties to *Xanthomonas oryzae*. Plant Dis. Reporter 57: 537-541.

Penning de Vries, F.W.T., D.M. Jansen, H.F.M. ten Berge & A. Bakema, 1989. Simulation of ecophysiological processes of growth of several annual crops. Simulation Monographs 29. Pudoc, Wageningen and IRRI, Los Banos. 271 pp.

Penning de Vries, F.W.T., H. van Keulen & J.C. Alagos, 1990. Nitrogen redistribution and potential production in rice. In: Proceedings of the International Congress of Plant Physiology, 15-20 February 1988, New Delhi, India. Eds S.K. Sinha et al., Volume I, ISBN 81-900-1370-X. pp. 513-520.

Reddy, A.P.K., 1976. Epidemiology and variability of *Xanthomonas oryzae* in India. International Rice Research Conference 1974, IRRI, Philippines.

Srivastava, D.N., Y.P. Rao & J.C. Durgapal, 1966. Can Taichung Native-1 stand up to bacterial blight. Indian Farming XVI: 15-17.

Watanabe, M. & T. Asaumi, 1975. Studies on physiological changes in the rice plants infected with *Xanthomonas oryzae*. 1. Relationship between the increase in respiratory rate and multiplication of bacteria in the infected leaves. Ann. Phytopath. Soc. Japan 41: 364-372.