Modelling rice growth under water limiting conditions

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Summary. A simulation model of rice *(Oryza saliva* L.) growth was constructed to predict grain yield under upland conditions where water is the main limiting factor to growth. The model assumes that crop growth rate is controlled by two factors; the amount of radiation if water is plentiful and the amount of transpiration if water is limiting. Grain yield is calculated using relationships established between crop growth rate and yield components. The model predictions for grain yield agreed closely with experimental outcomes with the coefficient of determination (r2) being 0.86 (P < 0.05). Furthermore. the model predicts that without rainfall. irrigation once every two weeks is not sufficient for rice growth.

Introduction

It is estimated that 48% of the world's 141 million hectares of rice is cultivated in rainfed fields where inadequate water availability during crop growth can limit yield (2). Most of the rainfed rice is cultivated under rainfed lowland conditions, and the rest under upland. Severe water stress occurs commonly in rice grown under upland conditions, and yields are very low compared with fully irrigated lowland rice. Our attempt here is to describe how water stress affects rice yield using a simulation model. There are several rice models available (e.g. CERES rice model), but none of them are sufficiently simple to apply for field management under water limiting conditions.

The present model describes the effects of water stress on rice growth under upland conditions, and can be used to assist management decision processes such as when to apply irrigation water to maximize yield. The model is currently being modified to estimate the effect of water stress in rainfed lowland conditions, so that it can estimate frequency and severity of stress in Asian countries, particularly in Thailand and Laos. This information will be used for development of suitable rice varieties for rainfed conditions.

Outline of the rice model

The model was constructed based on upland experiments in which rice plants were waterstressed at different developmental stages (1). It simulates crop growth and development from sowing to maturity and is divided into four main parts (submodels): phenology, water balance, growth and yield submodels. The model is run using daily values for maximum and minimum air temperatures, solar radiation, rain and pan evaporation. Furthermore, the model assumes no growth constraints by nutrient problems or by insect or disease damage, and plant density is assumed to be constant at 40 plants 1m2.

Phenology

Phenological development (i.e. panicle development, anthesis and maturity) is determined mainly by heat sum with a base temperature of 8?C. However, if water stress occurs before anthesis, phenological development is delayed and it accelerates the grain filling stage if it occurs after anthesis.

Crop growth

The crop growth (CGR) depends on the extent of the soil water deficit. If the soil water content is more than 80% of extractable water, CGR is estimated from intercepted radiation and a constant radiation use efficiency. However if severe soil water deficit develops, CGR is calculated from the daily rate of transpiration and transpiration efficiency. Transpiration efficiency is affected by LAI; it decreases as ground cover is reduced because the plants are more exposed to dry air.

Partitioning of daily assimilates into stems, leaves, roots or panicles, is related to the phenological stage. The allocations to root and leaf lamina decrease as plants develop, but partitioning to stem increases up to anthesis. Leaf area index is calculated as the product of leaf blade biomass and specific leaf area, and the latter parameter decreases as plants develop.

Water balance

The soil profile is divided into two layers; 0 to 10 and 10 to 100 cm. It is assumed that soil evaporation takes place from the top soil layer. Soil evaporation is dependent on the radiation level at the soil surface, which in turn is estimated from LAI, and soil moisture content in the top layer. Transpiration is dependent on evaporative demand (pan evaporation x % radiation interception) and soil water content.

Yield

Grain yield is determined from estimates of the individual yield components.

GY = PCN*SPP*(I-UFG/100)*(SGW/1000)

where GY = grain yield (g/m^2), PCN = number of panicles/m^2. SPP = number of spikelets per panicle, SGW = single grain weight (mg), and UFG = proportion of unfilled grain (%).

Since the variation in the number of panicles/m2 was small in all experiments, it was assumed to be constant at 340 m^2. SPP is linearly related to crop growth rate between panicle initiation and anthesis, whilst SGW is linearly related to crop growth rate between anthesis and maturity. Experimental results with shading treatments show that when water is not limiting growth UFG increases exponentially with decreases in CGR between anthesis and maturity. When water stress develops around anthesis, however, there is an increase in UFG.

Results and discussion

Model testing and calibration

The model was developed based on the data obtained from one set of experiments. To test model performance, data were used, firstly, from these experiments, and then using data from another set of experiments.

The model was run with appropriate weather data to simulate growth for four times of sowing under different conditions of water availability (irrigated, severe stress and mild stress), and simulated results were compared with actual results from the experiment. Sowing dates were 15 October, 5 November, 26 November and 17 December 1989 for sowing I (SI), sowing 2 (S2), sowing 3 (S3) and sowing 4 (S4) respectively.

Table I. Comparison between simulated (S) and observed (0) results for yield and yield components of four sowings, SI, S2. S3 and S4, grown under (i) irrigated, (ii) severe stress and (iii) mild stress conditions in summer 1989-90.

Sowing	GY (g/m^2)[a]		SGW (mg)[b]		UFG (%)[c]		SPP[d]	
	S	O	S	O	S	O	S	O
				(i) Irrigated trial				
S1	869	864	21.9	21.0	7.5	6.9	126	124
S2	822	844	21.5	20.7	9.1	5.9	123	128
S3	690	726	20.9	22.4	12.2	13.4	111	114
S4	614	641	20.2	22.4	17.0	24.4	108	112
				(ii) Severe stress trial				
S1	272	220	19.0	16.2	64.0	66.2	117	108
S2	0	0	0.0	0.0	100.0	100.0	77	79
S3	348	388	19.5	19.2	23.1	19.0	68	80
S4	334	472	19.4	20.5	23.8	28.6	66	72
				(iii) Mild stress trial				
S2	736	623	20.5	20.4	14.5	25.8	123	123
S3	202	304	19.6	17.5	72.0	38.5	108	88
S4	279	111	20.3	18.3	52.0	78.9	84	79

[a]GY-grain yield, [b]SGW-single grain weight, [c]UFG-unfilled grain, [d]SPP-spikelet number per panicle.

Grain yield and yield components estimated using the model under both irrigation and severe stress conditions agreed well with experimental results for all sowings (Table 1). Under mild stress, the model overestimated the grain yield in S2 and S4 which was due in part to the estimated UFG being lower than that observed. However the model underestimated grain yield for S3 (202 vs 304 g/m2) because estimated percentage of unfilled grain was much higher than that observed. This effect was largely due to the low water availability during the critical period in the simulation resulting in high spikelet abortion.

The model was run to compare the simulation results with experiments conducted over five years at Redland Bay. In all experiments there were irrigated controls as well as water stress treatments, and there was a total of 26 growing conditions. In each experiment phenological development was monitored and in some harvests total dry matter and LAI were also determined.

The agreement between simulation and experimental results of all the experiments is examined by calculating the coefficient of determination (r^2) for different attributes: phenological development r^2 = 0.97, total dry matter r^2 = 0.92, LAI r^2 = 0.83, grain yield r = 0.86, UFG r^2=0.81, and SPPr z=0.60.

The slope of the fitted line was not significantly different from 1.0 for any of these attributes. The relationship between simulated and observed data for SGW is poor (r^2 = 0.13), but the variation in this component was also small (between 19 and 22 mg).

Effects of frequency of irrigation

A simulation was conducted using the weather data for sowing 2 1989-90, but with all rainfall excluded and water supplied only through irrigation. Irrigation supplied an average of 50 mm water per week throughout growth for all treatments but there were differences in the frequency of this irrigation. Three irrigation regimes were commenced after crop establishment. These included irrigation applied twice a week (25 mm each), once a week (50 mm each) and once every 2 weeks (100 mm each).

The simulation shows no effect of irrigation frequency on the phenological development of the crop. Grain yield for the crop subjected to irrigation once a week was 7% less than that for the crop where irrigation was applied twice a week (Table 2). When the frequency of irrigation was reduced to once in 2 weeks, the grain yield was markedly reduced by about 50% compared to that where irrigation was applied twice a week. The effects on grain yield were mainly through high UFG and a lower SPP.

Table 2. Simulated effects of different irrigation frequencies on yield and yield components for sowing 2 grown with rain excluded in 1989-90.

Irrigation treatment	Yield and yield components			
	GY[a] (g/m^2)	UFG[b] (%)	SPP[c]	SGW[d] (mg)
Twice/week	822	9.0	123	21.5
Once/week	763	9.3	115	21.4
Once/2 weeks	433	36.0	96	20.7

[a]GY-grain yield, [b]UFG-unfilled grain, [c]SPP-spikelet number/ panicle and [d]SGW-single grain weight

Although the amount of irrigation water applied to crops over two weeks was similar, higher growth and grain yield were obtained with more frequent irrigation. However, differences between the application of irrigation twice a week or once a week on growth and grain yield were not as obvious as those found where irrigation was applied once in two weeks. Thus irrigation once a week would probably be sufficient, especially if the cost of labour was a concern. These simulation results confirm the findings of Valmonte (3) who found that grain yield of rice decreased by approximately 9% for irrigation once a week and 23% for once in two weeks, compared to that for irrigation twice a week. The simulated reduction in grain yield for a frequency of once every two weeks (50%) was greater than the experimental results, probably because of contribution of rainfall in the experiment.

References

1. Boonjung, H. 1992. PhD thesis, The University of Queensland.

2. Steponkus. P.L., Cutler. J.M. and O'Toole. J.C. 1980. In: Adaptation to water and high temperature stress (Eds. N.C. Turner and P.J. Kramer). pp. 401-18. (Wiley Interscience. New York).

3. Valmonte. O.S. 1988. MAgrSc thesis, The University of Queensland.