

1994

(In: IBSRAM, Proceedings of ASIALAND workshop
on interpreting data from field experiments on upland
soils., IBSRAM, technical notes, no 6. PAG. 103- 118).

Use of simulation modelling for interpretation and extrapolation of experimental data

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Simulation modelling aids the understanding of complex systems. This paper discusses how simulation modelling can help the interpretation and extrapolation of research results. Examples of different crop-simulation models are presented and their associated data needs are identified. Examples are also presented of how simulation models can be used in conjunction with long-term weather data to extend the value of field experiments conducted over a limited number of seasons. Combined with GIS, simulation models can be used to extend point-information across wider geographic areas. It is concluded that simulation modelling is a powerful tool for interpreting data and extrapolating research results.

Simulation modelling facilitates the understanding of complex agricultural systems. It is a powerful tool in agricultural research, and can be used to focus field experimental research, which is often restricted because of the time and expense involved. This is especially the case in many rainfed environments where rainfall is extremely erratic. To obtain results that can be used for recommendations, the experiments must be conducted over a series of years and planting dates, and on the relevant different soil types. Moreover, extrapolation of the research findings to other areas is difficult.

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In production situation-1, light and temperature are the main factors determining the crop growth rate. In ORYZA1, the measured or simulated leaf area index (LAI) and the vertical distribution of leaf area are used to calculate the light profile in the canopy. The photosynthesis profile in the full canopy is derived from single-leaf photosynthesis. The daily assimilation rate is obtained by integrating over the height of the canopy and over the day. Subtracting respiration requirements and losses due to the conversion of carbohydrates into structural dry matter gives the net daily growth rate in $\text{kg ha}^{-1} \text{day}^{-1}$. The dry matter produced is partitioned among the various plant organs, based on a partitioning coefficient that depends on the stage of phenological development.

In ORYZA1, the phenological development rate is a function of ambient mean daily air temperature. If the canopy is open, leaf-area development is calculated from the mean daily temperature. When the canopy closes, the increase in leaf area is obtained from the increase in leaf weight. The time step integration is one day.

Input requirements for ORYZA1 in production situation-1 are:

- daily solar radiation and air temperature,
- planting density,
- date of crop emergence or transplanting, and
- parameters that describe the morphological and physiological characteristics of the rice crop.

The morphological characteristics required are the leaf-area development and the light-extinction coefficient. The physiological characteristics needed include the assimilation-light response curve parameters, the dry-matter partitioning functions, the maintenance respiration coefficients, and the growth respiration coefficients.

Crop models that are used for production situation-2 need, in addition to the climate data for production level-1, data on windspeed, vapour pressure, and rainfall to calculate potential transpiration rates. Actual transpiration rates are calculated from the potential transpiration rate and the root zone water content, predicted by a soil-water balance model.

Soil water-balance models and associated soil data needs

Integral models

Integral models (Ten Berge *et al.*, 1992) or capacity models (e.g. Wagenet *et al.*, 1991) consider the soil as consisting of a root zone and a subsoil. Flux values at the system's boundaries are externally defined. The root zone can be seen as a 'box' with a water-holding capacity that is determined by two critical pressure

heads: field capacity and wilting point. When water is applied to the soil, it is assumed that it is rapidly redistributed at water contents above field capacity, and that water is only retained in the 'box' to field capacity level; the rest of the water flows downwards.

Water can be extracted to the wilting point; water held at lower pressure heads is unavailable for plants. 'Field capacity' is often determined under field conditions by flooding a field and measuring water contents after two days, while avoiding evaporation. Similarly, the wilting point is estimated by growing a crop and observing the moisture content at which wilting occurs (e.g. IBSNAT, 1988). These procedures are very laborious and hard to control. Formerly, the water content at -1.5 MPa pressure was taken to represent the permanent wilting point. This value has correctly been criticized because the wilting of plants depends not only on the soil-water state but also on the type of plant and the evaporative demand. The distinction of arbitrary 'field capacity' and 'wilting point' values poses a scientific problem, as we deal in nature with continuous processes of water transport and uptake.

The CERES crop growth model used by the International Benchmark Sites Network for Agrotechnology Transfer (IBSNAT) project (Jones and O'Toole, 1987) and the WOFOST crop growth model of the Centre for World Food Studies (van Keulen and Wolf, 1986; van Diepen *et al.*, 1988) use integral soil-water balance modules. CERES is an example of a multilayer integral model, as it allows the root zone to be comprised of several compartments.

In lowland rice paddy fields, rice is grown under submerged conditions. Waterflow is hindered by soil layers of high hydraulic resistance, often at various depths within the profile. The field capacity concept clearly does not apply here. Some integral models developed at the International Rice Research Institute (IRRI, Los Baños, Philippines), such as IRRIMOD (Angus and Zandstra, 1980) and PADDYWATER (Bolton and Zandstra, 1981) assume a constant percolation rate in the soil water-balance equation of the root zone as long as there is ponded water on the soil surface. If the ponded water level in the paddy field exceeds the bund height, excess water is lost as runoff.

Integral models cannot mechanistically compute fluxes between adjacent soil compartments. This is a problem in rainfed lowland rice cultivation, where capillary rise from the groundwater table to the root zone may be of crucial importance for the crop.

Differential models

Differential soil-water balance models are defined here as models that require both hydraulic conductivity ($k(h)$) and moisture-retention data ($h(q)$) to calculate fluxes between soil compartments. Such fluxes are computed from

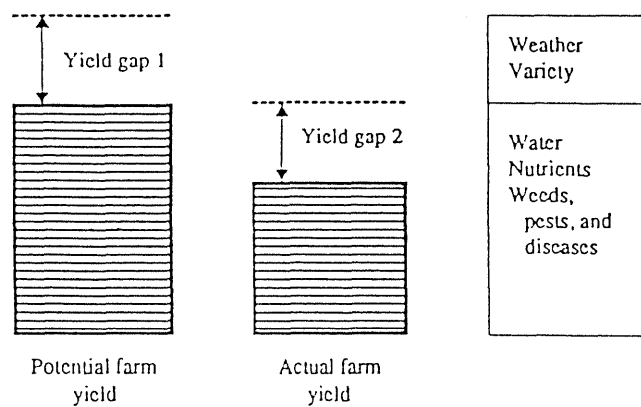


Figure 2. Yield gap analysis.

In most countries in Asia, rice varieties are tested using multilocation trial sites. This testing is done under optimal conditions to obtain:

- a statistical description of potential yields through time and space (caused by weather variability);
- a reference for actual yields obtained by farmers.

Production situation-1 simulation models could be used to simulate potential yields for areas where adequate weather data, but no trial sites, are available. They could also serve as a check to see if potential yields are reached at trial sites.

The decision regarding which model/approach to use, depends on the desired output of the study, data needs, and data availability. It is very important to define the output of the study before a systems approach is chosen (Figure 3).

The following three examples illustrate the importance of this methodology.

Example 1:

Output: Insight into how variability of rice yield is a function of the transplanting date under intensive irrigated cultivation.

Systems approach: Production situation-1 model parameterized for rice.

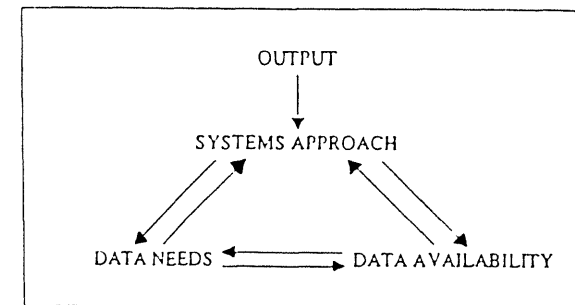


Figure 3. Interdependency of output definition, selected systems approach, associated data needs, and data availability in systems analysis.

Data needs:

At least 20 years of weather data (daily data on solar radiation; minimum and maximum temperatures); crop characteristics.

Example 2:

Output:

Feasibility study to investigate the possibilities of growing maize on a free-draining soil under rainfed conditions.

Systems approach:

Production situation-2 model parameterized for maize linked with a simple integral soil-water balance model.

Data needs:

At least 20 years of weather data (daily data on solar radiation; minimum and maximum temperatures, wind-speed, relative humidity, and rainfall); crop characteristics, including drought-stress responses; soil data (root zone water contents at field capacity, wilting point).

Example 3:

Output:

The effect of the position of the panicle in the rice canopy on photosynthesis, based on the hypothesis that a higher panicle results in lower photosynthesis

Qualitative land evaluation

The suitability of each LEU for a specific land use is determined. This step requires the input of expert knowledge, and results in the identification of unsuitable and potentially suitable LEUs.

Quantitative land evaluation

Quantitative land-evaluation techniques using crop-simulation models are applied to potentially suitable LEUs to evaluate production constraints. For a sound analysis of actual production constraints per LEU, data are needed on potential (irrigated), and water-limited (rainfed) yield in relation to the planting date, the variation in weather over a number of years, and crop variety. Data on the impact of fertilizer application and the effects of pests, diseases, and weeds on yield are needed as well. Such data can be generated using well-validated simulation models.

Display and interpretation of results

Maps or tables of unsuitable land units, crop yields, or yield gaps can be displayed easily using the GIS computer software.

The approach outlined above can result in numerous simulation runs with different combinations of input data, even if only water-limited production is simulated:

LUEs x year x soil type x planting dates x varieties x etc.

In view of the large number of parameter combinations, research by experimental studies is not feasible. Crop models that have been validated at carefully selected sites can be used instead. The key sites should represent the full range of situations where production is limited by water, and if possible nitrogen and pests/diseases. Testing will permit improvement of the models and may contribute to a better specification of the data input.

Regional application of simulation models also requires careful definition of desired output, systems approach, and associated data needs (Figure 3). Mapping yield losses due to drought in a province clearly needs a different approach than on a farm. An excellent example of the importance of scale was given in a study by Wösten *et al.* (1987). They used a crop-soil simulation model to investigate grass-yield losses incurred by farmers in the east of the Netherlands. In this area (1435 ha) watertables were being lowered by extraction for drinking-water. Three different soil maps (1:10 000, 1:50 000 and 1:250 000) were used as a basis for the soil-water balance module. Damage estimates for the area as a whole could be obtained using all maps. However, yield loss predictions for a particular farmer's field were only possible if the detailed 1:10 000 soil map was used as an input. Reliable output at this scale

depends on a more detailed input of soil information, which demands more sampling effort and higher costs.

Conclusions

The framework of crop-simulation models comprises four production levels, associated with an increased need for data.

Models can be used for the interpretation of experimental data, and can increase research efficiency.

Models can be used for the extrapolation of research results using a combination of well-tested models and GIS.

When simulation models are used, it is important to define clearly the output of the study, the approach to be followed, and the associated data needs.

The essential aspect of the methodology for the combined use of GIS and crop-simulation modelling is the use of different levels of detail regarding land evaluation. In a qualitative step, LEUs that are unsuitable for crop growth need to be identified. The simulation model is only used to predict crop growth at potentially suitable LEUs.

The combined use of GIS and crop-simulation modelling enables us to distinguish agroecological zones, and to rank technological constraints to agricultural production in a quantitative way. It can also help in the extrapolation of research results and in the identification of research priorities.

References

- ANGUS, J.F. and ZANDSTRA, H.G. 1980. Climatic factors and the modelling of rice growth and yield. In: *Proceedings of the WMO-IRRI Symposium on Agrometeorology of the Rice Crop*, 189-199. International Rice Research Institute. Los Baños, Philippines: IRRI.
- BELMANS, C., WESSELING, J.G. and FEDDES, R.A. 1983. Simulation model of the water balance of a cropped soil: SWATRE. *Journal of Hydrology* 63: 271-286.
- BLOEMEN, G.W. 1980. Calculation of hydraulic conductivities of soils from texture and organic matter content. *Zeitschrift für Pflanzenernährung und Bodenkunde* 143 (5): 581-615.
- BOLTON, F.R. and ZANDSTRA, H.G. 1981. A soil moisture-based yield model of wetland rainfed rice. IRRI Research Paper no. 62. International Rice Research Institute. Los Baños, Philippines: IRRI.

- WOPEREIS, M.C.S., KROPFF, M.J., BOUMA, J., VAN WIJK, A.L.M. and WOODHEAD, T., eds. 1993. *Manual for soil hydraulic measurements, field monitoring techniques and sampling strategies for rice based cropping systems*. International Rice Research Institute. Los Baños, Philippines: IRRI.
- WÄSTEN, J.H.M., BANNINK, M.H. and BOUMA, J. 1987. Land evaluation at different scales: you pay for what you get! *Soil survey and land evaluation* 7: 13-24.
- WÖSTEN, J.H.M., BANNINK, M.H. and BEUVING, J. 1987. *Water retention and hydraulic conductivity characteristics of top- and subsoils in the Netherlands*. Staring Series, Report no. 1932. Soil Survey Institute. Wageningen, The Netherlands: SSI.
- WÖSTEN, J.H.M., SCHUREN, C.H.J.E., BOUMA, J. and STEIN, A. 1990. Functional sensitivity analysis of four methods to generate soil hydraulic functions. *Soil Science Society of America Journal* 54: 827-832.

Applying nitrogen when transplanting rice - learning from the farmers

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Few Philippine farmers apply N basally, despite the government recommendation to apply one-half to two-thirds of their nitrogen fertilizer 'basally' to drained fields prior to final harrowing and transplanting, and the rest at panicle initiation. We interviewed more than 200 farmers in three irrigated areas about their rice crop management for the 1990 and 1991 wet seasons. We found that farmers continually adjust practices to fit their field conditions, and that overall these practices agree with research suggesting that yields do not increase with basal-N applications, and that N gives best economic returns when applied at midtillering and panicle initiation. It is concluded that consideration of farmers' practices should be part of the research process.

During the past 15 years, researchers have increasingly considered farmer perspectives in asking and answering problem-solving questions. Farmer-oriented approaches have included building on indigenous technical knowledge (Brokensha *et al.*, 1980; Rhoades, 1984; Richards, 1985; Chambers *et al.*, 1989; Fujisaka, 1990) and farmer-participatory experiments (Ashby, 1986; Box, 1987; Rhoades, 1987; Fujisaka, 1989), including farmer varietal testing (e.g. of rice: Prakah-Asante *et al.*, 1984; Maurya *et al.*, 1988; Richards, 1989; Chaudhary and Fujisaka, 1992). Such approaches incorporate farmer knowledge in the formulation of research, involve farmers in testing innovations, and complement research by U.S. land-grant universities and international agricultural research centres (Compton, 1989).

Ex post studies have examined farmer adoption of research or extension recommendations. Peruvian and Philippine farmers adopted diffused-light

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