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# THE IBSNAT SIMULATION MODELS AS A MEAN OF QLE IN DEVELOPING COUNTRIES

J. Comerma and L. B. de Guenni

CENIAP-FONAIAP, Maracay, Venezuela

## Introduction

We understand that Quantitative Land Evaluation (QLE) refers to the process by which a piece of land is rated in its suitability for a given land utilization type through a quantitative prediction. It implies a process of prediction as well as one of extrapolation. To a large extent it can be equated, in the area of Agriculture, to the process of Agrotechnology Transfer.

Developing countries occurring mostly in Tropical and Subtropical latitudes, have characteristically a large variability in the physical factors (soil, climate, vegetation, etc.) that affect the types of crops that can be cultivated and the ways of producing them. Concurrently, in many cases, the types of farming systems determined by the variety of socio-economic situations is also very variable. If we add to the above situation the insufficient and non-detail knowledge of our natural resources and of agricultural research and extension, we can easily visualize the tremendous importance of using the most efficient ways of transfering agrotechnologies or doing the most precise and valid predictions about the use and management of our lands through land evaluation.

## Means of Agrotechnology Transfer

According to Nix (14) there are various methods used in the process of agrotechnology transfer. They include: trial and error, transfer by analogy, by the use of statistical models , and through simulation models. In a process of land evaluation the trial and error is not included, as it refers mainly to the experiences of individual farmers through accomplishment and failures, and can not be used in a massive process of predictions for new areas. But any of the other means mentioned could serve the process of evaluating quatitatively the land units of a given area.

By analogy we could rate in quantitative terms, as yields or

economic benefits, all areas that have similar land qualities to the one for which we have quantitative results. It is probably by analogy that most land evaluations have been done up to now.

Through the use of statistical models we would be able to use regression equations to predict yields or benefits from sites or areas having values for the variables included in the equations. Generally the validity of the predictions produced by the empirical relationships established in those equations is circumscribed to the range of variables included in the areas from where they were derived.

Simulation models try to represent and predict, for different locations, the response of a given crop to the different radiation, temperature, moisture and nutrient regimes, simulating the occurrence of events and processes on a real time scale. As a main difference with the former means of transfer, they are dynamic as they incorporate time and have as a basis the sequential processes of growth and development of a given crop.

Among the different means of prediction and transfer that we have described, possibly the ideal one for an integral, objective and quantitative process of land evaluation would be the combination of a comprehensive (physical, biological and socio-economic factors considered), validated simulation model coupled with a detailed data base of the resource variables of a given area. That combination would allow a quantitative land evaluation for very specific purposes, for many different alternatives, and with a high efficiency. But these models are not yet completed, or have not been extensively tested in developing countries and the data bases of these countries are incomplete or too general to accomplish the ideal situation.

## Simulation models presently related to IBSNAT

The IBSNAT Project (International Benchmark Sites Network for Agrotechnology Transfer) is an international effort to try to use simulation models to asses crop performance in locations where the crops have never been grown (10). This will enable users to asses the suitability of particular lands for specific crops, estimate productivity of the land, and prescribe soil and crop management practices to obtain optimum production for specified conditions.

At present IBSNAT is working with models for ten crops: wheat, rice, sorghum, maize, soybean, peanut, phaseolus beans, potato, cassava, and aroids. Some are already operational, others are partially developed and others are in the conceptualization stage. The IBSNAT crop models are constructed to be independent of, and be able to accommodate differences in locations, seasons, crop cultivars and management systems. The relation between genotype and environment is highly stressed and the resulting phenological stages constitute an important basis for the analysis of the influence of factors like moisture and nutrients on yields.

The capability to predict the performance of any crop production system at any location and season depends on the provision of an specific minimum set of soil, crop, weather and management data (9). The minimum data set for soils includes the

following soil properties as a function of depth:horizon thickness, upper and lower limits for water retention, water saturation, initial soil water contents, bulk density, pH, organic carbon, total nitrogen, initial contents of nitrates and ammonium. Other special features like root distribution in the profile and a coefficient expressing the drainage rate are also included. The minimum set for weather includes the daily radiation, precipitation, maximun and minimum temperature. The crop minimum data requires specific coefficients for each cultivar related to its maturity types, photoperiod sensitivity, and yield components needed to evaluate optimum efficiencies within the constrains of weather and soil. The management data required is on sowing date, plant population, irrigation amounts and dates, fertilizer amounts and dates, residue management and plowing depth. Some models like SOYGRO, also include pest control factors.

The operational models , like CERES and SOYGRO, will process for any given locality, provided the minimum data set mentioned above, the phenological development of that cultivar in real time figures; a complete water balance of the soil during the growth of the crops, including the degree of water stress to the crop during critical periods; a complete nitrogen balance of the soil and the plant, also including possible stresses, and yield components like biomass, roots, grains, etc. The most detailed outputs are of a daily scale but a shorter output frequency is also possible. These outputs serve to evaluate the best strategies of management, or in other words many elements of the land utilization types for a given area.

Among the best technological elements that these models can analize for a given locality we have: the best adapted cultivar to that locality with respect to yields or to stability of yields for a long term; the best planting time and best population of plants as judged by average yields, risk analysis on long periods, and for crop combination in time; the most efficient rates and ways of application of N fertilizers, also judged by yields and/or economic benefits, and finally the best irrigation strategies to use in that locality.

The analysis of different crops and management strategies, for given sites or land units, with the above technological elements, can provide a very important instrument to do a precise, objective and quite comprehensive Quantitative Land Evaluation. It is true that still these models do not consider all factors that influence yields and/or socio-economic benefits (like oxygen deficiencies, weeds, many pests and plant diseases, attitudes of the farmers, etc.) but there are other means through which these missing factors can be accounted to make a more comprehensive land evaluation. Such a case is the Decission Support System for Agrotechnology Transfer (DSSAT) that is being developed by IBSNAT (11).

## Suggested steps in the use of simulation models in QLE

There are some suggested, and other necessary steps that should be followed in the process of applying simulation models for the land evaluation, specially in developing countries. Besides there



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are several unanswered questions or procedures that will have to be investigated and clarified before a sound methodology is established.

We believe the first condition is that the simulation models to be used have been validated for the environmental and crop conditions to which they are going to be applied. Validation implies (6) that we "trust" or have confidence in the predictions (partial or total) the models are doing for a given location and circumstance. As most of these models have not been constructed or validated in tropical and subtropical conditions, this is almost a prerequisite at the present time. In the IBSNAT project this is the stage where most collaborators from developing countries are concentrating at present. The process includes a comparison between experimental results and model predictions for the same site and time. In certain countries (3) a group of experiments covering the main agroecological and agricultural important regions have been established as a strategy of validation. It is also possible to use past experimental results, provided they have the minimum data set. Aspects like phenology, water and nitrogen balance and yield components are the main elements of comparison. Positive results with many of these elements have been obtained with the CERES - Maize in areas like Venezuela (3,4) and Hawaii (18) through formal statistical procedures of comparison.

In general we can not expect that simulation models will provide an exact fit for all circumstances and environments. Generally, model components have been built only considering certain ranges of environments, and the minimum data set never can cover all aspects of the environment or crop that may affect the results. To improve the above situation, a process of calibration or fine-tuning will be necessary before applying the model. The objective will be to minimize discrepancies between the model output and real system performance (6). The most sensible parameters of each model will be varied within certain bounds until the discrepancy criteria are reduced to a minimum.

Of special importance, and after validation of the model for an area, is the process of sensitivity analysis. In essence it comprise the evaluation of how sensible are the model outputs (ex. yields) to the different input variables. In other words: are yields more affected by a variation in the values of soil water retention parameters, or of initial nitrate values or of amounts of residue incorporated?. From this analisys we will know which are the most important input parameters and can derive recommendations for special considerations and methods in the collection of the minimum data set. Once we have enough confidence in the predictions the model can do for an area, provided with the neccesary data set, we can go into the process of model application.

As was mentioned at the beginning, probably the ideal situation for a QLE would be to couple a validated comprehensive simulation model to a detailed data base of the resources variables needed to run the model components. We have already dealt with the present situation of the IBSNAT models. Of course there are other models and other configurations (7,15,16), but in general there is a convergence of many modelers to structure their models in a



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similar fashion. The comprehensiveness is about the same and other approaches, different from simulation, like the use of Expert Systems (11), are being developed to cover aspects not included in simulation models but that are necessary in a Land Evaluation process. We think that with a reasonable effort developing countries can test, validate and calibrate, available crop simulation models. But a very important problem for these countries in the application of the ideal situation is the absence of a detailed data base of the resource variables needed by the models.

The ideal data base of the resource variables should contain point data of all the soil, weather, terrain, land use and socio-economic variables. But most developing countries only have broad scale maps of its territories and only small portions with semi or detailed level basic surveys. Besides weather data is point data but soil information is mostly areal. In these circumstances and if we want to apply simulation models there are several questions that have to be answered:

- Can we operate the simulation models with the available information derived from our basic studies?
- Are there reliable methodologies to increase or derive information on certain variables through time and space?
- What kind and at what level of confidence can predictions be done at different levels of detail of our resources variables?

We do not have the answer to all these questions but only some experiences and preliminary ideas. In relation to the first and second questions we have to separate the soil from the weather information. Soil information is mostly available as areas or delineations; very few point data is found mostly because of the low density of observations and because of procedures used in Soil Survey.

If we are using past soil survey data, we are forced, whether we like it or not, to use areal information together with models. That is a combination of models applied to the few point data available to make the predictions, and the extrapolations or transfer to analogous (probably mostly phases of taxonomic units) areas using the delineations of these units. The other implication of the question is if the basic surveys provide all the soil minimum data set necessary to run the model. The answer is generally no, as the water retention characteristics and nitrate-ammonium values of each layer is usually not collected in soil surveys. Nevertheless there are indirect methods, mostly through regression equations (2), that are used to predict water retention characteristics from particle size distribution, organic matter and bulk density. For the nitrogen components we still do not know of a way of estimating such values at a given time.

In case we are dealing with an area that already has a large amount of point data or an area in which land evaluation is to be done including the basic surveys, then the recomemdation is that all points studied are registered and that emphasis is given to the parameters that can be used to estimate these land qualities (water retention and nitrogen supply). In such cases the models would be applied to each point data and from the outputs we can then make delineations of quantitative classes that serve our

objectives.

In relation to weather information there are several aspects to be discussed. The ideal situation for model application would be to have a high density of meteorological stations with daily records during many years. These three conditions are never met in developing countries, but there are partial solutions to each of these situations. The daily records of many variables can be generated (19) from monthly records, provided we have long time records. The length of the records of one particular station can also be extended through various methods (8,13,20), either using the information of that station or from neighbor ones, in any case precipitation has to be generated first, then the other variables (17). The low density of weather information can also be partially solved by interpolation methods, like Kriging and others (8).

The third question relates to the scales or density of knowledge of our resources and the kind of predictions that we could expect at each level. It would be unrealistic and erroneous to apply a daily simulation model to a location with twenty years of weather records, but the soil information is at a density that only allows delineations of associations of great soil groups. For that location we could make a very detailed prediction with the model, but we can not extrapolate that prediction to all delineations that have the same soil associations. The level of the prediction and that of the vehicle used for that extrapolation would be incompatible. In other words we think that the different levels of detail (or scale) of natural resources have a corresponding level of detail in the predictions that can be done with a model. For instance, we are planning to test the hypothesis (5) that with the CERES-Maize we can only predict the suitable cultivars if we only have soil data at an scale of 1:250.000 or smaller, but if we have more detail and homogeneity in soils, like at a scale of 1:100.000 we can also predict the best planting time and plant population as we can deal with homogeneous areas in water balance; but if we also want to add nitrogen fertilization levels and ways of applying it, then we have to deal with more detail, possibly a scale of 1:25.000 or larger as in that case rather homogeneous areas in soil organic matter content would be a requisite for a successful extrapolation. Similar problems and approaches have been recently discussed by Dutch scientists (1,12).

## Conclusions

Among the various methods to do a quantitative prediction of crop adaptability and yields, and contribute to the process of quantitative land evaluation, simulation models stand as a most efficient, comprehensive, portable and versatile tool. But its application in developing countries requires, as a prerequisite, the validation and calibration to new latitudes.

For the use of validated models with present resource data bases it is required that new data will have to be derived or acquired, and in any case a combination of prediction at points with extrapolation by analogy, using existing soil maps, should be attempted. If new resource data bases are going to be

constructed to be used with models, more point data acquisition and more emphasis on certain parameters, like water retention and nitrogen supply qualities of the soils, will have to be done.

The level of knowledge in natural resources, or the scale of information have to be in correspondence with the level of prediction derived from the models. The factors not considered yet by the models, but that affect land evaluation, will have to be accounted by other means like the approach offered by Expert Systems.

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