A PROPOSED CROP YIELD MODEL

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Ringkasan

Tulisan ini merupakan suatu usulan model produksi tanaman yang merupakan salah satu bagian dari model analisis sistem untuk pembangunan pertanian. Dalam model ini digunakan tanaman padi sebagai contoh untuk membahas pengaruh interaksi antara derajat pengelolaan, faktor lingkungan dan sifat tanaman terhadap produksi.

Beberapa patokan yang digunakan dalam penyusunan model ini antara lain :

1. Pendekatan yang digunakan harus bersifat "convergence of evidence", artinya, produksi diduga melalui lebih dari satu cara. Hasil yang sama akan meningkatkan kepercayaan terhadap model tersebut, sedang hasil yang berbeda akan memberikan umpan balik bagi koreksi dan perbaikan model.
2. Mengandung berbagai persyaratan minimal yang harus dipenuhi.
3. Bersifat dinamis.

Konsep model produksi tanaman yang diajukan tersusun atas tiga sub-model yaitu (1) model pengurangan hasil, (2) model fenologi, dan (3) model keragaman hasil, yang satu sama lain berkaitan erat dan bersifat saling mendukung.

Penulis menyadari bahwa model yang dikemukakan masih sangat kasar sifatnya, serta perlu penjabaran lebih lanjut bagi setiap sub-modelnya.

I. Introduction

Crop yield models are simplified representation of the complex relationships between variables that comprise crop environment and crop performance using established mathematical of statistical techniques or both (Baier, 1977). These models can be relatively simple, or can also be complicated. Briefly, a model allows the synthesis and mobilization of existing knowledge about individual processes leading to yield and helps pinpoint deficiencies of knowledge. A model that works can calculate the crop's response to environmental changes.

Although much yield variation is due to weather, the effects of management, soil, and biotic factors must also be recognized. As a general strategy, the crop model should focus on factors responsible for most of the yield variation. Waggoner (1968) makes a distinction between strategic and tactical models. Strategic models are long-term oriented, while tactical models are for day-to-day decisions and assessment of currently growing crops. Tactical models are subdivided into those which forecast regional yields and those that assist the farmer in management activities.

This paper emphasizes the crop management - environment interaction leading to yield using rice crop as a model. The model will be oriented to crop physiology and the assessment of the impact of environmental parameters. It is constructed so that the following guidelines apply :

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1. It should employ a "convergence of evidence" approach; that is, yield is predicted via more than one calculation mechanism. Similar results increase confidence; different results establish the need for further analysis.
2. It should incorporate a "most limiting factor" concept into the model logic.
3. The model should not static. It changes and becomes more precise as new information gathered.

II. Crop Yield Model Conceptualization

The overall yield model has four major components : (1) a data base, (2) a yield reduction model, (3) a phenology model and (4) yield variances model (Figure 1). The data base is the input source to all three models. The phenology models is developed based on the model of physical crop production, as developed by the Centre for World Food studies (Research Report SOW-80-5). This model interfaces with the yield reduction model and yield variances model, and these in turn provide independent yield estimates. The final yield prediction value is derived from these yield estimates.

2.1. *Data Base*

Data that will be needed for optimum model operation should be gathered, interpreted, coded, formatted, and entered into the data base for retrieval during model execution. Probably not all these data will be available. In this case, judgement will provide, especially for critical model driving data, while for non critical data, perhaps can be left empty.

2.2. *Yield Reduction Model*

The yield reduction model assesses the impact of various environmental parameters on yield. The model is operated such that environmental occurences with the most significant impacts on yield are examined first, followed by those which affect yield to a lesser degree. The yield reduction model is developed by assuming that yield is influenced by the environment and management practices in the following manner :

$$Y = Ym \; ij \, \Pi \, (1 - Rij) \qquad (2 - 1)$$

where Y is predicted yield, Ym is maximum potential yield (i.e., yield under ideal environment and optimum management practices), and Rij is yield reduction expressed as a fraction of Ym, caused by stress in the ith environment or management factor at the jth growth stage. The maximum potential yield Ym is calculated from the mean yield plus three standard deviations above that mean.

The model, equation 2 - 1, specifies that each environmental and management stress reduces the maximum potential yield by a given percentage, and that the final yield is computed as the yield under ideal environment and management minus the cumulative yield reduction due to all stresses. The specific yield reduction equation needed for the estimation of each Rij. Some of the yield reduction equations are the same for all growth stages, whereas others varied widely from one growth stage to another. Another reduction equation may be can be assumed to be important only at a particular growth stage.

The maximum potential yield can be calculated for any year, but if a historic yield ever exceeds it, then the trend must be reanalyzed. If after reevaluation a historic yield is still larger than the recalculated Ym, then the highest historic yield is used as the Ym.

2.3. *Yield Variances Model*

The model operation is based on the procedures of making crop inferences by comparing the present growing season's environmental parameters with those of past seasons. Meteorological variables such as temperature, rainfall, and wind velocity are compared with historic means, variances, and abnormalities are flagged as causing potential yield impact. If flags are not raised, then the yield estimates are derived from multiple regression analysis :

$$Yi = bo + \sum_{i=1}^{k} biXi \qquad (2 - 2)$$

where : Yi is the predicted yield, bo is the estimated intercept and bi is the ith least squares estimates of regression coefficients for the ith predictor Xi.

2.4. *Phenology Model*

The phenology model operating as part of the crop yield model, supports the yield impact assessments made by moisture, temperature, solar radiation, nutrients etc. As mentioned earlier this model is developed based on physical crop production model developed by CWFS.

The model is based on the assumption that the physical production of a particular crop is dependent on the characteristics of that crop and of the sits where the crop is grown. The main determinants of a site are soil and climate characteristics, including topographical and hydrological conditions. Reclamation levels are also considered in this context. The models have a hierarchical relationship, introducing sequaentially the constraining factors of photosynthetic energy, water availability and nutrient supply.

The main factor influencing crop production at a particular site are the levels of solar irradiance, available water and available nutrients. All these change in the course of the cropping period. Hence, the model employs time intervals during which a steady state situation is assumed to exist. The intervals need to be as short as permitted by the relaxation time of the system.

The first production factor considered is the level of irradiance. At each site and for any time interval total irradiance can be measured. Its level governs the rate of CO2 assimilation and hence the maximum rate of dry matter accumulation of crop. Two distinctly different photosynthetic pathways exist, known as C3 and C4 pathways. Plants of the two types differ in physiological characteristics; a major difference lies in the maximum rate of CO2 assimilation, i.e. the assimilation rate of light saturation which the plant can achieve. The dry matter production of a standard crop is calculated for all time intervals in the growing season of the crop. Addition of these partial production figures yields the standard production of the crop (Pst), i.e. the production limited only by physiological plant properties and the prevailing conditions of temperature and irradiance.

The quantity of water which is available for use of the crop during each time interval is analyzed at the second hierarchical level in the model. Shortage of available water during part of the growing season is common to most cropping systems. The quantification of water availability during each time interval is rather complicated because it involves land and soil characteristics, precipitation and evapotranspiration as well as irrigation and/or drainage. To determine the amount of water available at the onset of the growing period, the conditions preciding the time of sowing have to be taken into account as well. The whole procedure is described with the aid of a water balance sub model.

With the aid of the water balance, the potential dry matter production (Ppot) is calculated, under assumption that direct proportionally exist between water use and dry matter production of water is the limiting factor. The harvested index i.e. the ratio between dry matter accumulated in the harvested product and the total dry matter produced, is used to calculate the potential economic yield at the chosen site under the prevailing conditions of water availability and under the assumption that all other production factors are not limiting. This potential yield (Ypot) can be increased by measures of land emelioration that augment the quantity of available water or by breeding new crop varieties which make more efficient use of the available water or both.

The availability of plant nutrients, notably of Nitrogen (N) phosphorus (P) and potassium (K), is analyzed at the third hierarchical level of the model. In many systems where fertilizers are not applied, shortage of plant nutrients, particularly nitrogen limit crop production. A host of experiments on soil fertility, including the effect of manure, compost, and artificial fertilizers on the uptake of NPK by crops and on the efficiency of fertilizer applications should also be available. This information forms the basis of a generally applicable method to predict the nutrient response of crops. It applies at all levels of technology. Reliable data on the natural fertility status of the soil is of importance. If the nutrient status of the soil is known, the calculated potential yield (Ypot) can be transformed into the expected yield at a specific nutrient level (Y nut).

In addition to these main factors, a number of other production factors are successively introduced in the model. These are :

- weed control
- plant protection
- soil erosion and conservation measures
- harvest losses.

They may or may not reduce Y nut to the calculated real yield (Y end) expressed at standard moisture content.

This short outline suffices to illustrate the hierarchical approach followed; the model is open ended and more factors can be added, should the need arise. The structure of entire hierarchy is outlined in figure 2.

Diagram in figure 2 concerns only the production by one crop. However if the model is applied to a region or country, more than one crop has to be considered. These crops are possible grown in a rotation at a great many sites with varying weather and soil conditions and under different levels of reclamation/amelioration. In addition, a number of technology levels are possible. This implies a considerable number of possible combinations, not all of which are relevant in a given situation. An intelegent choice has to be made to narrow down all possibilities to a limited number of farming systems, considered relevant for the purpose of the study.

The whole modelling exercise can only be made if essential data are available or if reliable estimates can be made. It is a major advantage of the hierarchical approach to the problem of quantifying crop production that partial knowledge is used to the maximum. A disadvantage may be that it is difficult, some times impossible, to describe feedbacks between hierarchical levels. Insufficient knowledge of crop-soil relationships remain the main bottleneck at present.

III. Analyst Evaluation

Yield models are only tools. The crop yield model discussed have uses a convergence of evidence approach, so that the analyst can make a more reliable yield estimate.

The model also flags the main factors influencing yield so the analyst can troubleshoot if something appears wrong.

The first thorough test of a model is often the comparasion of the behavior of its output with that observed of the real system in an analogous situation. This behaviour includes, for instance the general shape of the time course of variables, the presence of discontinuities and the qualitative sensitivity of output to parameter values (De Vries, 1977). One should be aware, however, that aspects of model behaviour that seem counter-intuitive at first some times turn out to be realistic.

If the behaviour of a model matches qualitatively that of real world system, a quantitative comparison and an evaluation of the predictive success of the model should be made. At this stage, statistical tools can be useful.

A useful form of behaviourial analysis is an extension of sensitivity analysis. It is done by increasing or decreasing one parameter value over a broad range, and comparing direction and shape of the output with the known or expected direction.

In interpreting the model estimates, the confidence level of the results must be determined. Confidence levels can be added to the data stored within data base. Then a confidence level factor can be generated along with the yield estimates. For, example, if the meteorological data for an area or region are generated by spreading program because there are no meteorological data for that area, the confidence level in the yield estimates will be lower. If the area/region has a large variation in topography, then the confidence level of the data may be further reduced. This provides the analyst with a reliability factor that can be taken into account in his final yield prediction.

Success in yield predictions from the model allows the evaluation of factors limiting yield in an area or region. Research can then be brought to bear to reduce the impact of the limiting factors.

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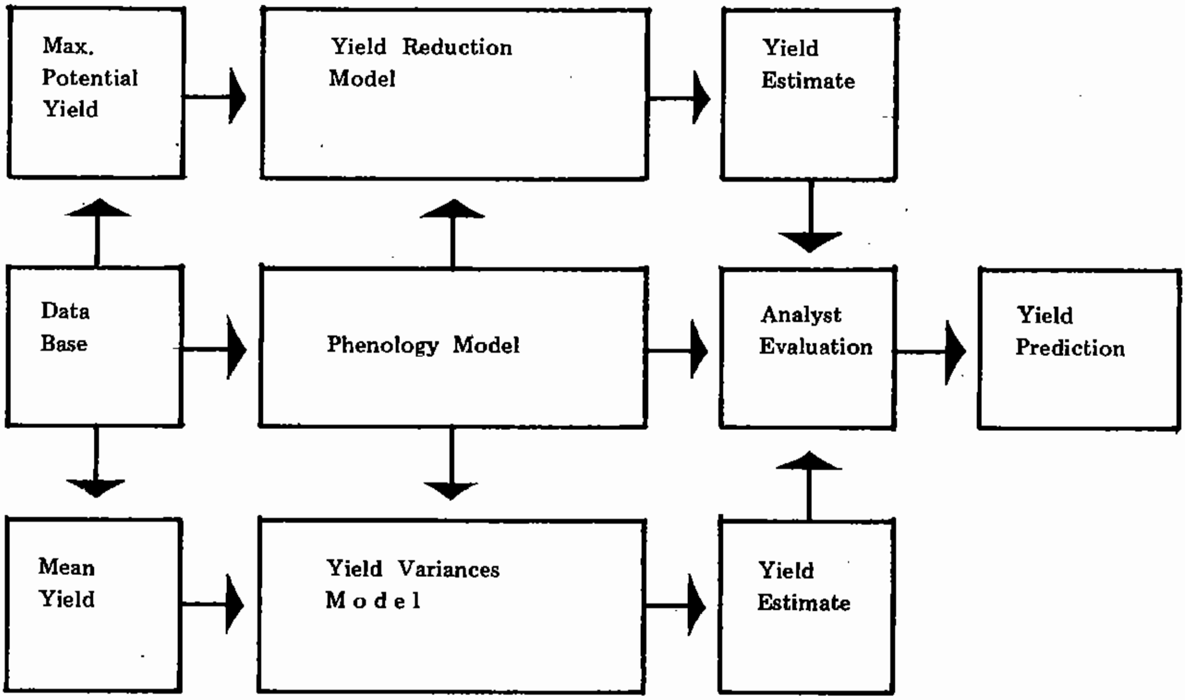

Figure 1. Function flow overview of conceptual crop yield model.

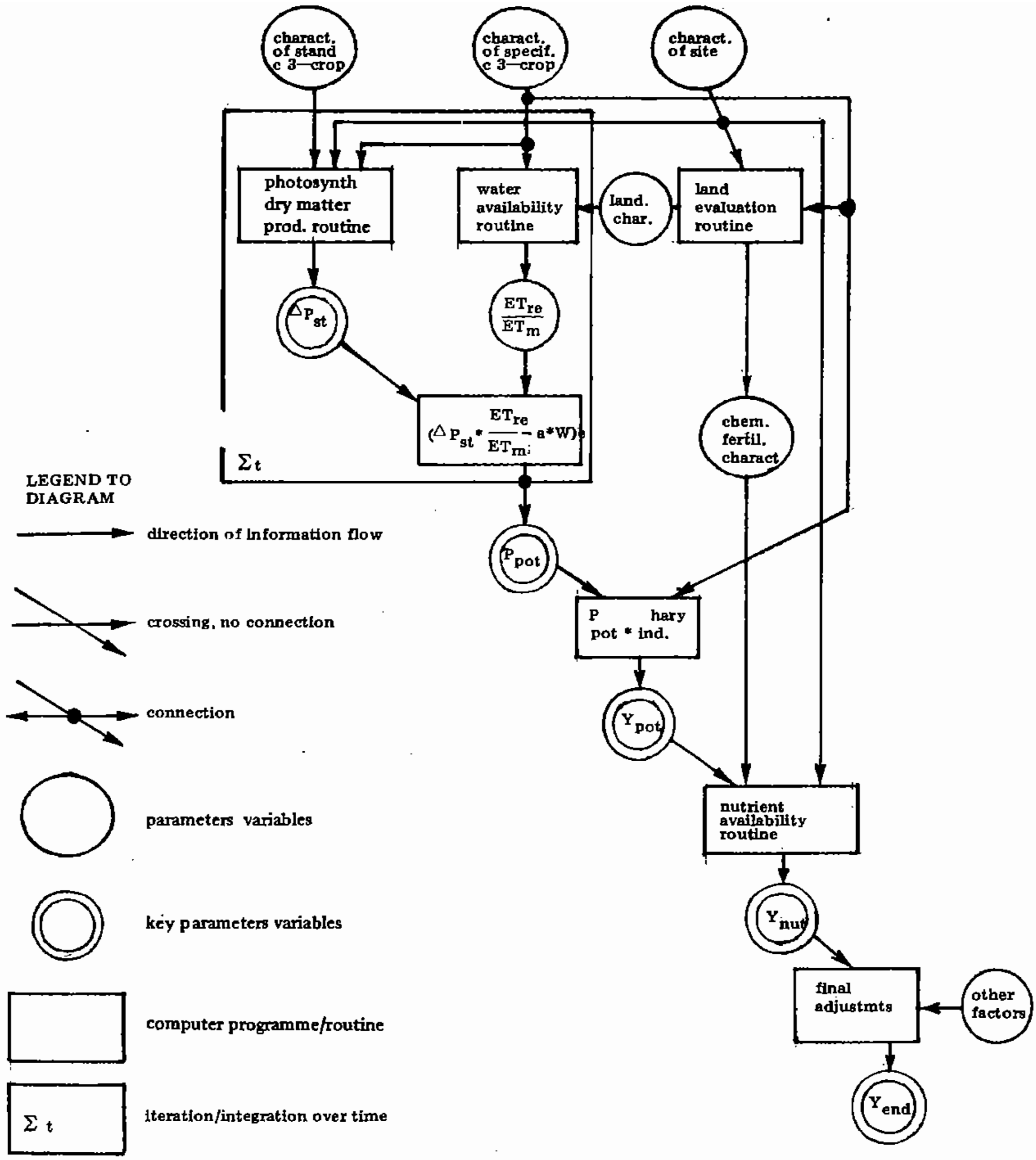

Figure 2. Hierarchical analysis of the main factors determining the physical production of a specific C_3—crop at a specific site.