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USE OF SIMULATION IN EVALUATING POTENTIAL YIELD AND WEATHER-RELATED VARIABILITY IN CROP PRODUCTION*

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ABSTRACT

Estimation of potential yield of a crop over an area and evaluation of its stability due to weather fluctuation are important concerns in crop production. The use of a crop growth model that provides a sound ecophysiological basis for evaluating crop yield and yield variability due to weather or other factors that are otherwise difficult to analyze through field experiments or on-farm trials is presented. Applications of simulation as a scientific tool in crop production research and development are illustrated by simulating crop behavior under different management situations and weather conditions.

Introduction

Statistics on yields and areas under crops are often used as determinants of crop production. Reliable estimates of crop production are imperative in formulating and planning national programs to meet the food requirements of increasing population. Crop production data are used for such purposes as implementing policies on importation or exportation of agricultural products during deficit or surplus periods, formulating price policies (including subsidies) to encourage improved crop production, measuring the contribution of agriculture to the gross domestic product (GDP), and assessing agricultural productivity level (FAO, 1982).

The impact of weather on agricultural production is often evaluated in terms of crop yield stability or yield loss due to extreme weather conditions. However, assessment is usually based on subjective measurements through interviews or ocular inspection, or on empirical procedures, such as regression models or some yield loss indices. But the planning and decision-making applications of such important basic information require more improved methods and reliable and valid agricultural statistics, such as crop areas and yields as well as the associated variability due to weather fluctuations.

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Estimation of Crop Yield

Several methods of estimating crop yields have been used to provide data on crop production components. One widely used method is eye estimation or "guesstimation" of expected yield per unit area, and also of areas under different crops. This method can provide reliable estimates only if the data collector is highly experienced and results are further validated by other means. Another method is by crop-cutting where a smaller area under a crop is harvested and the yield for a much bigger area is estimated by extrapolation. This method is very accurate but may be costly and time-consuming. An alternative method being used, particularly in developed countries, is the aerial estimation technique using aerial photographs and/or imageries. This procedure is used only for large areas where the cost of aerial photographs is relatively cheap or minimal. It requires experience and is expected to provide reliable estimates.

The use of yield prediction models has also become popular because of its accuracy and ease of application. The method is largely statistical, requiring historical data series on which to base or develop the model. There are quite practical reasons for moving from the purely experimental/statistical approach to a process-type approach. Just recently, the use of crop models (Penning de Vries, *et al.*, 1989) to simulate crop growth and also determine crop yield were proposed. Such process-based crop models may also be used to evaluate impacts of factors, such as weather fluctuations and/or biological constraints on crop production (see e.g. Penning de Vries, *et al.*, 1989; Lansigan, *et al.*, 1989).

Evaluating Crop-Weather Relations

Weather is an important factor in crop production and greatly influences the stability of crop yields. Weather variables, such as rainfall, solar radiation, and temperature influence significantly the rate of crop growth. In the tropics, weather-related perturbations such as droughts, floods, typhoons, and strong winds account for significant loss in crop yields. Weather also indirectly exerts influence on biotic stresses to crop growth like pests, diseases, and weeds.

One commonly used indicator in evaluating crop-weather relations is yield performance of crop grown under weather conditions or climatic zones. The reliability of the assessment depends on the ability to replicate a weather condition under which the crop is grown, as well as in the ability to control other factors in the field excluding weather. Unfortunately, however, this is almost impossible to do.

There are two basic methods in evaluating crop-weather relations. In the first method, the statistical or correlation approach, empirical relations or functions are determined between yield and one or more weather variables usually by regression analysis. The form of the model may vary in the number of variables, type of weather data used, and crop being considered, and may apply only for a specific location or region. Although statistical models can provide reasonable quantification of weather effects, they require a large set of data on crop yields and weather variables. Thus, their applicability may be quite limited. Moreover, since these models do not relate to the ecophysiological processes governing crop growth, they are less useful in research on crop production and on crop-weather interactions.

The second approach is by using crop simulation models. Since these models are based on crop physiology, they are applicable for any crop anywhere, provided the quantitative information on the processes required in the model are available. Construction of crop models uses the systems analysis approach whereby the key processes involved in crop growth are incorporated in the simulation models. However, the reliability of the models depends on the quantitative representation of the basic processes involved. Due to the large data sets required and iterative calculations to be handled, crop simulation models necessitate the use of computers with adequate storage memory. Moreover, modeling in the computer requires the use of an efficient simulation language.

This paper illustrates the potential uses of crop modeling and simulation in estimating crop yield and evaluating yield stability in crop production due to weather variability. The presentation is concerned with rice since it is an important crop, although the same approach may be used for other crops as well. Summary models for rice (e.g. RICEMOD, IRRIMOD, etc.) are already available and have been validated. Applications of such models in agricultural research particularly on rice-based cropping system will be presented by citing some of the research and simulation results that have already been done elsewhere.

Crop Simulation Model

A crop simulation model is a simplified representation of a crop considering the processes governing crop growth. Such as model can be used to determine the crop behavior under a specific environmental condition. Several crop simulation models have already been developed and documented (see e.g. Penning de Vries *et al.*, 1989; McMennamy and O'Toole, 1983), and have been demonstrated to give satisfactory results during evaluation. Utilizing the systems approach, these models allow identification of those processes and interactions which are not yet sufficiently understood oı quantified. Thus, they easily help define directions and goals for further research.

Figure 1 shows a relational diagram of a model for a crop growing under optimal conditions, i.e. no water stress, without soil nutritional deficiency, and no pest and disease problems. The relations among key crop growth processes such as photosynthesis, maintenance respiration, and assimilate partitioning are indicated, so are the effects of light and temperature on crop growth and development. Since the model is process-based, other process components may be introduced without changing its basic form. For instance, a crop growing under limited water may be modeled by incorporating a soil water balance component into the basic crop model (see Figure 2). Likewise, the effects of pests and diseases on crop can easily be introduced in the basic model (see e.g. Rabbinge *et al.*, 1989).

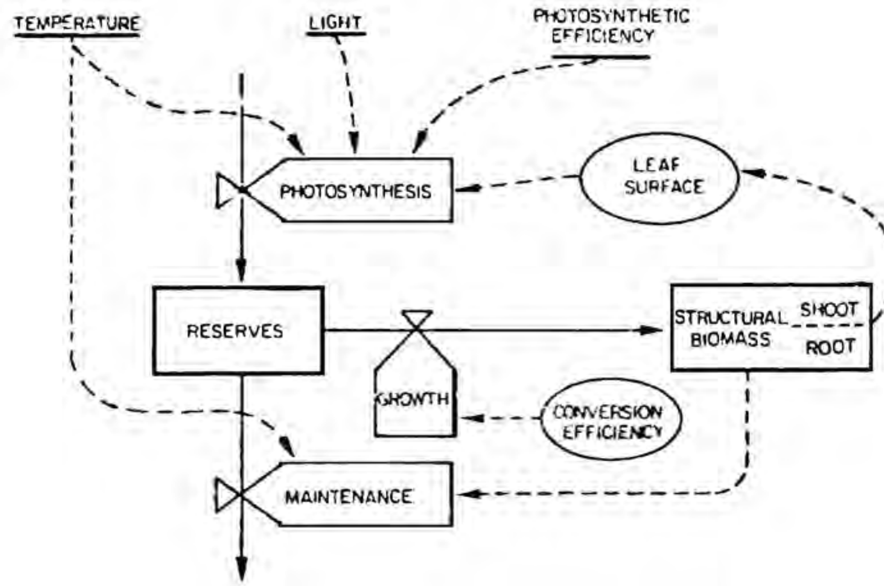

Figure 1. A Relational diagram of a model of a crop growing under well-watered condition and without nutritional or pest problems (Penning de Vries and van Laar, 1982). Light and temperature affect growth and development.

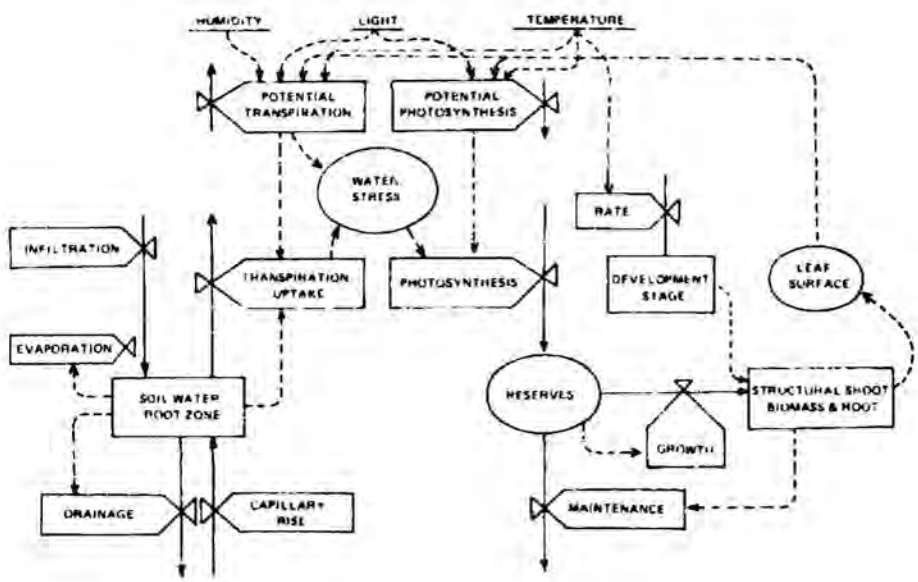

Figure 2. A relational diagram of key processes in crops growing with limited water. From: Penning de Vries *et al.*, 1989.

Since the crop model considers the key ecophysiological processes affecting crop growth and development, many input data sets are required in the simulation. Aside from the crop data and weather data sets (either historical or generated), the model may require soils data (e.g. soil depth, number of soil layers, soil type, etc.). Although some quantitative information on the basic processes are available for some crops such as rice, description of the processes still need to be based on experimental data.

The dynamic rice growth model (Penning de Vries *et al.*, 1989) is a summary model that simulates the such processes as photosynthesis, respiration, and crop phenological development for time increments of one day (De Wit, *et al.*, 1978). One computer language that is widely used in crop simulation model is CSMP which has been adapted recently for IBM PC micro-computers or compatibles.

Some Practical Applications of Crop Models

Determination of Optimal Cropping Calendar

One useful application of a crop model in determining the best time to plant crop in a particular location. The optimal planting period can be approximated by simulating crop yields given, say, 20 years of weather data (Lansigan, *et al.*, 1987), and evaluating at which time periods the yields are relatively high and stable.

Figure 3 shows the simulated yields of a rice crop planted during different dates throughout the year under Los Baños condition based on 20 years historical weather data. It is noted that yields are high during the period of April-November which coincides with the wet season in the area.

Evaluating Weather-Related Yield Variability

Weather-related variability in potential production can also be evaluated quantitatively using a crop model by determining crop performance under different weather conditions and management situations. Figures 4 and 5 show the simulated yields of rainfed rice and computed yield variabilities for Iloilo and Davao, respectively. The figures indicate the different behavior of crop yield under two different climatic regimes. Yield variability is relatively low during May-October in Iloilo; it is also low throughout the year in Davao.

Influence of Biological Constraints

The effect of pests and diseases on crop yield can also be assessed by incorporating a pest model component in the basic crop model. For example, stemborer damage on rice crop has been simulated, and validation with experimental data in the field show good results (Xia, 1988).

On the other hand, yield reduction due to weeds has also been evaluated and simulations show satisfactory results (Legaspi, *et al.*, 1987). Crop-weed competition

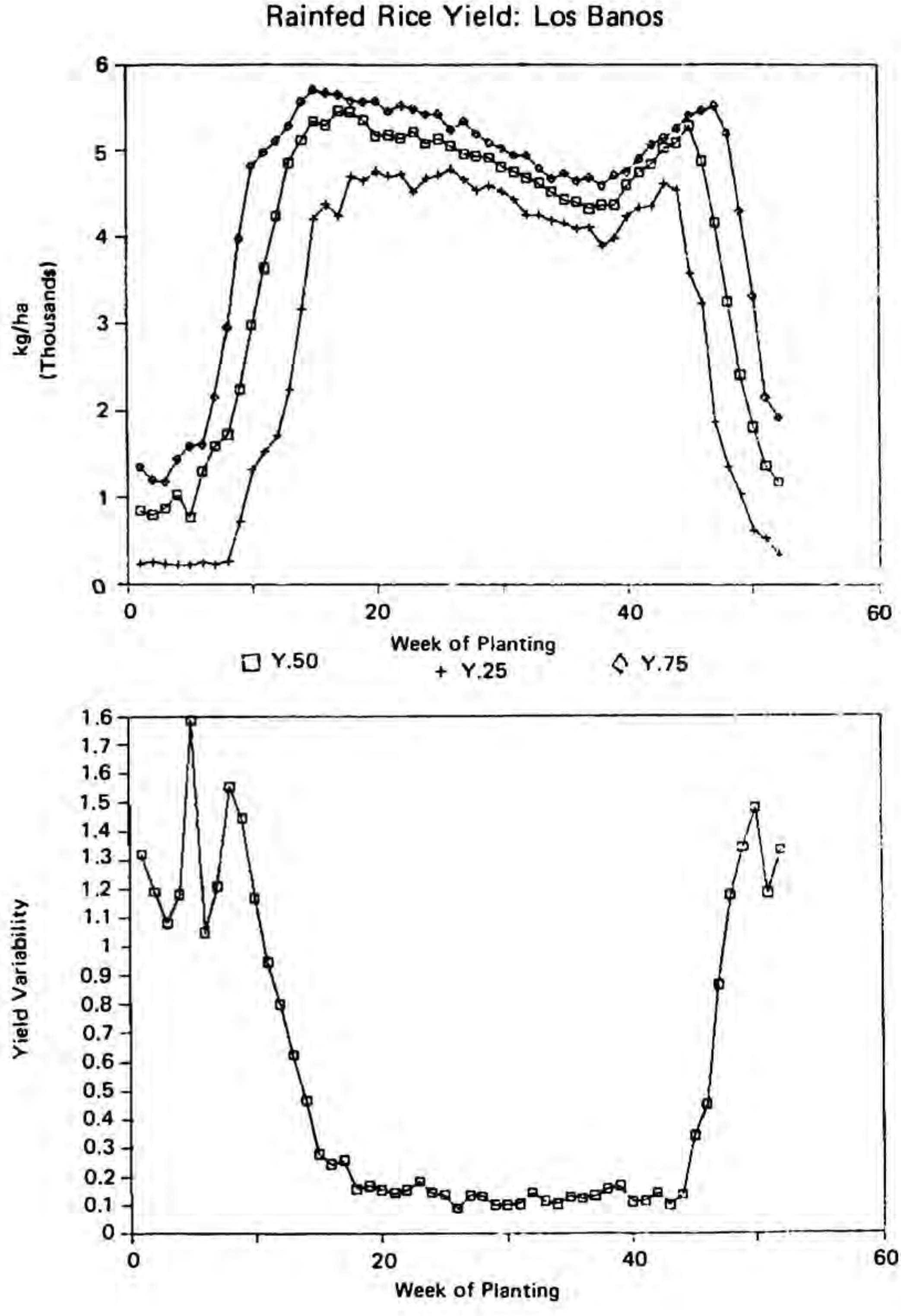

Figure 3. Simulated potential rainfed rice yields and associated variability under Los Baños conditions.

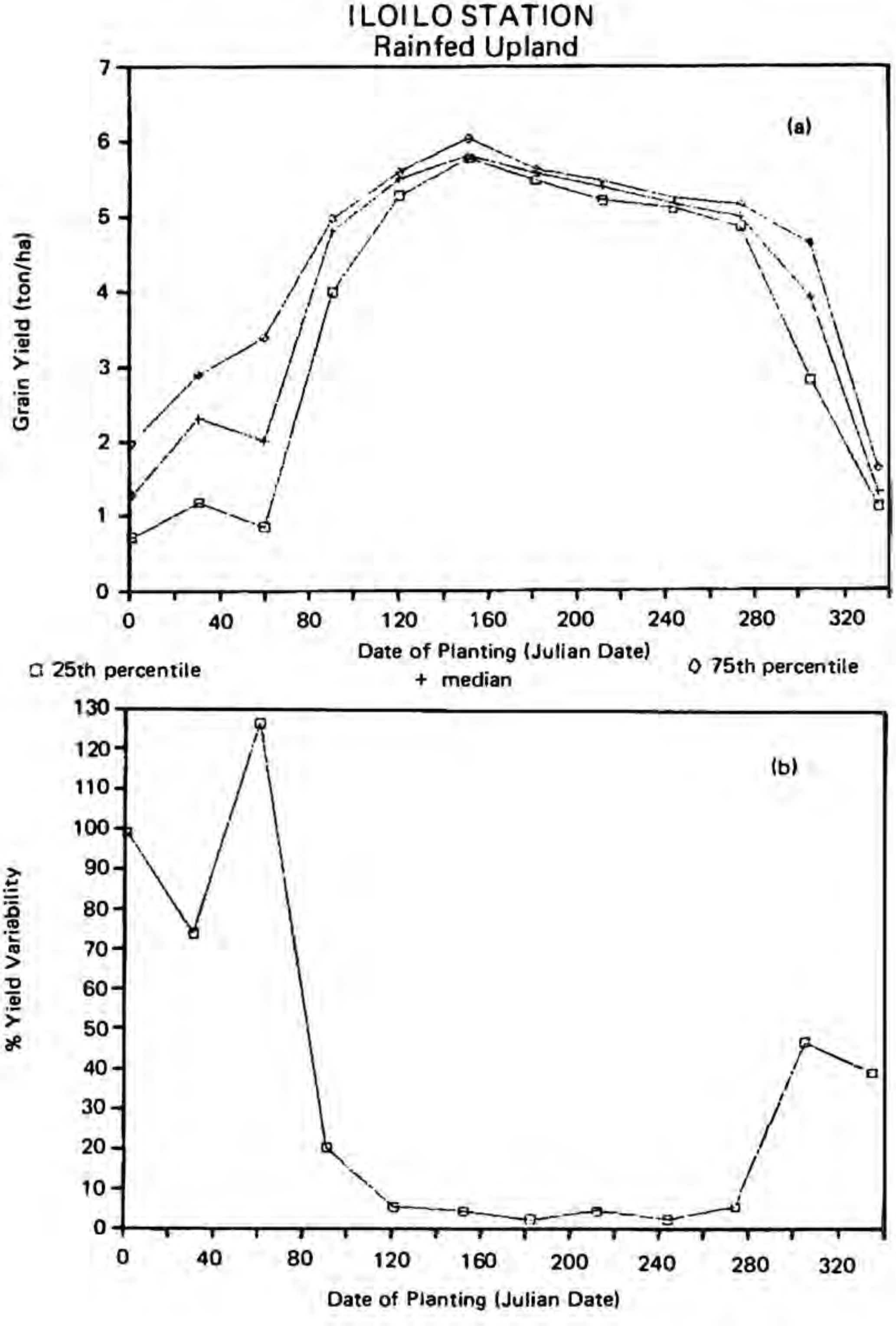

Figure 4. Simulated (a) median and quartile yields of rainfed rice; and (b) computed yield variability for Iloilo.

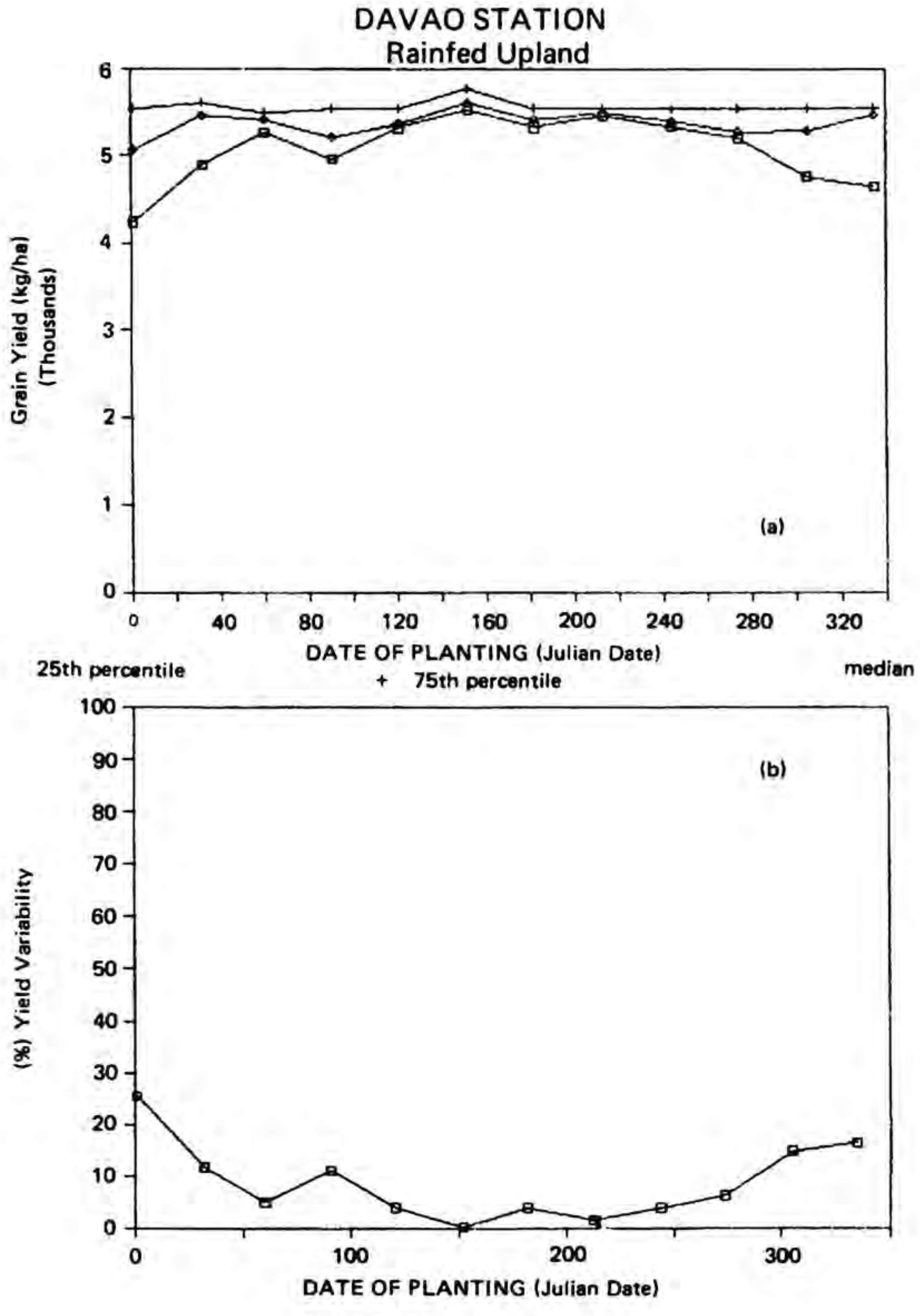

Figure 5. Simulated (a) median and quartile yields of rainfed rice; and (b) computed yield variability for Davao.

is simulated by treating the weeds as another crop that competes with the rice crop in water, nutrients, and sunlight. The crop-weed competition model can then be used to determine the frequency and timing of weeding during rice crop growing period.

Concluding Remarks

Crop simulation has been shown in several practical applications to be a potentially useful tool in crop production research particularly in the quantitative evaluation of crop performance under different management situation and environmental conditions. The crop models that have been developed based on the present scientific knowledge and understanding of the ecophysiology of the crop can be used to identify and study the factors that influence growth and development, and thus define the knowledge or information gaps which can be addressed in future research.

Dynamic crop simulation models allow a more objective estimation of potential yield and evaluation of weather-related variability in crop production which are difficult to conduct otherwise. The use of crop simulation models in conjunction with other conceptual models provides for a cost-effective and efficient approach in agricultural research particularly on crop production.

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