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Crop Modelling – A Futurist Tool for Agricultural Research

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Abstract

Agricultural models are mathematical equations that represent the reactions that occur within the plant and the interactions between the plant and its environment. Process-based models capture our understanding of key processes that interact to determine productivity and environmental outcomes. Combining measurements and modelling together help assess the consequences of these interactions, identify knowledge gaps and improve understanding of these processes. The model simulates or imitates the behaviour of real crop by predicting the growth of its components, such as leaves, roots, stems and grains. Thus, a crop growth model not only predicts the final state of total biomass or harvestable yield, but also contains quantitative information about major processes involved in the growth and development of a plant. Crop modeling enables research works more relevant to the real-world problems. Over a short period of time and low costs, large number of management strategies can be analyzed. Thus, crop models can be used as tools for supporting strategic and tactical decision making under current scenario of climate change conditions.

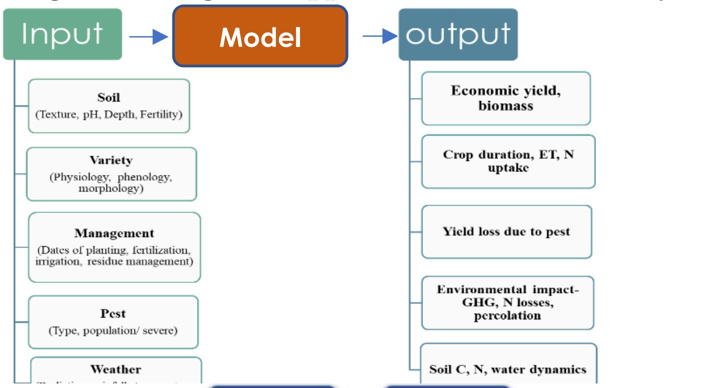
Introduction

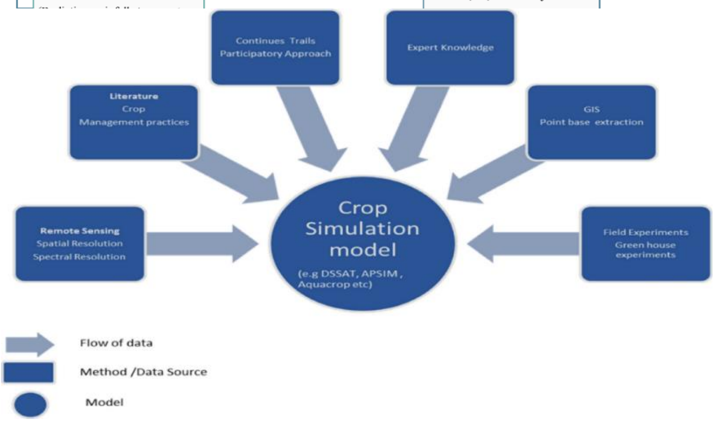
The Earth's land resources are finite, whereas the number of people that the land must support continues to grow rapidly. This creates a major problem for agriculture. Production must be increased to meet rapidly growing demands while natural resources must be protected. New agricultural research is needed to supply information to farmers, policy makers and other decision makers on how to accomplish sustainable agriculture over the wide variations in climate around the world. In this direction the use of crop models in research is being encouraged. Crop simulation models are used over past 20 to 30 years by scientists to hypothesize ways to improve agricultural production under seasonal and daily variability in weather (Kadiyala *et al.,* 2015). These models in connection with different General Circulation Models (GCM) predict the future agricultural practices that can adapt to different climate change scenarios (Araji *et al*., 2018). In this way it is more important for planning and policy of food security and national development strategies.

Models help us understand system behaviour by illustrating what is happening with things which we can't or don't measure and playing "what if" games with models is inexpensive and fast. We can give prediction to different locations, soils, crop varieties and different potential future climate scenarios (CO_2, temperature, rainfall patterns) (Li *et al*., 2004). This is difficult to do with field experiments – easy with model. Modelling does not replace rigorous experimental work, but it can complement and extend experimental data in space and time (Lustick, 2000). In the present context, 'Model' is expressed as a computer program that can be repeatedly run several times for computing several designed mathematical or statistical expressions (equations) governing crop growth-environment relations, given appropriate input data. It was mathematical algorithms that capture the quantitative information of agronomy and physiology experiments in a way that can explain and predict crop growth and development. They can simulate many seasons, locations, treatments, and scenarios in a few minutes. Numerous complex physical processes taking place at any given time. (Crop growth, soil water dynamics, decomposition, nutrient dynamics, climate., etc). Scheidegger et al. (2015) describe Model is a simplified description (often, a mathematical representation of a system to assist calculations and predictions). These processes are interacting with each other and complexity of these interactions can surpass our ability to 'guess' what is going to happen. Harrison et al (2018) studied models as Integrated economic and biophysical simulation models that capture the key biophysical and economic factors/processes and their interactions can play a useful decision support role as represented in **Figure 1**. Once calibrated and tested enable rapid analysis of implications of a wide range of system design and management options and sensitivities. Enable extrapolation to other seasons and sites – temporal and spatial variability. Useful as a tool for learning / understanding / training as depicted in **Figure 2**. The challenges of producing locally relevant and climate informed results from crop simulation models across various time frames from seasonal to future climate change for agriculture is complex (Kephe *et al.*, 2021). In order to establish resilient and sustainable agricultural systems in the face of climate change, there is a need for effective adaptation measures to be established.

Fig 1. Over view of Inputs and Outputs in a Model

Fig 2. An integrated approach to data availability





for input into crop models

Basic steps in crop modelling

Step 1. Define Goals: Agricultural system (we should have definite objective).

Step 2. Define system and its boundaries**:** Crop model (based on the objective we should choose the model).

Step 3. Define key variables in system

a. State variables: Variables that can be measured. Eg: Soil moisture content.

b. Rate variables: Variables that measure the rate of various processes.

   Eg: Photosynthesis rate, Transpiration rate.

c. Driving variables: Variables that are not part of the system but are essential for analysis. Eg: Climate.

d. Auxiliary variables: Variables which are the intermediate products. Eg: Dry matter partitioning.

Step 4. Quantify relationships (Evaluation): Developing relationships and interaction between the variables.

Step 5. Calibration**:** In many instances, in crop models the simulated values do not exactly comply with the observed data and minor adjustments have to be made for some parameters. To make the model work correctly, some of the parameters in the equations and even some of the relationships have to be adjusted. This process is called as calibration.

Step 6. Validation**:** A practical model should be rigorously validated under widely differing environmental conditions to evaluate its accuracy on overall yield predictions, as well as the performance of major processes in the model. Normally, the results from the validation process are used to refine the model or to guide modellers to further experiments that will produce a better model. Only after extensive experimental validation, a crop model become an actual working tool capable of providing guidance on the practical management of agricultural systems.

Step 7. Sensitivity Analysis: Most crop simulation models have a large number of parameters, many of which are not directly measurable. Consequently, it is worthwhile to concentrate on the most influential parameters, i.e., those to which model outputs are the most sensitive which is known as sensitivity analysis.

Policy Interventions that can be driven from modelling

1. **Best management practices**

Model having chemical leaching (or) erosion components can be used to determine the best practices over the long-term. EPIC model has been used to evaluate erosion risks due to cropping practices and tillage.

2. **Yield forecasting**

Yield forecasting for industries over large areas is important to the producer, the processing agent as well as the marketing agency. The technology uses weather records together with forecast data to estimate yield across the industry.

3. **Introduction of new crop**

Agricultural research is linked to the prevailing cropping system in a particular region. Hence, data concerning the growth and development of a new crop in that region would be lacking. Developing a simulation model based on scientific data collected elsewhere and a few data sets collected in the new environment helps in the assessment of temporal variability in yield using long-term climate data. Running the simulations with meteorological data in a balanced network of locations also helps in locating the industry.

4. **Global climate change and crop production**

Increased levels of CO_2 and other greenhouse gases are contributing to global warming with associated changes in rainfall pattern. Assessing the effects of these changes on crop yield is important at the producer as well as at the government level for planning purpose.

Applications of Crop Modeling

i. Can understand the plant, soil, weather and management interactions
ii. Predict crop growth, yield and timing (outputs)
iii. Optimize management using climate predictions
iv. Diagnose yield gaps, actual vs. Potential
v. Optimize irrigation management
vi. Greenhouse climate control
vii. Quantify pest damage effects on production
viii. Precision farming
ix. Climate change effects on crop production
x. Can be used to perform "what-if" experiments on the computer to optimize management.

Table 1: Some of the models developed in India and models used in India

Model name	Applications
Developed in India	
WTGROWS	Simulating the Wheat crop.
ORYZA1N	Variety selection & Nitrogen optimization in non-water stress condition.
INFOCROP	Chickpea, Cotton, Maize, Mustard, Pearl millet, Pigeon pea, Potato, Rice, Sorghum, Soybean and Wheat.
INFOSOIL	Soil related model.
Models used in India	
DSSAT	Framework of crop simulation models including modules of CERES, CROPGRO and CROPSIM.
APSIM	Sugarcane, potential growth, water and nitrogen stress.
CROPSYST	Wheat and other crops.
ORYZA1	Lowland rice.
WOFOST	Quantitative analysis of the growth and production of annual field crops.
DNDC	Carbon and nitrogen biogeochemistry in agroecosystems.

Limitations in Crop Modeling

a. Inaccurate projections of natural processes
b. Unreliable and unrealistic projections of changes in climate variability
c. Crop models are not universal (No site specificity).
d. Inappropriate for heterogeneous plot
e. Inherent soil heterogeneity over relatively small distances
f. Model performance is limited to the quality of input data.
g. Sampling errors also contribute to inaccuracies in the observed data.
h. Rudimentary model validation methodology
i. Plant, soil and meteorological data are rarely precise and come from nearby sites.

j. An ideal crop model cannot be developed because of complex biological system.

Way forward

Modelling is a sophisticated process and that need to be trimmed precisely in accordance with the local scenario provided. A well documentation of weather elements on regular basis is the much-needed input. Along with it result oriented input data must be noted periodically and for this modern instrument need to be accessed. Proper calibration and validation are mandatory before the model usage, modelled results must be statistically studied and evaluated.

Conclusion

The challenges of producing locally relevant and climate resilient production systems from field experiments across various time frames from seasonal to future climate change scenarios in agriculture is complex. In order to establish resilient and sustainable agricultural systems in the face of climate change, there is a need for effective adaptation of crop models. Crop modelling has also a great contribution in developing strategic decision-making process. The issue is related to the possibilities of feeding the booming world population and the effects of climate change on production systems. A model output can be explained, indicating when to plant, irrigate, how much to irrigate, harvest and the type of management practices is provided as conditional. Another type of tactical decision support crop forecasting, which emphasizes on the prediction of climatic and related yields over the current season or year.

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