NEW ERA AGRICULTURE MAGAZINE

Crop Modeling: A tool for Future Agriculture

Abhilash Singh[*], Narendra Pratap Verma, Ankit Singh and S.K. Pande

Introduction:

Timely and accurate crop yield forecasting and prediction on regional to national scales is increasingly becoming important both in developing and developed countries. Yield forecasting is defined as the estimation is advance what the yield of a certain crop will be at the end of the growing season, whereas yield prediction is the estimation of actually realized yields after harvest. Especially for yield forecasting, methods are being investigated that are based on new objective techniques such as crop growth modeling and remote sensing.

Crop Modeling

Modeling is the use of equations or sets of equations to represent the behaviour of a system. In effect crop models are computer programmes that mimic the growth and development of crops. Model simulates or imitates the behaviour of a real crop by predicting the growth of its components, such as leaves, roots, stems and grains. Thus, a crop growth simulation model not only predicts the final state of crop production or harvestable yield, but also contains quantitative information about major processes involved in the growth and development of the crop. Reactions and interactions at the level of tissues and organs are combined to form a picture of the crop's growth processes.

Brief history of Crop Modeling

Jame (1992) reviewed the history of attempts to quantify the relationships between crop yield and water use from then early work on simple water-balance models in the 1960s to the development of crop growth simulation models in the 1980s. The first attempt to model photosynthetic rates of crop canopies was made in 1960s. Although the relevance of crop growth simulation models in crop agronomy was challenged initially, crop growth modeling has changed dramatically during the past 40 years.

Types of models

Depending upon the purpose for which it is designed the models are classified into different groups or types. A few of them are:

1. **Empirical models:** These are direct descriptions of observed data and are generally expressed as regression equations (with one or a few factors) and are used to estimate the final yield. This approach is primarily one of examining the

Abhilash Singh[*], Narendra Pratap Verma, Ankit Singh and S.K. Pande

[1]*Assistant Professor, School of Agriculture Science, LNCT University, Bhopal (M.P.)*

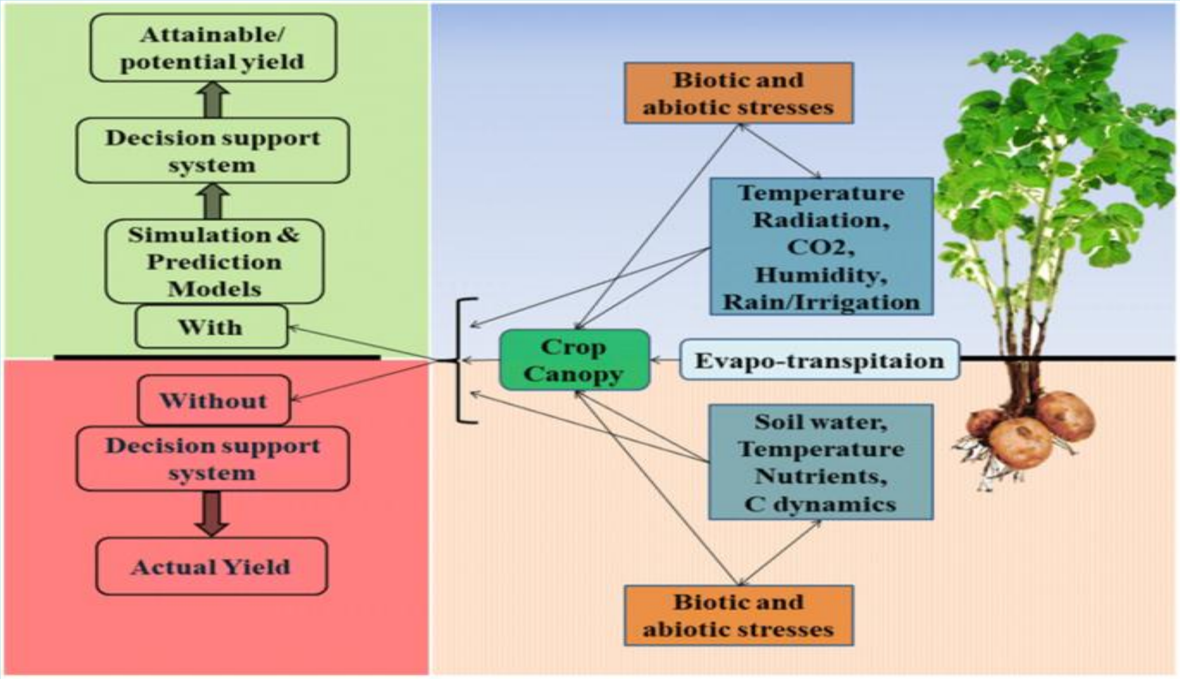
data, deciding on an equation or set of equations and fitting them to data. These models give no information on the mechanisms that give rise to the response. Examples of such models include those used for such experiments as the response of crop yield to fertilizer application, the relationship between leaf area and leaf size in a given plant species and the relationship between stalk height alone or coupled with stalk number and/or diameter and final yield.

2. **Mechanistic models:** A mechanistic model is one that describes the behaviour of the system in terms of lower level attributes. Hence, there is some mechanism, understanding or explanation at the lower levels (eg. Cell division). These models have the ability to mimic relevant physical, chemical or biological processes and to describe how and why a particular response occurs.
3. **Static and dynamic models:** A static model is one that does not contain time as a variable even if the end products of cropping systems are accumulated over time. In contrast dynamic models explicitly incorporate time as a variable and most dynamic models are first expressed as differential equations.
4. **Deterministic models:** A deterministic model is one that makes definite predictions for quantities (e.g. crop yield or rainfall) without any associated probability distribution, variance, or random element. However, variations may occur in biological and agricultural systems, due to inaccuracies in recorded data and heterogeneity in the material being dealt with. In certain cases, deterministic models may be adequate despite these inherent variations but in others they might prove to be unsatisfactory e.g. in rainfall prediction. The greater the uncertainties in the system, the more inadequate deterministic models become.
5. **Stochastic models:** When variation and uncertainty reaches a high level, it becomes advisable to develop a stochastic model that gives an expected mean value as well as the associated variance. However, stochastic models tend to be technically difficult to handle and can quickly become complex.
6. **Simulation models:** These form a group of models that is designed for the purpose of imitating the behaviour of a system. Since they are designed to mimic the system at short time intervals (daily time-step), the aspect of variability related to daily change in weather and soil conditions is integrated. These models usually offer the possibility of specifying management options and they can be used to investigate

a wide range of management strategies at low costs.

Optimizing models: These models have the specific objective of devising the best option in terms of management inputs for practical operation of the system. For deriving solutions, they use decision rules that are consistent with some optimizing algorithm.

basic research that is carried out in different regions, countries and continents. This ensures a reduction of research costs (e.g., through a reduction in duplication of research) as well as the collaboration between researchers at an international level.



Crop model applications

1. **Research understanding:** Model development allows the identification of the major factors that drive the system and can highlight areas where knowledge is insufficient. Thus, adopting a modeling approach could contribute towards more targeted and efficient research planning.
2. **Integration of knowledge across disciplines:** Adoption of a modular framework allows for the integration of
3. **Improvement in experiment documentation and data organization:** Simulation model development, testing and application demand the use of a large amount of technical and observational data supplied in given units and in a particular order. Thus, data handling forces the modeler to make formal data organization and database systems.
4. **Site-specific experimentation:** Specific site selection can be used to predict crop

performance in regions where the crop has not been grown before or not grown under optimal conditions.

5. **Yield analysis:** When a model with a sound physiological background is adopted, it is possible to extrapolate to other environments. Quantification of yield reductions caused by non-climatic causes (e.g., delayed sowing, crop spacing, soil fertility, pests and diseases) becomes possible through modeling. Simulation models are used to climatically-determined yield in various crops.
6. **Climate change projections:** The variability of our climate and especially the associated weather extremes is currently one of the concerns of the scientific as well as general community. Crop production is highly dependent on variation in weather and therefore any change in global climate will have major effects on crop yields and productivity. Elevated temperature and carbon dioxide affects the biological processes like respiration, photosynthesis, plant growth, reproduction, water use etc. Proper understanding of the effects of climate change will therefore help scientists to guide farmers to make crop management decisions such as selection of crops, cultivars, sowing dates and irrigation scheduling to minimize the risks.
7. **Scoping best management practices:** Simulation can be done to determine the best management practices under a certain cropping system. In the past, the main focus of agronomic research has been on crop production. Recently, in addition to profitable crop production, the quality of the environment has become an important issue that agricultural producers must address. Solutions to this new challenge require consideration of how numerous components interact to effect plant growth.
8. **Yield forecasting:** Reasonably precise estimates of crop yield over large areas before the actual harvest are of immense value to both the researcher and the farmer in terms of planning. In this approach the model is run using actual weather data during the cropping season for the geological region of interest. Weather years for typical years are used to continue simulations until harvest.
9. **Breeding and introduction of a new crop variety:** Development and release of a variety is a **complex** process that may extend over a period of 5 – 15 years. Since the modeling systems approach integrates different components of agro ecosystems, it can be used to conduct multi-location field experiments to understand genotype by environment (G x E). Such studies can help in reducing the number of

sites/seasons required for field evaluation and thus increase the efficiency of the process of variety development.

Crop modeling in vegetable crops

Regression models were generated to mimic the behavior of minerals in tomato plants and they were included in the model in order to simulate their dynamic behavior. The results of this experiments showed that the growth model adequately simulates leaf and fruit weight. As for harvested fruits and harvested leaves, the simulation was less efficient. Simulation of minerals was suitable for N, P, K whereas it was found to be low in the case of Ca and Mg. These models can be used for planning crop management and to design more appropriate fertilization strategies. A mechanistic crop growth model for glasshouse tomato (TOMSIM) has been developed In the area of greenhouse operation, yield prediction still relies heavily on human expertise. Automatic tomato yield predictor to assist the human operators in anticipating more effectively weekly fluctuations and avoid problems of both over demand and overproduction if the yield cannot be predicted accurately.

Greenhouse environment data and crop records from a large scale commercial operation, Wight Salads Group (WSG) in the Isle of Weight, United Kingdom, collected during the period 2004 to 2008, were used to model tomato yield using an Intelligent System called "Evolving Fuzzy Neural Network" (EFuNN). There results showed that the EFuNN model predicted weekly fluctuations of the yield with an average accuracy of 90%. The contribution suggests that the multiple EFUNNs can be mapped to respective task-oriented rule-sets giving rise to adaptive knowledge bases that could assist growers in the control of tomato supplies and more generally could inform the decision making concerning overall crop management practices

In an experiment in Cucumber, the results showed that the fitted simplified Penman Monteith formula accounted for more than 90% of the measured hourly canopy transpiration rate, signifying that this formula could be used to predict water requirements of crops under Mediterranean conditions and improve irrigation control in a substrate culture. However, the model coefficients will have to be adjusted for specific climate and crop conditions.

Simple model of carbon distribution for the simulation of root development of cucumber crop. Roots are an important sink and growth of small fruits (before flowering) may be strongly inhibited in the case of low photosynthetic activity. Root growth is an opposite function of the fruit load and there is a close correlation between the simulated rate of root growth and the root lengthening

Besides tomato and cucumber, studies on crop modeling has been done in other vegetable crops like onion, lettuce, cassava, *etc*.

Crop model limitations

1. **Inaccurate projections:** Crop models are not able to give accurate projections because of inadequate understanding of natural processes and computer power limitation. As a result, the assessments of possible effects of climate changes, in particular, are based on estimations.
2. **Possibility of misuse:** As different users possess varying degrees of expertise in the modeling field, misuse of models may occur.
3. **Non universal:** Since crop models are not universal, the user has to choose the most appropriate model according to his objectives. As a result, the assessments of possible effects of climate changes are based on estimations.
4. **Difficult to use in agricultural system:** Agricultural and biological models are reflections of systems for which the behaviour of some components is not fully understood and differences between model output and real systems cannot be fully accounted for. Crop models are therefore not able to give accurate projections because of inadequate understanding of natural processes and computer power limitation.
5. **Rudimentary methodology of model validation:** The main reason is that, unlike the case of disciplinary/traditional experiments, a large set of hypotheses is being tested simultaneously in a model. The validation of models at present is further complicated by the fact that field data are rarely so definite that validation can be conclusive.
6. **Sampling errors:** An ultimate crop model would be one that physically and physiologically defines all relations between variables the model reproduces and universally realworld behaviour. However, such a model cannot be developed because the biological system is too complex and many processes involved in the system are not fully understood.

Conclusion

As a research tool, model development and application can contribute to identify gaps in our knowledge, thus enabling more efficient and targeted research planning. Models that are based on sound physiological data are capable of supporting extrapolation to alternative cropping cycles and locations, thus permitting the quantification of temporal and spatial variability. However, most models are virtually untested or poorly tested, and hence their usefulness is unproven. Indeed, it is easier to formulate models than to validate them. An intensely calibrated and evaluated model can be used to effectively conduct research that would in the end save time and money and significantly contribute to developing sustainable agriculture that meets the world's needs for food.