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Crop Simulation Modeling

Athulya S.[1], Sreeju K. B.[1] and Unni Ravi Sankar[1]
[1]Assistant Professor, Farming Systems Research Station,
Kerala Agricultural University, Sadanandapuram
*Corresponding Author: athulyaspillai2309@gmail.com

Model is a set of mathematical equations describing/mimicking behaviour of a system. Simulation models, in general, are mathematical representation of a real-world system. Simulation modeling is the process of creating and analyzing a digital prototype of a physical model to predict its performance in the real world (Figure 1). Crop simulation modeling in agriculture uses quantitative measurements of eco-physiological processes to predict plant growth and development based on environmental conditions and crop management inputs. These models simulate a crop's response (for example growth or yield) to the environment, management practices, water, weather, and soil parameters, as they interact over the course of a growing season. These tools mimic the growth and development of crops to mathematically represent the various components within the cropping system. The concept of crop modeling dates back to the 1960s when researchers modeled agricultural systems by combining both physical and biological principles. Crop simulation models rely on measurable inputs (by sensors, machines, or hand measurement) to determine whatever output is of interest (plant growth, crop yield, soil nitrogen, crop staging, *etc.*).

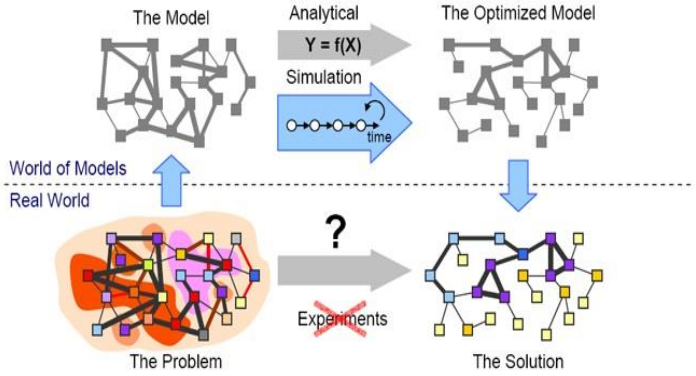


Figure 1: Simulation Modeling

Types of simulation models

There are mainly six types of simulation models. They are,

- Statistical/Empirical models
- Mechanistic models
- Deterministic models
- Stochastic models
- Static models
- Dynamic models

Statistical/ Empirical models

Statistical modelling is the use of mathematical models and statistical assumptions to generate sample data and make predictions about the real world. It is a collection of probability distributions on a set of all possible outcomes of an experiment. In statistical models, direct descriptions of observed data, generally expressed as regression equations are used. These models give no information on the mechanisms that give rise to the response. Eg: Step down regressions, Clustering *etc.*

Mechanistic models

Mechanistic models use mathematical expressions that best describe the physical or biological processes which allows one to calculate a future event exactly, without the involvement of randomness. These models attempt to use fundamental mechanisms of plant and soil processes to simulate specific outcomes. Eg: Photosynthesis based model

Deterministic models

A type of model or a part of a model in which the outcome is completely and exactly known based on known input. These models estimate the exact value of the yield or the dependent variable. Eg: NPK doses are applied and the definite yields are given out

Stochastic models

A stochastic model is a model for predicting statistical properties of possible outcomes by accounting for random variance in one or more parameters over time. For a selected duration, the random variance is typically based on variations

found in historical data using standardized techniques. These models are based on the probability of occurrence of some event. For each set of inputs different outputs are given along with probabilities. These models define yield or state of dependent variable at a given rate. Eg: Markov-Chain Models

Static models

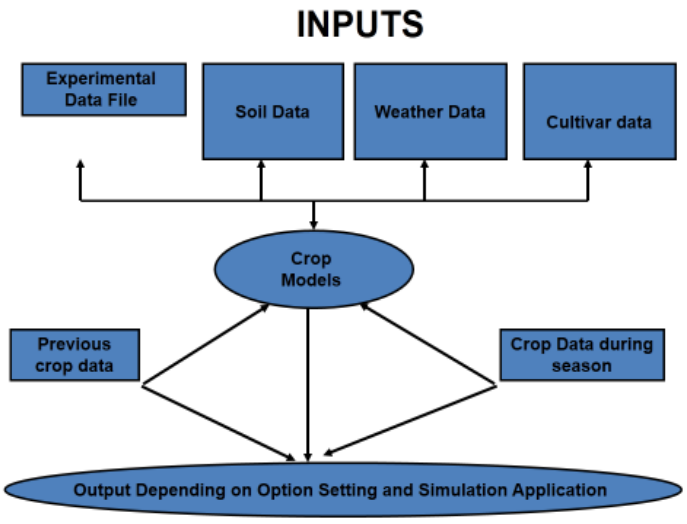
A static model describes the static structure of the system being modelled, which is considered less likely to change than the functions of the system. In particular, a static model defines the classes in the system, the attributes of the classes, the relationships between classes, and the operations of each class. Time is not included as a variable in these models.

Dynamic models

Dynamic simulation models are based on the assumption that the state of each system at any moment can be quantified, and that changes in the state can be described by mathematical equations. These models use computer programmes to model the time-varying behaviour of a dynamic system. These models help in predicting changes in crop status with time.

Data needed for crop modelling

Crop modeling tools require a minimum set of data as inputs in order for the model to accurately complete a prediction. Some types and examples of inputs include management practices (planting date, planting density, crop variety, fertilization, and irrigation), soil (drainage class, pH, organic matter content, and sand/silt/clay content), physiology (leaf area index, total biomass above ground, plant height, and stand count), and climate (rainfall, air temperature, wind speed, photoperiod) (Figure 2). In order to create a crop simulation model, data on a variety of the inputs mentioned above need to be collected as well as the measurement of the factor that one wants to predict. This then allows to calibrate the model after determining what factors were the most influential or important in the model. Then the model needs to be validated with an independent data set to determine its accuracy and fine-tune the number of inputs that are necessary. Typically, a model with the fewest variables but greatest accuracy, is desired.



There are a variety of public and privately-used crop modeling tools focusing on specific crops or regions.

Figure 2: Crop simulation modeling: an overview

Applications of crop growth simulation models

There are numerous benefits to crop simulation modeling, such as increased efficiency, increased yields, and lower environmental footprint. Various applications of crop growth simulation models include,

- Crop yield modeling can help drive efficiency in agricultural production systems by allowing farmers to manage their inputs more efficiently
- To assess the effect of environment, crop genotype and management of input resources on crop yields, and to quantify yield gaps with existing knowledge
- These models work to achieve maximum crop performance while minimizing inputs, such as fertilizers, irrigation *etc.*
- By understanding what inputs are most important to increase yield, farmers can identify the key time points for management practices to optimize their yield
- Simulation models have good practical results in arid, tropical and temperate zones for drought mitigation
- For taking proper adoption measures, assessment of future climate change impact on productivity, simulation models can offer better prospects

- To undertake strategic and policy decisions to increase the productivity of resource based efficient cropping systems
- Influence of changing climatic conditions on crop growth, productivity can be studied using crop simulation models
- Integration of simulation and global circulation model give impact assessment of climate change on different crops on regional and global basis

Limitations of crop simulation models

Crop simulation models are having few limitations such as,

- The findings reported in the different studies depend on many assumptions built into the crop simulation models
- Acclimatization of the crop to changes in its environment is not taken into account in the models
- There is no single program or set of model parameters that have been identified for all global regions and crops
- There's limited precision to quantify crop responses to micronutrient stress, and there is a limited amount of validation data available to improve models across crops

Conclusions

Even though there are some lacunas, crop simulation models can be used as a better estimator of climate change impacts on food security. Crop modeling in agriculture has the potential to provide valuable insights and solutions for agriculture professionals. With improved agronomic data collection, predictive modeling using multiple datasets will allow researchers and farmers to better understand the parameters and management practices that are most influential on crop growth. Being able to explore potential outcomes over time, in accordance with changes in climate or other inputs, crop simulation modeling opens up a whole new arena as we work to improve agricultural input use efficiency and reduce environmental footprints.

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