UNIT 5  FUNDAMENTALS OF CROP SIMULATION MODELS

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5.1 INTRODUCTION

For more than 50 years, considerable attention has been paid in the engineering sciences to the analysis of complex, dynamic systems, and with considerable success. The approach, which is now being adopted in the biological sciences, is characterized by the terms: systems, models and simulation. While a system is a part of reality that contains interrelated elements, a model is a simplified representation of a system. Simulation may be defined as the art of building mathematical models and the study of their properties in reference to those of the system. Although any model should have definite goals, be lucid and achieve its objective, it seems, in practice, that goals are too often described in such broad terms that sufficient lucidity is reached only for the initiated and that the models are achieving less than expected by the biologists (De Wit and Rabbinge, 1979). In this unit, we would endeavour to discuss the fundamentals of crop simulation models through different types of models and steps in modelling. Further, the unit would emphasize the application and limitations of crop model.

5.2 OBJECTIVES

After studying this unit, you should be able to:
- list the different types of models;
- explain the steps involved in modelling; and
- explain the application and limitations of crop model.

5.3 SYSTEM

System is literally defined as a set of things working together as part of a mechanism or interconnecting network, a complex whole. In general, system consists of dependent and independent variables, which are interconnected and interlinked in such a way that they are working among themselves. A system must interact with all variables regularly as a single unit. The system is mainly classified into open system and closed system. Open system, which has different sets of variables and their relationship among themselves and with their environment as whole. On the other hand, closed system does not have any interaction with environment. Hence, the open systems are being used for describing many real world phenomena.

5.4 MODEL AND MODELLING

A model is a simplified representation of a system or a process. A model is a computer program, which describes the mechanism of the process or a system. Modelling is based on the assumption that any given process can be expressed in a form of mathematical statement or set of statements or a sets of statements to depict the real world system. Modelling is classified into descriptive modelling
and explanatory modelling.

5.4.1 Descriptive Modelling

Descriptive model is a mathematical statements or a sets of statements, which describe the real world phenomena or events and the interrelationship between the factors involved in the process. The important aspects of descriptive modelling are as follows.

5.4.1.1 Segmentation of Process

The main process will be segmented into different subgroups, so that all variables of that main process will be accounted. For example, soil water availability is the main process and the sub groups are soil physical, chemical and biological properties as well as the plant community present in the soil.

5.4.1.2 Segmentation Based on Importance

The most important processes are identified in the system and due importance are given accordingly. For example in growth and development of a plant, the most important events are photosynthesis and respiration. Hence, photosynthesis and respiration process will be given more weightage than other process of the events. It does not mean that the other process will not be taken into account, the other processes are also included with due weightage.

5.4.1.3 Interlinking of Different Processes

Interlinking of interconnected process must be done for effective imitation of the processes or system of real world phenomena. For example, the soil water availability depends on rainfall, irrigation, solar radiation, soil temperature, evaporation, transpiration, soil colour, etc., and all the processes have to be interlinked in the study of soil water availability as sub process.

5.4.1.4 Weightage of Important Processes

Different weightage will be given for different processes of model based on its importance in the particular system. In the soil nutrient dynamics, much importance will be given to nitrogen followed by phosphorus, potassium and so on.

5.4.2 Explanatory Modelling

The explanatory models describe why and how the things works or why and how the phenomena is the way it is. The explanatory models are being used as a substitute for full explanatory model now a days, because full explanatory model is too long and cumbersome in the modelling. Hence, explanatory models describe, why and how for important process instead of all process, which is available in the model. Few examples of explanatory models are explanatory model of illness; the patient explanatory model (Kleinman model); explanatory model of health diseases among South Asian Immigrants; and explanatory model of health inequalities (WHO).

5.4.3 Deterministic Modelling

Deterministic model is a mathematical model, which produces outcome precisely through relationship among state variable and events with initial conditions, without any random variation. Hence, it will produce same output of the given input at all time. Example: Chemical reactions.
5.4.4 Stochastic Model
Stochastic model is a mathematical model, which estimates the probability distributions inputs into potential outcomes by allowing for random variation in inputs over the period of time. The standard time series techniques is being used for making random variation in fluctuations observed in historical data for a selected period. Large number of simulation (stochastic projection) is used to produce potential outcome for the random variable inputs. Simulation is the process of building models and analyzing the system.

- **Discrete model**: The state variables change only at a countable number of points in time. These points in time are the ones at which the event occurs/change in state. Example: Statistical model

- **Continuous model**: The state variables change in a continuous way, and not abruptly from one state to another (infinite number of states). Example: Crop Simulation Model.

5.5 ANALYTICS IN SIMULATION MODELLING
In the simulation modelling, three important analytics are being used for simulating the real world phenomena.

5.5.1 Descriptive Analytics
In descriptive analytics, summarization of all raw historical data, processing of the data and interpreting the data are performed. The descriptive analytics will answer the question “What had happened in the past?”. For example for answering the question “Whether the climate change is real phenomena?”, we need to do descriptive analytics.

5.5.2 Predictive Analytics
We use different assumption in predictive analytics to predict or forecast the future. This analytics is being used to answer the question “What could happen?”. Example to study the change in climate in the near future by using Ocean circulation models, Atmospheric circulation model, General circulation model or coupled model. Quantification of climate change impact on crop production is also called predictive analysis.

5.5.3 Prescriptive Analytics
In prescriptive analytics, we optimize different parameter, inputs or new technology (New heat and cold tolerant varieties, new technology for increasing water use efficiency etc.,) under changing climate. This prescriptive analytics answer the question “What should we do?”. Climate change adaptation and mitigation studies are coming under prescriptive analytics.

Check Your Progress 1

**Note:**

i) Use the space given below for your answers.

ii) Check your answers with those given at the end of the unit.

1. What is a model?
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2. What are the differences between the descriptive and explanatory model?
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3. What are the differences between the deterministic and stochastic model?
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5.6 CROP SIMULATION MODEL

The crop simulation models are in fact a simple and meaningful representation of a crop; and they are construed as systems research tool, which aid in solving the problems associated with agricultural crop production. So in effect, the crop simulation models are needed to distil the knowledge obtained through field based experimentation and observations. Further, it provides a platform for interdisciplinary collaboration. Also the systems approach adopted by crop simulation models help in solving problems arising from the crop production. Operationally, the crop models require input data pertaining to and limited to crop type and varieties, soil types and characteristics; weather data and agronomic practices. Crop simulation models are used to gauge the effects of soil, climate, and crop management practices on growth and development of crop; and agricultural productivity and sustainability of agricultural production system. The use of the crop simulation models for agricultural research, greatly reduce the cost and time involved in the field experiments. This is because the results obtained for one location or season can be extrapolated to other location and seasons. Of late, the development of crop simulation models, along with application of decision support system approaches, greatly aid in augmenting resource use and agricultural productivity; minimising the environmental impacts borne out of agricultural practices; and mapping the yield gaps.

Historical interpretation of functional changes in agro-ecosystems is useful to enrich the theoretical knowledge on agriculture and ecology, and to support well founded decisions in applied fields such as soil, farm and land management. Now-a-days, trends in ecology studies combine and compliment different approach, methods and information sources to strength the interpretation of ecological processes (Carpenter et al., 1995; Forter et al., 1998; Fuller et al., 1998; Butterbury and Bebbington, 1999; Debussche et al., 1999). The biophysical characteristics of the agro-ecosystem, including soil texture and climate, are critical determinants of the economic performance and sustainability of the production system. The ability of the soil provides the necessary crop growth requirements, particularly water, which is a critical factor determining the sustainability of the agro-ecosystem in the simulation. As a result, management practices that increase soil water, such as summer fallow, play an increasingly important role in areas with greater soil constraints (Belches et al., 2004).
There are several tools of systems research related to computer and information technology now available which can help in solving agricultural problems. One such tool is crop growth simulation model. These models are based on quantitative understanding of the underlying processes, and integrate the effect of soil, weather, crop, pest and management factor on growth and yield. The process could be crop physiological, meteorological, and soil physical, chemical or biological. Depending upon the objective, knowledge base of various agricultural disciplines can be integrated in a crop model.

These models need input data that mimic ‘genetics’ of a crop/variety. And, as the area of interest expands say to water, nutrient, pest limited or actual productivity, knowledge base of several additional disciplines are tapped and integrated into the model. Once the integration and its validation is successful, crop simulation models can help us in analyzing the effect of various climatic factors on crop growth and yield considering the interaction with edaphic, biotic and agronomic factors. Such an analysis is normally not possible with conventional experimental methods.

Agricultural system model have gone through more than 40 years of development and evolution. Prior to the mid-1980s, most of the modelling work focused on individual processes of agricultural systems (Ahuja et al., 2002), such as soil hydraulic properties (Brooks and Corey, 1964), evapotranspiration (Monteith, 1965), photosynthesis (Sacki, 1960), plant growth (Brouwer and de Wit, 1968) and soil nutrients (Olsen and Kemper, 1967). The earlier models have served as a foundation for the development of agriculture system models in the last 20 years. Earlier examples of systems models have focused, for example, PAPRAN for pasture systems (Seligman and Van Keulen, 1981), CREAMS for soil, chemical and nutrient run off from cropping system (Knisel, 1980), EPIC for soil erosion and soil productivity (Williams and Renard, 1985), CERES for crop growth (Ritchil et al., 1986), GLEAMS for ground water pollution (Leonard et al., 1987) and CENTURY for plant production, nutrient cycling and soil organic matter dynamics (Parton et al., 1987). Physiological growth and production models have shown to be very useful for guiding improvements in cropping systems of various annual crops (e.g., wheat, rice, potato; Van Laar et al., 1997; Bouman et al., 2002).

A wheat crop model was developed based on radiation capture principles and thermal reflectance in 1982 at the Indian Agricultural Research Institute (IARI) in collaboration with Space Application Centre, Ahmedabad (Ajai et al., 1984). This dynamic model was basically designed for forecasting wheat yield on a regional basis, using remote sensing signature as input. This model was further developed as WTGROWS to understand the dynamics of interaction between weather elements, soil factor, variety, water and N management (Aggarwal et al., 1994).

“The model, written in CSMP and FSE, simulates daily dry matter production as a function of radiation temperature, and water and nitrogen availability. While the crop sub-model covers the crop related processes like crop development, photosynthesis, respiration, carbohydrate partitioning, dry matter production, leaf area, grain growth and transpiration, the soil water balance model was integrated in the crop model to simulate water uptake and to determine water stress. Another sub-model determines
Fundamentals of Crop Simulation Models

Several dynamic crop growth simulation models such as DSSAT, CERES, WOFOST, SUCROS, and APSIM have been developed during the last few decades. These models integrate the effects of different factors on productivity and have been used to determine the production potential, optimize crop management, quantify yield gaps, and to study the consequences of climatic variability and climatic change (Kropff et al., 1996; Berge et al., 1997; Tsuji et al., 1998; Matthews and Stephens, 2002). At the same time, several other models such as EPIC (Williams and Renerd, 1985), DAISY (Hansen et al., 1990), CANDY (Franko et al., 1996), and CENTURY (Parton et al., 1993) were developed, which described the soil carbon dynamics in detail. Lately, some models such as MERES (Matthews et al., 2000) and DNDC (Li, 2000) have been developed that have a routine for the calculation of emission of greenhouse gases from agro-ecosystems.

Most of these models, however, are not able to fully meet the expanding requirement of integrated information on global change impacts, greenhouse gases emissions and soil carbon and nitrogen dynamics while simulating regional variations in crop productivity. Further, they are not user-friendly, and these models are complex and require voluminous data. To overcome these drawbacks, Indian Agricultural Research Institute, under the National Agricultural Technology Project developed InfoCrop, a generic crop model to assess the global change impacts (Aggarwal et al. 2004). The model InfoCrop is written in FORTRAN Simulation Translator language (FST). InfoCrop is indeed a Decision Support System (DSS), used “to simulate the effects of weather, soils, agronomic management (including planting, nitrogen, residues and irrigation), and major pests on crop growth, development and yield. Its general structure is based primarily on SUCROS (van Laar et al., 1997) and further supported by MACROS (Penning de Vries et al., 1989), WTGROWS (Aggarwal et al., 1994), and ORYZAI (Kropff et al., 1994) models. The model is user-friendly, requires easily available inputs, and is targeted to increase applications of crop models in research and development” (Aggarwal et al. 2004).

5.7 STEPS IN MODELLING

5.7.1 Define Goals

The complexity of the Agricultural Production System demands interdisciplinary approach. The development of crop model is indeed a challenging task involving scientists and crop modellers form diverse fields. Based on the objective of the model, the expertise of the scientists are dovetailed to develop a crop model.

5.7.2 Define System and its Boundaries

Subsequent to defining goals, there is a need for defining the system and its boundaries.
5.7.3 Define Key Variables in System

Consequent upon defining the system and its boundaries, the variables such as state, rate, driving and auxiliary variables are defined. “State variables are those which can be measured or quantified, e.g. soil moisture content, crop yield, etc. Rate variables are the rate of different processes operating in a system, e.g. photosynthesis rate, transpiration rate. Driving variables are those variables which are not part of the system but they affect the system, e.g. sunshine, rainfall. Auxiliary variables are the intermediated products, e.g. dry matter partitioning water stress, etc. These variables are identified in the crop field. After identification of these variables, relationship among different variables should be determined and a relational diagram must be drawn. This helps in better understanding of the whole process involved in the crop simulation modelling” (https://www.docsity.com/en/agriculture-with-agronomy/2006757/).

5.7.4 Quantification of Relationships

After establishing the relationship among the variables, quantification of variables should be done by using different mathematical equations and functions in the crop model.

5.7.5 Calibration

After development of model, it requires calibration, which is one of the most important steps in the modeling. First the model is run with any experimental data set and calibrated accordingly. It is checking the model response by changing the different conditions or parameters like crop phenology (days to germination, 50% flowering and physiological maturity), crop growth and development (leaf area index, specific leaf area, dry matter production and partitioning, yield).

5.7.6 Validation

The calibrated model should be run for different location, soil and weather condition and the process is called validation. The model validation is fitting the model for all crop growing area of the particular crop.

5.7.7 Sensitivity Analysis

The calibrated and validated model is further tested for its sensitivity to different factors such as temperature, rainfall, fertilizer nitrogen dose, carbon dioxide concentration, etc. Sensitivity analysis is performed to know how the model respond to the changes in the above-mentioned factors.

5.7.8 Simplification

Though the models are written originally in computer programming languages, in order to make the model user friendly, popular, and adaptable, the crop models are simplified.

5.7.9 Use of Models in Decision Support

After development, calibration and validation of any model, it can be used in any decision support system for forecasting or making suitable decisions regarding crop management such as climate change adaptation and mitigation studies.
5.8 APPLICATIONS OF CROP MODEL

5.8.1 Estimation of Potential Yields
Calibrated and validated model will predict the potential yield perfectly under no stress condition.

5.8.2 Estimation of Yield Gaps
Model will be used to estimate the yield gaps between potential yield and attainable yield; potential yield and actual yield; and potential yield and farmers' yield. It also finds the principal causes, contribution and remedial measures for yield gap and bridging the yield gap.

5.8.3 Yield Forecasting
Calibrated and validated models are useful for yield forecasting, which will be useful for marketing of produce in right time at right place and at right price.

5.8.4 Climate Variability and Climate Change Impact Assessment
The models are also be used for quantifying the climate variability (short term) and climate change (long term) effect on the agricultural production. The models are used to assess the impact of climate change and climate variability on weeds, insect pests and diseases dynamics as well.

Fig 5.1: Relational diagram showing the variables and feedbacks among different processes in Infocrop. By using appropriate switches, different combinations of selected critical processes can be simulated (Aggarwal et al., 2006 a and b)
5.8.5 Optimizing Management

The calibrated and validated models are used to optimize the agronomical management such as dates of planting/ sowing, variety (short, medium or long duration), irrigation (amount, time and method of application) and nitrogen fertilizer (amount, time and method of application).

5.8.6 Environmental Impact

The environmental impact such as percolation, N losses, GHG emission, SOC dynamics are also assessed by crop simulation model.

5.8.7 Plant Type Design and Evaluation

The validated model is used to design a plant type of variety and evaluation of variety in the different location and different period. It will reduce huge experimental cost and environmental degradation.

Check Your Progress 2

Note:  
i) Use the space given below for your answers.  
ii) Check your answers with those given at the end of the unit.

1. What is a crop simulation model? What is the need for crop simulation model?

2. What is InfoCrop?

3. What are the steps involved in crop modelling?

5.9 Limitations of Crop Simulation Modelling

5.9.1 Input Data

Models require large amount of input data to get desirable output, which normally may not be available with the user.

5.9.2 Manpower

Skilled manpower is required to develop, calibrate and validate the model. For field data collection, we need experienced, unbiased labour to collect an authentic data.
5.9.3 Knowledge of Computers & Computer Language

For using developed models, a basic knowledge on computers, and computer language is required.

5.9.4 Limited Awareness and Acceptance Towards Modeling

Both scientific community and farmers’ community have little awareness about modelling and its application.

5.9.5 Multidisciplinary Knowledge

Model development and interpretation of model output require multidisciplinary knowledge, which is always lacking among scientific community and interdisciplinary approach is also lacking at the institute level.

Further, inability of the models to comprehend the diverse and complex biological systems result in errors in simulation results. Also the crop models can only aid in improving our understanding about the agricultural production system, and they cannot replace field experiments altogether. Application of models developed for a region, require parameterization and calibration before being applied in other regions.

5.10 LET US SUM UP

Though agricultural production in most countries of South Asia increased during the last few decades, it still faces challenges due to increasing human population, stagnation of farm productivity, declining agricultural resources, environmental degradation, and global climate change. In order to increase agricultural production, agricultural planning coupled with rational decision making and increased resource use are the need of the hour. Towards this end, many system research tools are developed such as crop simulation tools, modelling tools, etc. crop growth simulation models are based on the quantitative understanding of the crop growth and development processes, and they also dovetail the effects of soil, weather, pest and agronomic practices on crop growth and yield. In this unit, we have discussed the fundamental underpinnings of crop simulation model, along with steps in crop modelling, application and limitations of crop model.

5.11 KEY WORDS

System : System is literally defined as a set of things working together as part of a mechanism or interconnecting network, a complex whole. In general, system consists of dependent and independent variables, which are interconnected and interlinked in such a way that they are working among themselves.

Model : A model is a simplified representation of a system or a process. A model is a computer program, which describes the mechanism of the process or a system.
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Modelling : Modelling is based on the assumption that any given process can be expressed in a form of mathematical statement or set of statements or a sets of statements to depict the real world system. Modelling is classified into descriptive modelling and explanatory modelling.

Discrete Model : The state variables change only at a countable number of points in time. These points in time are the ones at which the event occurs/change in state. Example: Statistical model

Continuous Model : The state variables change in a continuous way, and not abruptly from one state to another (infinite number of states). Example: Crop Simulation Model

Simulation Modelling : Simulation modelling is the process of creating and analyzing a digital prototype of a physical model to predict its performance in the real world.

5.12 SUGGESTED FURTHER READING/REFERENCES


### 5.13 ANSWERS TO CHECK YOUR PROGRESS

#### Check Your Progress 1

1. A model is a simplified representation of a system or a process. A model is a computer program, which describes the mechanism of the process or a system.

2. Descriptive model is a mathematical statements or a sets of statements, which describe the real world phenomena or events and the interrelationship between the factors involved in the process. On the other hand, the explanatory models describe why and how the things works or why and how the phenomena is the way it is.

3. Deterministic model is a mathematical model, which produces outcome precisely through relationship among state variable and events with initial conditions, without any random variation. Also, it will produce same output of the given input at all time.

   Stochastic model is a mathematical model, which estimates the probability distributions inputs into potential outcomes by allowing for random variation in inputs over the period of time.

#### Check Your Progress 2

1. Crop simulation models are simple and meaningful representation of a crop. They are construed as systems research tool, which aid in solving the problems associated with agricultural crop production. As regards to their need, the crop simulation models are needed to distil the knowledge obtained through field based experimentation and observations. It also provides a platform for interdisciplinary collaboration. Further, the systems approach adopted by crop simulation models help in solving problems arising from the crop production.

2. Indian Agricultural Research Institute, New Delhi under the National Agricultural Technology Project developed InfoCrop, a generic crop model “to simulate the effects of weather, soils, agronomic management (planting, nitrogen, residues and irrigation), and major pests on crop growth, development and yield”. The model InfoCrop is a Decision Support System (DSS), written in FORTRAN Simulation Translator
Assessment Tools

language (FST). *The model is user-friendly, requires easily available inputs, and is targeted to increase applications of crop models in research and development*.

3. The steps involved in crop modelling are defining goals; defining the system and its boundaries; defining key variables in system; quantification of relationships; calibration; validation; and sensitivity analysis.