

Crop simulation modelling:

a hope in the climate change era

Anil Nath¹ and Deepak Pandey²

Govind Ballabh Pant University of Agriculture and Technology, Pantnagar (Uttarakhand) 263 145

The climate change has been recognized as the biggest threat to agricultural production and world food security. Climate change is basically the change in the long-term weather patterns especially in temperature and rainfall. Increased anthropogenic activities such as industrialization, urbanization, deforestation, unsustainable agricultural practices, burning of fossil fuel, change in land use pattern etc. lead to emission of greenhouse gases which is the prime cause of climate change. Climate change mainly results into higher temperature, changes in precipitation (droughts, floods, cloudbursts and storms), sea-level rise, drying of rivers, environmental health risks and the overall impact on agriculture.

Key words: Climate change, Crop simulation, Modelling

ACCORDING to Fifth Assessment Report of the United Nation Intergovernmental Panel on Climate Change (IPCC) will continue even if emissions of CO₂ and other greenhouse gases are stopped. Scientists pointed out that the global surface temperature increase by the end of the 21st century is likely to exceed 1.5 °C relative to the 1850 to 1900. Over the period 1901 to 2010, global mean sea level rose by 0.19 [0.17 to 0.21]m. The atmospheric CO₂ concentration has increased from 280 to 400 ppm between 1750 and 1900. Other greenhouse gases like CH₄, CFC and N₂O are also responsible for global warming as they are increasing at alarming rate.

Why climate change is a concern in agriculture?

There are various factors which affect and shape the agricultural sector. Over the last decade or so, climate change has been recognized as an additional factor which affects the agricultural production by uncertainties driven by climatic variations, including extreme events

such as flooding and drought. World agriculture is facing a serious decline in world food production due to climate change. Overall agricultural productivity for the entire world is projected to decline between 3 and 16 % by 2080. Climate change is likely to have negative effect on crop production in tropical countries whereas its effect may be positive in temperate countries. Some developing countries, which already have average temperatures near or above crop tolerance levels, are predicted to suffer an average 10 to 25% decline in agricultural productivity by 2080. This is likely to have effects on international food prices and trade system. Besides low agricultural production, climate change is also responsible for long-term water and other resource shortages, poor soil conditions, desertification, disease and pest outbreaks on crops and livestock, sea-level rise, and so on. Climate change also affects soil conditions such as soil-water content, run-off and erosion, salinization, soil-biomass, organic carbon (C) and nitrogen (N) contents in soil etc. due to changes in

temperature and in precipitation patterns. Sea level is increasing due to high temperature, resulting into loss of farmland by inundation and increased salinity of groundwater in coastal areas. Thus the increased uncertainty of climate effects has been recognized as an additional burden that farmers have to address. The climatic change could affect agriculture in several ways such as quantity and quality of crop production, growth rates, photosynthesis and transpiration rates, increased crop respiration rate, hasten nutrient mineralization process in soil, decrease fertilizer use efficiency, increased evapo-transpiration, reduction in duration of crops or forced maturity, moisture availability etc. The promising impact of climate on agriculture is that the agriculture sector itself is a driving force in the greenhouse gas (GHG) emissions. The agricultural processes i.e., rice cultivation and enteric fermentation in cattle [methane (CH₄) emissions], application of N fertilizer and mineralization process (nitrous oxide emissions) etc. result into emission of greenhouse gases.

Indian agriculture and climate change

In India, agricultural sector is the major source of employment and agricultural production mainly depends on monsoon. Any change in monsoon trend drastically affects agriculture production. The south-west monsoon accounts for almost 75% of total rainfall which is important for *kharif* crop production, and leads to more than 50% of the food-grain production and 65% of the oilseeds production in the country. Due to climate change, 10 to 15% increase in monsoon precipitation in many regions as well as 5 to 25% decline in rainfall in drought-prone central India and a sharp decline in winter rainfall in northern India is projected. This results into changes in output of winter wheat and mustard crops in north-western India. A decrease in number of rainy days (5 to 15 days on an average) is also expected in most part of India, along with an increase in heavy rainfall days during the monsoon. The monsoon rainfall variability in India leads to large-scale droughts and floods, resulting in low food grain production. These changes are expected to increase the vulnerability of Indian agriculture. The major impacts of climate change will be on rainfed or unirrigated crops. This is particularly important in India, as 56% of the cropped area is rainfed and more than 350 million people are dependent on rainfed agriculture. Productivity of most of the crops is likely to decrease marginally by 2020 but would decline sharply to the tune of 10 to 40% by 2100 due to increases in temperature, rainfall variability, and decreases in irrigation water. According to IPCC, 0.5 °C rise in winter temperature would reduce wheat yield by 0.45 tonne/ha in India.

A rise in temperature and precipitation by 1.5° C and 2 mm, respectively, could result in a decline in rice yields by 3 to 15 %. It is estimated that India needs 320 million tonne of food grains by 2025. For this, farmers and policy makers have to overcome the problem of decreasing crop yield owing to climate change.

Crop simulation modelling: a promising tool to mitigate climate change

Crop simulation modelling is the way by which agricultural system can be transformed effectively and food security can be ensured in a changing climate. In simulation the essential characteristics of the system are reproduced in a model without reproducing the system itself. Thus simulation modeling is an act of mimicry or a set of equations which represent the behaviour of a system, with the purpose of aiding, understanding and improving performance of the system.

Crop modelling helps us to understand the existing crop-weather-management relationships of the particular crop agro-ecosystem. Models serve the purpose of predicting the behaviour of crop response to the weather variations. Crop models are excellent tools to study agricultural systems as they simulate the biological interactions under the influence of prevailing weather during crop growth, soils, cultivar characteristics and management practices. Recently, there has been increased interest in crop simulation modelling to predict vegetative and reproductive growth and development of different cultivars under various crop management and environmental conditions. Various crop models were developed to characterize growth and yield of specific cultivar with respect to environmental conditions and to quantify the interactions that occur between plant and environment. As the plants respond to weather, soil characteristics, and management practices so model requires data related to management practices (such as soil and crop data), environmental conditions and knowledge of cultivar-specific traits (genetic coefficients) as inputs to predict growth and development of the plant. Crop modelling has made it possible to simulate the yield and growth of several crops under different soil and weather conditions with different management practices. Simulation models can be used to meaningfully reduce additional experimentation and decision making to increase yield. Crop simulation

models are valuable research tools in agricultural decision making. Using crop simulation models, the effects of climate change and climatic variability on crop growth and yield have been predicted. Crop responses to climatic variations like elevated temperature and carbon dioxide (CO₂) level can be predicted. Models help in identifying the most critical phenophase, sensitive to a weather parameter and to assess the environmental modification effect on crop productivity. In simulation modelling, assessment of environment modification effects is done changing the climatic parameters with a constant number, such as an increase or decrease of 1, 2, 3, 4°C etc. for temperature. Similarly for rainfall and solar radiation, such as an increase or decrease of 10, 20, 30% etc. Now these changes are applied to the daily weather data and the crop simulation models are run with these modified inputs. In this way, crop simulation modelling provides a scientific approach to study the impact of climate change/variability on crop production and gives a proper understanding of the effects of climate change which helps scientists to guide the farmers to make their crop management decisions such as selection of crops, cultivars, sowing dates and irrigation scheduling, harvesting dates etc. according to the guideline provided on climate change scenario to minimize the risks. Thus farmers' adaptation to climate change by changing different farming practices such as time of sowing, irrigation, fertilizer application, cropping patterns etc. will help to ease the impact of climate change.

One important aspect of crop growth simulation modeling is its calibration and validation test, which is usually done by comparing simulation results with observed ones. Crop simulation model once calibrated and validated for a particular crop and location become capable to predict crop growth and yield response more accurately to weather, soils, crop management, and genetic factors of that particular crop and location. These models can be used to evaluate crop performance

under diverse environment and management scenarios. Crop growth models can be used to predict crop performance in regions where the crop has not been grown before or not grown under optimal conditions. It also facilitates to have pre-harvest estimate of any crop's production. Such applications are of value for regional development and agricultural planning.

Scope and constraints

The weather parameters strongly influence the crop performance; but amongst them, only few parameters are significantly contributing to the crop growth. Therefore, it is necessary to identify such parameters and quantify their contribution besides developing the relations with growth and yield of crop. Crop simulation models are being more widely used to improve agricultural production under seasonal and daily variability in weather. These models capture temperature, solar radiation, rainfall, soil traits and crop management. Crop models have an increasingly important role in research understanding, crop management, and policy questions. Depending upon the purpose, different kinds of models are available such as statistical models, mechanistic models, deterministic models, stochastic models, dynamic models, static models, simulation models, descriptive model, explanatory model etc. Under Indian and African climatic conditions Crop simulation models are extremely useful. The reason behind it is the dependence on monsoon rains for all agricultural operations in India and the frequent dry spells and scanty rainfall in crop growing areas in Africa. Once the onset of monsoon is delayed the farmers, policy makers and agricultural scientists have no way other than waiting for the rainfall for sowing specially in rainfed areas in India. They need to go for contingency plans. These models

enable to evaluate alternative management strategies, quickly, effectively and at no or low cost. Now several crop models are available for the same crop that can be employed for impact assessment of climate change. Crop models can be used to understand the effects of climatic variations such as elevated carbon dioxide, changes in temperature and rainfall on crop growth, development and yield. Crop simulation models can predict responses to large variations in weather.

The major limitation in the use of simulation models is the absence of calibration/validation of such models in areas other than where they are developed. They are developed under a specific crop, soil and climatic set up. Before their application on a regional-scale in different regions, they need standardization and calibration with locally measured soil, plant and weather parameters. Thus, standardization, calibration/validation and performance evaluation are the basic requisites for application of simulation models at new locations. To increase its general applicability, models need to be evaluated in diverse conditions and there is a need to test its location specific performance. This will help to make necessary modification so that the model can be more widely acceptable in the region.

One of the limitations of the current crop simulation models is that they can only simulate crop yield for a particular site. At this site weather data must be available. Normally weather data (like soil and management) are not available at all locations where crops are grown. Easy access to weather data, preferably through the internet and the world-wide web is the pre-requisite for the application of crop models. Further more, biological and agricultural models are reflections of systems for which the behaviour of some components is not fully

understood. So there is always a difference between model output and real system. Crop models are therefore not able to give accurate projections of changes in climate variability on local-scale because of inadequate understanding of natural processes. An ultimate crop model would be one that defines universally real world behaviour. However, such a model cannot be developed because many processes involved in the biological system are complex and are not fully understood. Since crop models are not universal, the user also has to choose the most appropriate model according to his objectives as there is always a chance of misuse of models.

SUMMARY

There is a growing concern that climate changes will lead to significant impact on agriculture, thus having a global effect in food production. Crop simulation models can be used to understand the effects of climate change such as consequences of elevated carbon-dioxide, Changes in temperature and rainfall on crop development, growth and yield etc. Crop growth model is a promising tool for predicting possible impacts of climatic variations on crop growth and yield. Different kinds of models such as statistical, stochastic, dynamic, static and simulations etc. are available for assessing the environment modification effects on crop growth and yield. These models are useful for solving various practical problems in agriculture, thus enabling more efficient and targeted research planning. Adequate human resource capacity has to be improved and validated simulation models have to be developed across the globe.

¹PhD Scholar, C/O National Seeds Corporation Limited Padari bazar, Gorakhpur (Uttar Pradesh), ²Ph D Scholar, Department of Agronomy, Corresponding authors' e mail: anil07nath@gmail.com

Pradhan Mantri Krishi Sinchai Yojana

This Yojana brings

- Per Drop More Crop.
- Inputs from MoWR and DOLR received.
- Increase in agricultural production and productivity and enhance farm income.