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Crop Growth Simulation Modelling - A Review

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ABSTRACT

Agriculture plays a key role in overall economic and social wellbeing of the specially developing countries. Now it is the right option to increase the quality and quantity of food production through the technological and managerial interventions like crop growth and yield prediction models. Agricultural models are mathematical equations that represent the reactions that occur within the plant and the interactions between the plant and its environment. 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 Growth Simulation models are a formal way to present quantitative knowledge about how a crop grows in interaction with its environment. Using weather data and other data about the crop environment, these models can simulate crop development, growth, yield, water, and nutrient uptake. Crop models are 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. Crop models contribute to agriculture in many ways. They help explore the dynamics between the atmosphere, the crop, and the soil, assist in crop agronomy, pest management, breeding, and natural resource management, and assess the impact of climate change.

Introduction

Agriculture in India has a large share in GDP 19.9% in 2020-21 (Shagun Kapil, 29 Jan 2021) but still one fifth of our population is under malnutrition. Most of the developing countries also faces same problem. So, meeting the two square meals of the exponentially growing population are the major challenges of farming and scientific communities. The global warming and climate changes are further increasing these challenges of food security. Land is a limited natural resource that cannot be expended to bring under farming activities. Field experiments to evaluate appropriate agronomic practices are laborious, expensive & time consuming specially when a number of parameters are to be tested and require multi-year data for verification. The only option left is to increase the quality and quantity of food production through technological and decision-making intervention tools like crop growth and yield prediction models.

Crop growth model is a very effective tool for predicting possible impacts of climatic change on crop growth and yield. Crop growth models are advantageous for solving various practical problems in agriculture. Adequate human resource capacity has to be improved to develop and validate simulation models across the globe.

Types of Models

Statistical models

Mechanistic models

Deterministic models

Stochastic models

Dynamic models

Static models

Simulation models

Computer models, general these are a mathematical representation of a real world system. One of the main goals of crop simulation models is to estimate agricultural production as a function of weather and soil conditions as well as crop management. These models use one or more sets of differential equations, and calculate both rate and state variables over time, normally from planting until harvest maturity or final harvest.

Input Data Required

Implementations

DSSAT Model

Singh *et al.,* (2018) conducted a study to assess fertilizer effect on wheat yield and soil fertility. Treatments differed significantly in influencing soil fertility and grain and straw yields of wheat crop. The study result concluded that addition of 100% NPK + FYM + PSB + Azotobacter+ Zn + Fe + Mn recorded significantly higher value of growth and yield attributes in terms of plant height (cm), drymatter accumulation (g m^{-1}), number of effective tillers (m^{-1}) and yield attributes character grains $spike^{-1}$,1000-grain weight (g), harvest index (%), grain yield (58.40 q ha^{-1}) and straw yield (83.9 q ha^{-1}). The 100% NPK + FYM + Azotobacter + Zn+ Mn+ Fe could be recommended for attaining maximum wheat crop productivity and sustainability of soil under semi-arid and sub-tropical sandy loam.

Malik and Dechmi, (2019) calibrated and evaluate the DSSAT model for the major crops grown in the fields of the La Violada Irrigation District, Spain. The adjusted irrigation management application showed a potential reduction in the seasonal irrigation depth for short-season maize (27%), long season maize (18%) and sunflower (16%). In a broader context, optimum irrigation practices can reduce the amount of leached N and deep percolation losses by 31% (4.48 T) and 34% (1.2 hm^3), respectively, considering the cultivated crop area in each soil type in the entire VID.

Zha *et al.,* (2014) conducted research in Northeast China for basic soil productivity (BSP) of spring maize in black soil under long-term fertilization based on DSSAT model. Results showed that after 22-yr fertilization, the yield by BSP of spring maize significantly increased 78.0, 101.2, and 69.4% under the NPKM, 1.5NPKM and NPKS, respectively. They recommend that a balanced chemical plus manure or straw fertilization (NPKM or NPKS) should be the fertilization practices to enhance spring maize yield and improve BSP in the black soil of study area.

AQUACROP Model

Kumar *et al.,* (2018) conducted a field experiment on maize in *Rabi* season at Pusa in Bihar to evaluate the FAOAquaCrop model. They found that the

AquaCrop model was more accurate in predicting the Rabbi maize yield under full and 75% of Control Irrigation as compared to the rainfed and 50% control irrigation.

Salemi *et al.,* (2011) simulated wheat yield and yield component responses to deficit irrigation in arid Gavkhuni river basin, central Iran by using Aqua Crop model. The results of reliability indices such as RMSE, d, E, CRM and deviation percent were 2.31 to 5.63, 0.97 to 1.00, 93 to 99, -0.15 to 0.016 and -0.70 to 12.00% respectively, water productivity for the studied crop was in the range of 0.91 to 1.49 kg m-3 and its maximum value was in 40% deficit irrigation treatment. Thus it can be used to compare the attainable against actual yield in a field and to identify the constraints in crop production and water productivity.

Vanuytrecht *et al.,* (2014) Aqua Crop model simulates final crop yield in four steps. 1. Development of the green crop canopy cover 2. Crop transpiration 3. Above-ground biomass, and 4. Final crop yield which makes the modelling approach transparent. AquaCrop as a water-driven dynamic model that is able to simulate the attainable yield of herbaceous crops under various management practices and environmental conditions by using relative few conservative crop parameters and a minimum number of input variables.

EPIC Model

Williams *et al.,* (1989) tested the EPIC model in terms of crop yield throughout the United States. He found that a significant relationship between observed and simulated yield i.e. a= 0.05. It also precisely simulated corn yield response to irrigation, subsequently it can be used for irrigation scheduling & significant in decision making.

Choruma *et al.,* (2019) the EPIC model was evaluated for its potential ability to simulate maize yield using limited data from field trials maize cultivars in the Eastern Cape, South Africa. Simulated yield after model calibration improved to 11.23 t ha^{-1} from 8 t ha^{-1} with a coefficient of determination, (r^2) = 0.76 thus calibrated model can provide significantly accurate simulations.

WOFOST Model

Dua *et al.,* (2014) calibrated WOFOST model for the different Indian potato cultivars that is for late maturing, medium maturing and early maturing. The results demonstrated that WOFOST model can be used for potato crop under Indian situation but model must be validated for different conditions before it can be widely used. Mishra *et al.,* (2009)calibrated & validate WOFOST model for growth & yield of wheat crop under middle Gujarat agroclimatic zone. Concluded that the WOFOST model satisfactorily simulated the growth & potential yield of wheat crop verity G. W. 496.

SWAP Model

Zhao *et al.,* (2020) conducted experiment in the Shiyang River Basin of Northwest China during 2017 and 2018. They studied the SWAP model parameters to simulate the soil water–heat process and crop growth & the effect of film mulching on soil evaporation, temperature, and crop growth, to predict the impact of future climate change on crop growth and evapotranspiration (ET). As film mulching increased soil temperature and LAI increases during the early growth & improved the aboveground dry biomass, yield, and WUE of seed-maize. Frequent irrigation increased seed-maize yield in the presence of film mulch. Paper and Ababaei, (2012) simulated SWAP model to check effect of quantity & quality levels of irrigation water. On yield, solute transport & soil water under different conditions of ground water levels for different crops of the Rudasht region of Esfahan in IRAN.

Info-Crop Model

Boomiraj *et al.,* (2013) Assessed experiment to validate & effect of climate change on Indian crops like Maize, Sorghum& Mustard with the help of

Info-Crop model. Found that expected reduction of maize yield would be 5%, 13%, 17% and 21%, 35%, 35% in 2020, 2050 and 2080 respectively & sorghum yield is likely to increase in 2020 (3.3 and 1.7 % in CSH 16 and CSV 15 respectively) with no change in 2050 and yields will be reduced at 2080 in both varieties. Whereas under irrigated conditions, the yield reduction in 2020, 2050 and 2080 would be higher in EasternIndo-Gangetic Plain region followed by Central-Indo Gangetic Plane. Overall simulation study shows the adverse impacts of future climate change on Maize, Sorghum & Mustard growth and yield.

Kumar, S. N. *et al.,* (2008) calibrated and validated Info-Crop model with data compiled from 1978 to 2005 of different geographic locations all over India. Time to first flowering varied between 4 and 6 years, leaf production varied from 8 to 15 leaves year^{-1} and nut yield ranged from 3000 to 27,000 nuts ha^{-1} year^{-1}. Model efficiency and validation performance were analysed statistically. Total dry mass and its partitioning, and nut yield agreed closely with observed values. For an agro-climatic zones, simulated potential yields varied from 26 to 30 Mg ha^{-1} year^{-1}where as the potential annual dry mass production varied from 52 to 62 Mg ha^{-1}.Info-Cropcoconut can be used to increase the efficiency of agronomic experiments for coconut crop management.

CROPWAT Model

G *et al.,* (2020) determined reference evapotranspiration using CROPWAT model of region middle of Godavari G- 5 Sub basin lies between latitudes 18^0 20' N and 19^0 25' N and longitudes 77^0 36' and 79^0 56' East. They computed yearly reference evapotranspiration from 2000 to 2014 throughout which in year 2008 maximum yearly reference evapotranspiration was 1250.5 mm/day & minimum yearly evapotranspiration computed as 1119.13 mm/day.

Gangwar *et al.,* (2017) Estimated the crop water requirement of Bina command area lies between longitude of78^0 02' to 78^0 25'E & latitude 23^0 47’ to 24^0 27' N. Crop water requirement was observed for wheat 5.70 – 43.0 mm/day & Crop evapotranspiration 0.90-4.27 mm/day. Where computed data can be used to supply appropriate amount of water for irrigation as per crop water requirement.

Crop-Syst Model

Bellocchi *et al.,* (2002) evaluated CropSyst model for its ability to simulate maize biomass and nitrogen uptake at Pisa, Central Italy in response to different types of tillage practices. CropSyst gave substantial estimates of crop area index i.e. average modelling efficiency, (EF = 0.96), biomass (EF = 0.82) and soil water content (EF = 0.75).

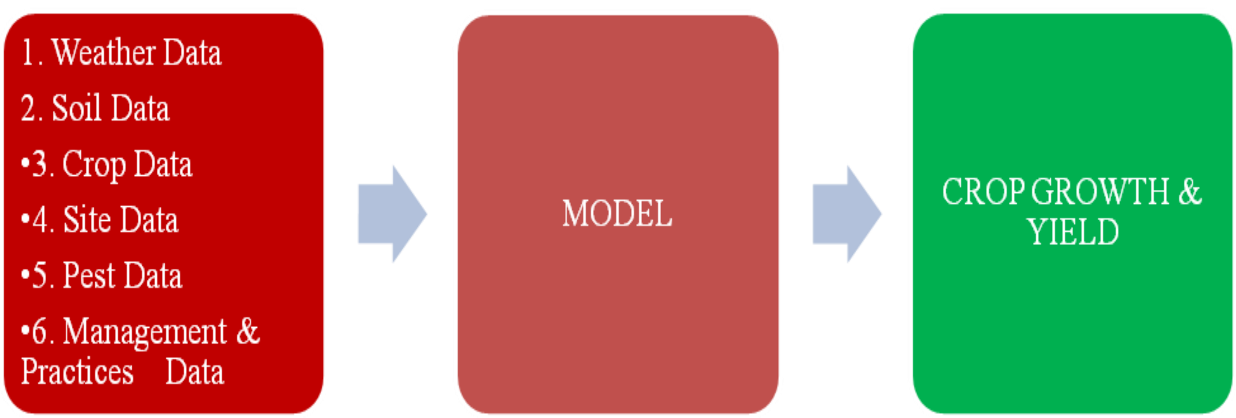
Sommer *et al.,* (2008) calibrated CropSyst model for the cotton variety Khorezm-127 in the Khorezm region of Uzbekistan. Observed that leaf area index & biomass can be simulated with relative accuracy using this model. He found that the agreement between simulated and observed leaf area index & biomass was satisfactory (RMSE) as 0.36 m^2 m^{-2} and 0.97 Mg ha^{-1}, respectively.

Crop growth simulation models are useful for the decision making, as research purpose and as a technology transfer tool to answer the “What If” questions. These models can predict the crop yield as well as simulate the growth characteristics. Which helps to many researchers and farmers worldwide for making the decisions for specific crop to various management practices and under different environmental conditions.In present review paper attempts and illustrated implementations of various crop growth simulation models. These are utilised all around the world for decision making, research, and technology transfer at little or low cost and in a short period of time.

Table.1 Models, their websites, Developed Agency, Year of Published & Author.

Model Name	Website to Download	Developed By	Year	Author
1.DSSAT	https://dssat.net/	IBSNAT & ICASA	1989	Gerrit Hoogenboom
2.AQUACROP	http://www.fao.org/aquacrop/en/	AFO	2009	P. Steduo & Dirk Raes *et al.,*
3.EPIC	https://epicapex.tamu.edu/download-epic-1102/	USDA	1984	William & Renerd *et al.,*
4.WOFOST	https://www.wur.nl/en/Research-Results/Research-Institutes/Environmental-Research/Facilities-Tools/Software-models-and-databases/WOFOST/Downloads-WOFOST.htm	CWFS	1988	Van Dipen
5.SWAP	https://www.swap.alterra.nl/DownloadRecent/swap4.0.1/Swap4.0.1.htm	ISMC	1978	Reinder Feddes *et al.,*
6.Info-Crop	https://www.iari.res.in/index.php?option=com_content&view=article&id=554&Itemid=403	IARI	1995	Aggarwal *et al.,*
7.CROPWAT	http://www.fao.org/fileadmin/user_upload/faowater/Applications/CRW8.ZIP	FAO	1991	Martin Smith
8.Crop-Syst	http://modeling.bsyse.wsu.edu/rnelson/cropsyst/download/install_cs_suite_4_20-07-02.exe	FAO	2003	Claudio Ostackle *et al.,*

Fig.1 Input Required and Schematic Approach of Crop Growth Models



The models are now freely available to students, researchers, and farmers. Anyone can use crop-related data to benefit from these software models for virtual outputs that are close or accurately simulates observed data. 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.

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