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Crop Simulation Models: A Tool for Future Agricultural Research and Climate Change

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Authors' contributions

This work was carried out in collaboration among all authors. Authors AF, YRK and BAL designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Authors SK, ZAD and FR; and author IA, FN and AK managed the analyses of the study. Author AK managed the literature searches. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/AJAEES/2021/v39i630602

Editor(s):

(1) Prof. Md. Abiar Rahman, Bangabandhu Sheikh Mujibur Rahman Agricultural University (BSMRAU), Bangladesh.

Reviewers:

(1) Samuel Adewal, Lagos State Polytechnic, Nigeria.

(2) Magda Mahmoud Amin Sabbour, Agriculture and Biological Division, National Research Centre, Egypt.

Complete Peer review History: <http://www.sdiarticle4.com/review-history/69888>

Review Article

Received 15 April 2021

Accepted 20 June 2021

Published 29 June 2021

ABSTRACT

A crop simulation model is a computerized program which is used to describe the process of growth and developmental stages of crop in relation to weather data, crop conditions and soil conditions to solve the real-world problems. Crop simulation models play an important role in decision making process as these models can save time and resources. The prediction accuracy of simulation models is one of the most vital components in decision making process. Our review shows the prediction accuracy and efficiency of the simulation models like DSSAT and APSIM. We have compared the prediction accuracy of these models on various growth and development stages of crops along with yield prediction. Both the models have performed well while predicting various growth and developmental stages of crops. The present scenario of traditional research is site-specific, Resource consuming and time consuming. Hence the information obtained through traditional research by qualitative analysis has many limitations, Because of changing climate and weather parameters there is a need for computerized based statistical tool which can provide decision support system for more than 10-15 years. By this we strongly believe that Crop simulation models can be a vital tool in future agricultural research and climate change mitigation strategies.

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Keywords: APSIM; DSSAT; simulation models; research; climate change.

1. INTRODUCTION

Research studies on crops are evaluated by using agronomic parameters and these type of studies are conducted by using conventional methods of research. The present scenario of traditional research is site-specific, resource consuming and time consuming. The conventional methods of research is based on Correlation and Regression concepts which are used to provide Qualitative analysis [1]. This type of analysis is very site specific and it is for localized conditions, this type of analysis is used when the sites are having same climate, similar soil conditions and similar crop management practices. Hence the information obtained through traditional research by qualitative analysis has many limitations [2]. Because of changing climate and weather parameters there is a need for computerized based statistical tool which can provide decision support system for more than 10-15 years. Advances in modern research and technology has made it possible to find the integrated approach of soil conditions, climate conditions and crop management practices to predict the yield of crops accurately [3]. Due to rapid increase in population and to sustain the needs of ever increasing population there is a need to shift conventional research into a modern era of research and development, one such tool for future agriculture research is crop simulation models [4]. Due to the limitation of natural resources, increasing in attack of pests and insects, low fertility status of soils, and because of climate uncertainties we need a smart farming approach with strategic planning to mitigate these biotic and abiotic stress. Crop simulation modelling can create a new revolution in agriculture which can achieve the objectives and goals of sustainability. A well efficient and

validated model can be used for optimization of resources, to forecast weather elements, to predict the incidence of pests and insects, yield analysis, for mitigating climate change and to have a information regarding market policies [5,6].

What are crop simulation models?

A crop simulation model is a computerized program which is used to describe the process of growth and developmental stages of crop in relation to Weather data, crop conditions and soil conditions to solve the real world problems. These models use fundamental mechanisms to predict crop growth and developmental processes which are influenced by crop management [7].

A crop simulation model is a computerized program which is used to describe the process of growth and developmental stages of crop in relation to Weather data, crop conditions and soil conditions to solve the real world problems [8]. These models use fundamental mechanisms to predict crop growth and developmental processes which are influenced by crop management and various biotic and abiotic factors. Crop simulation models plays an important role in decision making process as these models can save time and resources. The prediction accuracy of simulation models is one of the most vital component in decision making process [9]. Crop simulation models are not only used to predict the yield but are also useful in terms of quantitative analysis. These models contain the information regarding interactions of tissues and plant organs to have a overall information about plant growth and developmental processes.



Fig. 1. Yield crop harvest procedure

Table 1. Model evaluation

Based on	Models are based on soil conditions, weather elements and crop management practices.
Evaluate	Fertilizer requirements of crops, Harvest yield, growth and development of crops, Irrigation requirement etc
Required information	Weather, crop needs, management practices etc

Crop simulation tools useful for

- 1) Agronomists and extension researchers
- 2) Policy makers
- 3) Farmers
- 4) Educational institutions
- 5) Private and commercial sectors

Most popular and widely used crop simulation models

- 1) DSSAT (Decision support system for agro-technology transfer)
- 2) APSIM (Agricultural production system simulator)
- 3) AQUACROP
- 4) INFOCROP

Source : <https://en.m.wikipedia.org/wiki/DSSAT>

There are numerous models but among these most widely used simulation models are:

- 1) Decision support for Agro-technology transfer (DSSAT) and
- 2) Agriculture production system simulator (APSIM)

1.1 Agriculture Production System Simulator Model

APSIM model was originally developed by Agricultural production system research unit (APSRU) The Agricultural production system simulator is a simulation model which is developed to estimate the biophysical functions and processes in agriculture. This model is used for the comprehensive estimation of economic and ecological activities of crop management to mitigate climate uncertainties and risk. Apart from its ability to mitigate climate risk APSIM is also used to solve real world problems like food security [10].

Components of APSIM [11]

- 1) Biophysical modules
- 2) Management modules
- 3) Data input and output modules
- 4) Simulation engine

Biophysical modules: Biophysical modules are useful for prediction of biological functions and other physical processes in crops

Management models: Management modules are to regulate the scenario of prediction in a reasonable manner and to control the factors that impact simulation models.

Data modules: Data modules provide the required input and output data that is necessary for simulation process

Simulation engine : A simulation engine acts as driving force which can regulate effective communication between various modules .

APSIM is known as farming system simulator which is used to estimate the yield of crop in response to management practices along with prediction of effects on farming practices upon soil resources [12]. Crop simulation model can synthesize information in an accurate manner however the reliability of simulation model is based on natural process.

Kpongor [13] conducted an experiment to compare the efficiency of APSIM model over Other models and reported that model has predicted the response reasonably well. Similar conclusion was made by [14] while evaluating the performance of model in maize phenology.

It has been reported that silking in maize was delayed due to increased N stress, this clearly indicates that maize phenology is dependent on nitrogen levels.

Table 1 clearly indicates that there is no major difference between simulated and observed mean days of maize taken for silking stage [13].

Table 2 clearly indicates that APSIM model has predicted the mean number of leaves at flowering stage in accurate manner without much deviation from the actual observations, the efficiency and elegance of model has been shown under the maize variety (S9235).

Table 2. Simulated and observed mean days to silking under different N rates in maize variety (S9235)

N RATES kg ha ⁻¹	Simulated	Observed	% Deviation
30	64	66	-3
60	64	65	-2
90	64	63	2
120	64	64	0

Table 3. Comparison of simulated and observed mean leaf number at flowering stage in maize variety (S9235)

N rates kg ha ⁻¹	Simulated	Observed	% Deviation
30	21	19	11
60	21	20	5
90	21	19	5
120	21	20	5

1.2 How good is APSIM MODEL at Predicting Yield

One of the important aspect of any model is to predict the yield which plans an important role in commercial cultivation of crops. APSIM model has been tested to predict the yield under wide range of growing conditions. Fosu [15] has evaluated the performance of APSIM model to compare the trend of simulated and observed maize yield under the experiments of N and P applications, the model has effectively simulated the maize yield under these experiments. Miao et al. [16] has reported that the model of APSIM has performed well with errors accounting for less than 10%. Kpongor [13] also evaluated the efficiency of APSIM model on sorghum to

simulate the grain and biomass yield. A good positive correlation has been found between the simulated and observed grain and biomass yield.

Comparison between observed and predicted yield and dorke maize cultivars .The model has performed well to simulate maize grain yield under the applications of inorganic N and P fertilizer experiments.

The model has performed well to simulate corn yield for two different hybrids (33G26 and 33J24) over the years (2001 and 2003) under the application rates of N (0 – 336 kg ha⁻¹). The model has shown the 93% variability of yield and it was effective at non zero N rates. The errors were less than 10%.

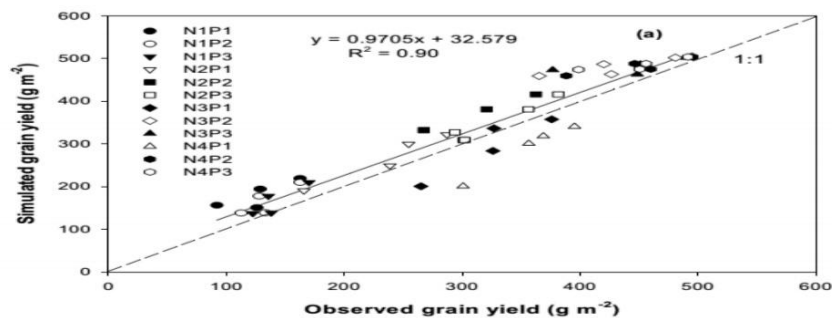


Fig. 2. Simulated and observed grain and biomass yield
(Source : Ecology and development series, 2013)

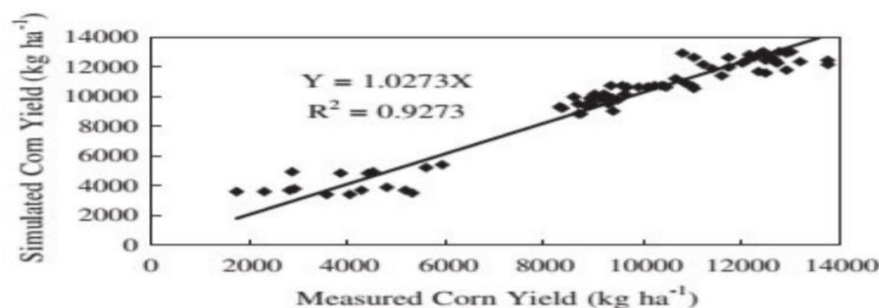


Fig. 3. Observed and Simulated corn yields for two different hybrids (33G26 and 33J24)
(Source: Miao et al., [16])

According to Kiros and hrui [17], APSIM model has performed well under different environmental conditions to simulate the yield and growth of sorghum, maize and wheat. Considering all these things, agriculture production simulator model can be adopted in modern agricultural research for better prediction of conditions as well as for accurate decision making in selecting crops and for good management practices to promote sustainable development of resources, however the model should be examined carefully before recommending it for use under normal field conditions.

1.3 Decision Support System for Agro Technology Transfer (DSSAT)

The decision support system for agro-technology transfer has been developed with an objective to evaluate the applications of research in agriculture. The initiative of this model is based on integrated approach of soil, climate and crop management practices to promote better decision making regarding transformation of technology from one site to another under varying climate and soils (Uehara and Tsuji, 1998).

Jones and Ritchie (2003) acclaimed that the decision support system for agro-technology transfer is an effective tool for conducting agricultural research. Since the last 15 to 20 years this tool has been widely used by the researchers throughout the globe. This model will allow researchers to solve the real world problems faced in the field of Agriculture. DSSAT model is based on set of computer applications which are used to predict the growth and development of crops. This technique is rapidly spreading throughout the world and it has been adopted in more than 100 countries by researchers to conduct analysis on farming systems and methods used. DSSAT can become an effective tool to tackle climate change and mitigate climate related stress and uncertainties in agriculture. One of the main advantage of DSSAT model is that it can be combined with other software applications such as GIS making

this model more flexible and reliable. This model works based on input information such as soil conditions, weather data and management practices performed under field conditions such as fertilizer application, irrigation and variety of crop. DSSAT plays an important role to help decision makers and policy makers by saving time and resources required for evaluating complicated decisions [18].

Applications of DSSAT in Agriculture

- 1) Crop management studies
- 2) Irrigation scheduling
- 3) Fertilizer applications
- 4) Pest and disease management
- 5) Precision farming
- 6) Climate and weather related studies
- 7) Yield prediction
- 8) Sustainable agriculture
- 9) Education and research
- 10) Variety performance

1.4 Response of DSSAT Model to Manure and Fertilizer Applications

An experiment was conducted to find out the efficiency of model under manure and fertilizer treatments. The simulated and observed days are so close and the model has reasonably predicted well under no manure and no fertilizer treatments, and there was no much deviation [19].

Similar results were found between the predicted and observed days under no manure and 100% Fertilizer treatments. Further on, the model has also been evaluated under application of 3 tonnes of FYM and no fertilizer.

There is no major difference between Observed and simulated days taken to anthesis and physiological maturity stages under no manure and full fertilizer application. But the deviation in percentage is close to 10% for grain yield and the percentage of deviation is more than 10% for simulated and observed biomass under DSSAT model.

Table 4. Response of model to no manure and no fertilizer treatments

Parameters	Predicted data	Observed data	Deviation%
Anthesis stage	55	56	-1.8%
Physiological maturity	90	90	0.0%
Grain yield kg ha ⁻¹	1099	1087	-1.1%
Biomass kg ha ⁻¹	3895	4071	4.5%

(Source : <https://www.frontiersin.org/articles/10.3389/fenvs.2019.00013/full>)

Table 5. Response of model to no manure and full fertilizer application

Parameters	Predicted data	Observed data	Deviation%
Anthesis stage	55	56	-1.8%
Physiological maturity	90	90	0.0%
Grain yield kg ha^{-1}	2847	3068	7.8%
Biomass kg ha^{-1}	7119	8272	16.2%

(Source : <https://www.frontiersin.org/articles/10.3389/fenvs.2019.00013/full>)**Table 6. Response of model to 3 tonnes of manure and Fertilizer application**

Parameters	Predicted data	Observed data	Deviation %
Anthesis stage	55	56	-1.8%
Physiological maturity	90	90	0.0%
Grain yield kg ha	2039	1983	2.8%
Biomass kg ha	6121	5820	5.2%

(Source : <https://www.frontiersin.org/articles/10.3389/fenvs.2019.00013/full>)

Decision Support system for Agro-Technology transfer model has performed well while predicting the Anthesis, Physiological maturity, Grain yield and Biomass at harvest under different treatments of manure and fertilizer applications. By evaluating above results and benefits of application of organic sources of fertilizers for soil health, combined application of fertilizer and micro applications of small quantities of manure can maintain soil health and can also promote sustainable use of resources.

1.5 DSSAT Model Comparison between Observed and Predicted Maize Grain and Biomass Yield

A comparison has been made between observed and predicted maize grain and biomass yield to find out the efficiency of the model under the application of 3 tonnes of manure or Zero manure and (zero) no fertilizer, 50% Fertilizer or 100% Fertilizer over 2 years. The model predicted well in recording response to the mixed application of manures and fertilizers over 2 years. The grain yield for RMSE was 327 kg/ha. Efficiency of model was 0.70 and the D index for model was 0.96. The model has also showed effective performance while predicting biomass yields. The RMSE (Root mean square error) and RRMSE were 569 kg/ha and 8%. The d(Index of agreement) and E1(Coefficient of efficiency) was 0.97 and 0.69.

1.6 Role of Crop Simulation models in Mitigating Climate change

Climate change has been a serious constraint for agriculture production as well as for research

based activities. The conventional research through agronomy trails are getting inappropriate due to changing climate. So we need a universal model which is used to predict climate change and can help the farmers to plan their field operations accordingly. Mitigating climate change through crop simulation model is the main focus and integrated approach is being made to assess the risk of climate and weather on farming systems (Ewert et al., 2015)

1.7 Tackling Risk and Uncertainty

To tackle risk and uncertainties in agriculture a great interaction should be developed between various systems such as forestry, agriculture, water conservation etc which can play a key role in assessing the risks of climate change [20]. Along with mitigating climate change crop modelling can also be used as a tool for understanding uncertainties in food production which will help the globe to reduce food scarcity problems for promoting better food quality and food security [21].

1.8 A Tool for Environment Protection

Excessive use of chemicals even since green revolution has poised many negative impacts on agriculture. Agriculture by products contribute about 12.5% in global greenhouse gas emissions. Site specific farming approach should be promoted in agriculture sector to reduce the indiscriminate use of chemicals. Crop simulation modelling can simulate the optimum resources required for crop cultivation according to development, growth stages and requirement of crops through computerized programs.

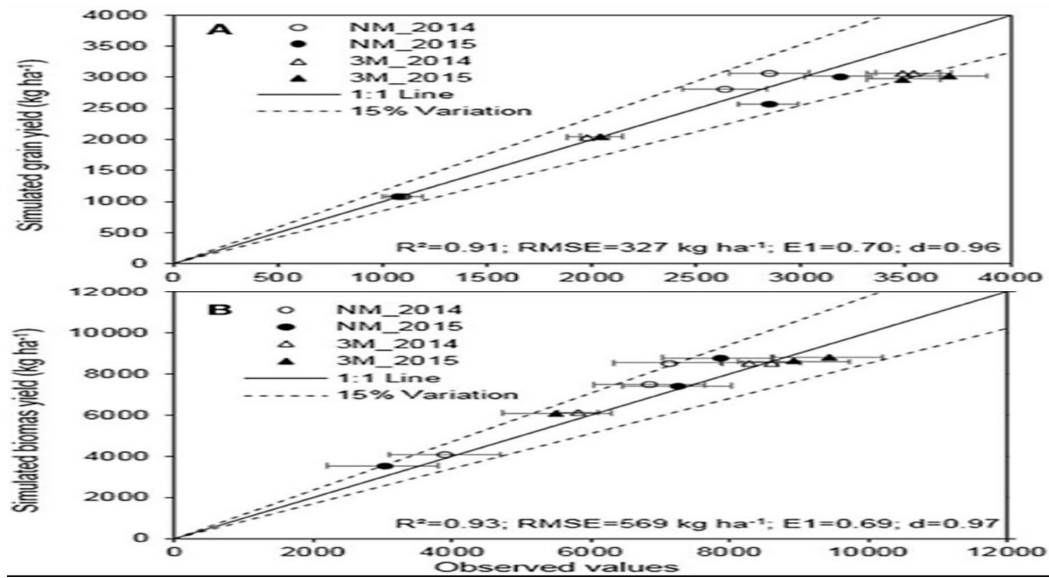


Fig. 4. DSSAT tool can become an effective technology for future analysis of nutrient applications under different diversified conditions [19]

Table 7. Greenhouse gas emissions from different sectors

Sectors	Percentage
Industrial pollution	16.8%
Transportation	14.0%
Agriculture	12.5%
Fossil fuels	11.3%
Commercial sources	10.3%
Biomass burning	10.0%
Waste disposal	3.4%
Power plants	21.3%

Source: European environment agency, <https://www.eea.europa.eu/data-and-maps/indicators/greenhouse-gas-emission-projections/greenhouse-gas-emission-projections-assessment-2>

Table 8. Annual nitrogen emission sources

Nitrogen sources	Percentage %
Natural soils	40%
Oceans	20%
Agriculture fields	14%
Industrial pollution	9%
Livestock	14%
Biomass	3%

Source: Food and Agriculture Organization <http://www.fao.org/3/y3557e/y3557e11.htm>

Agriculture is one of the major source of greenhouse gas emissions, large sources of carbon dioxide are released due to the burning of biomass and excessive use of nitrogenous fertilizers has lead towards water pollution. Agriculture is also contributing towards major greenhouse gas like methane, half of the percentage of methane gas emissions are from

agriculture fields. Smart farming with crop simulation models will reduce the global greenhouse gas emissions of agriculture.

About 15 million tonnes of Nitrogen emissions are released into the environment annually out of these Agriculture contributes for about 14%, which is a serious threat to the environment

considering all these things a new approach with crop simulation tool can reduce the negative impacts on environment by target specific use of resources and cutting off the excessive losses of inputs. Many major issues like nutrient imbalances, weed incidence, insect and pest attack and climate risks can be sorted out by using efficient and validated simulation models (Food and Agriculture Organization).

2. CONCLUSION

Crop simulation model can be an effective tool for future agricultural research and for mitigating climate related stress. Simulation models like DSSAT and APSIM have shown greater efficiency and elegance in predicting various growth and developmental stages of crop. Simulation models have also shown their impact on market efficiency and market surveillance, these models will help policy makers and are having a wide role to play in extension services. Considering all these things crop simulation models can be a better option for decision making and for choosing optimum management practices under wide range of climatic conditions. Simulation models can create a new chapter in the history of agriculture and are having a lot of scope in future agriculture research. One of the main objective of simulation model is to achieve the goals of sustainability and these models can play a huge role in sustainable development of resources. Smart farming with crop simulation models can reduce greenhouse gas emissions and it can be solution to reduce the global greenhouse gas emissions from agriculture sector.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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The peer review history for this paper can be accessed here:
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