*Chronicle of Bioresource Management* 2024, 8(4): 141-146

Chronicle of Bioresource Management
An International E-magazine

December, 2024 Popular Article

# Sustainable Agriculture through Precision Modeling and Decision Support

R. S. Bana, Ramanjit Kaur*, Sk Asraful Ali, Dileep Meena, S. L. Meena and Teekam Singh

Open Access

Corresponding Author
Ramanjit Kaur
*e-mail*: ramaan180103@yahoo.com

***Citation:*** Bana et al., 2024. Sustainable Agriculture through Precision Modeling and Decision Support. Chronicle of Bioresource Management 8(4), 141-146.



***Data Availability Statement:*** Legal restrictions are imposed on the public sharing of raw data. However, authors have full right to transfer or share the data in raw form upon request subject to either meeting the conditions of the original consents and the original research study. Further, access of data needs to meet whether the user complies with the ethical and legal obligations as data controllers to allow for secondary use of the data outside of the original study.

***Conflict of interests:*** The authors have declared that no conflict of interest exists.

***Keywords:***

APSIM, cropping system models, DSSAT, InfoCrop, sustainable agriculture

***Article History***

Article ID: CBM5968
Received on 04th December 2024
Received in revised form on 20th December 2024
Accepted in final form on 25th December 2024

## Abstract

This paper offers a comprehensive overview of cropping system models, highlighting their scope, applications, and future potential in agricultural research and decision-making. Models such as APSIM, DSSAT, STICS, InfoCrop, and EPIC are discussed, each with distinct features that cater to various agricultural needs. These models are essential for researchers, agronomists, and policymakers, providing critical insights into the complexities of cropping systems and informing sustainable agriculture strategies. Looking forward, cropping system models are poised to address significant challenges like climate change adaptation, sustainable intensification, and food security. As technological advancements continue, these models will integrate scientific knowledge with stakeholder engagement to enhance agricultural practices. To fully realize their potential, it is crucial to invest in research, capacity building, and technology transfer. Collaborative efforts across disciplines and regions will be vital in leveraging modeling tools to tackle the intricate challenges in agriculture and foster a resilient and equitable food system for the future.

## 1. Introduction

Crop modeling serves as a fundamental pillar in modern agriculture, providing a potent tool to simulate and predict crop growth, development, and yield across diverse environmental scenarios. Rooted in interdisciplinary collaboration spanning agronomy, meteorology, soil science, and plant physiology, these models play a crucial role in guiding crop management strategies, informing decision-making processes, and assessing the impacts of climate change on agricultural productivity (Peng et al., 2020). Their central role lies in fostering agricultural sustainability, productivity, and resilience amid escalating global food demands and shifting climatic patterns. With the integration of cutting-edge advancements in data science, computational modeling, and interdisciplinary research, crop models continually evolve, expanding their capacity to offer informed decision support and facilitate policy formulation within the agricultural sector (Figure 1).

Standing prominently in the modeling landscape is the APSIM model, renowned for its robustness and versatility in simulating cropping systems.

***Author's Address***

Division of Agronomy, ICAR-Indian Agricultural Research Institute, Pusa Campus, New Delhi (110 012), India

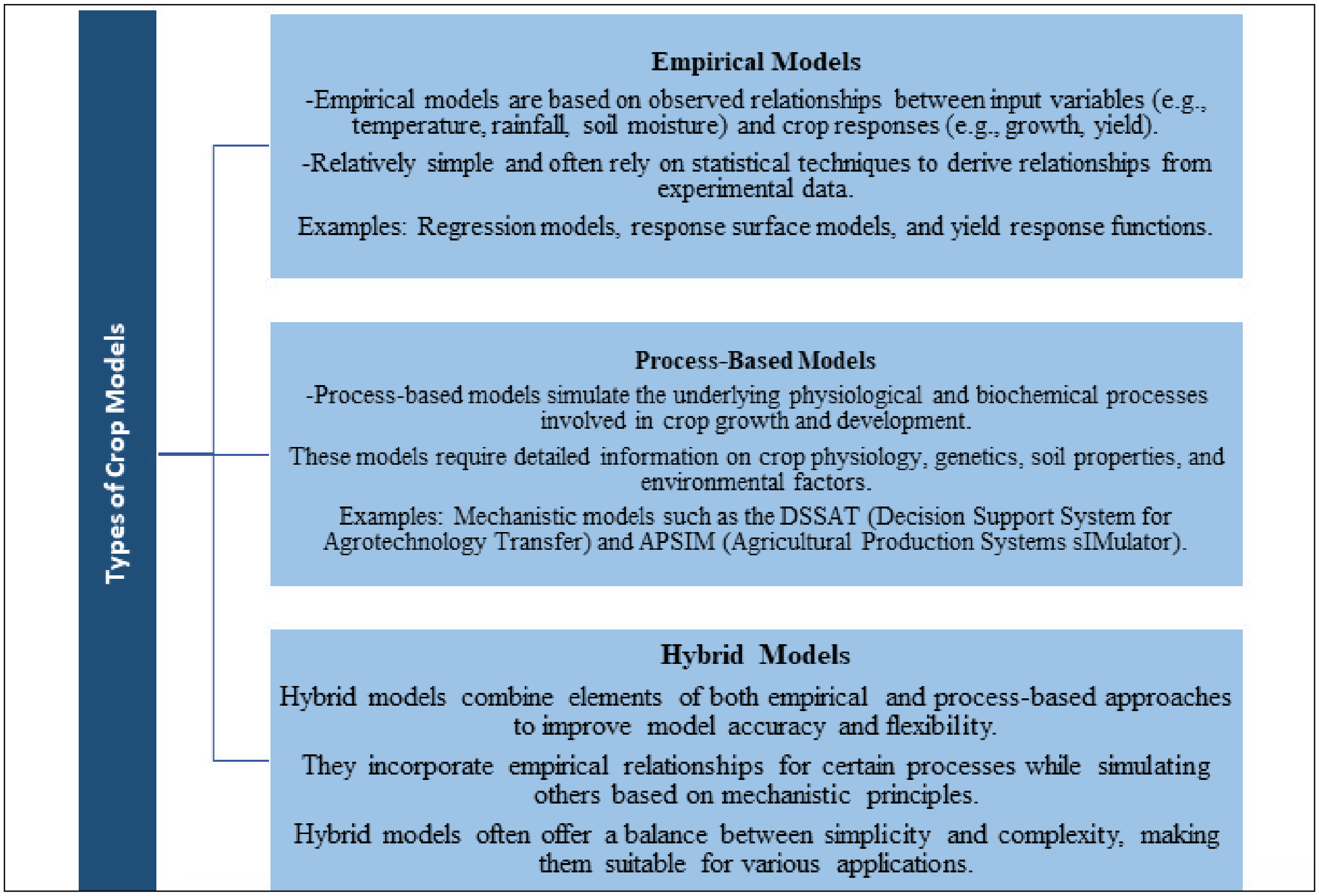


**Figure 1: Types of crop models**

As a comprehensive agricultural modeling framework, APSIM features a rich array of components that capture the intricate interactions between crops, soils, climate, and management practices (Figure 2). Its strength lies not only in accurately simulating crop phenology, growth, and yield under varying conditions but also in its ability to elucidate the underlying mechanisms driving these processes. APSIM's modular architecture allows for tailored simulations across a wide range of cropping systems, enabling users to explore diverse management scenarios and assess the impacts of climate change. Despite the remarkable strides made in crop modeling, several challenges persist, necessitating concerted efforts to overcome them. Key among these challenges are data limitations, model validation, scaling issues, and uncertainty propagation. Addressing these challenges is crucial to unlocking the full potential of crop modeling in addressing future agricultural dilemmas. Through ongoing research, innovation, and collaboration, the field of crop modeling is poised to play an increasingly pivotal role in shaping the future of agriculture, ensuring sustainable food production in an ever more uncertain world. This chapter delves into the intricacies of crop models, including the APSIM model, exploring their types, components, applications, and challenges.

## 2. Components of Crop Models

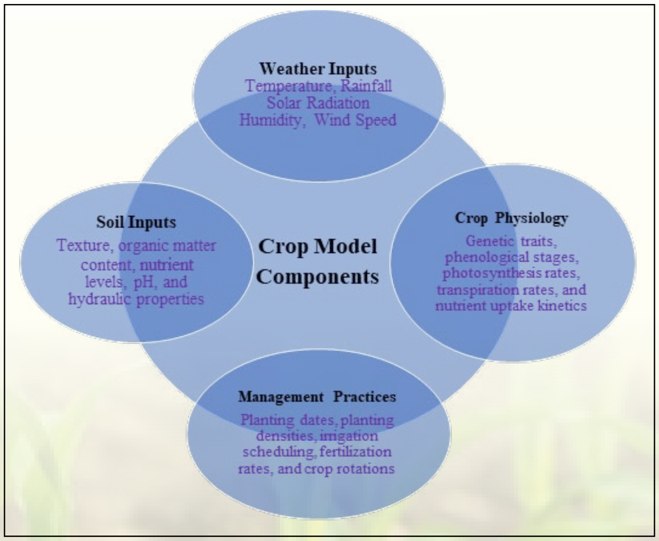


Figure 2: Components of crop models

# 3. Applications of Crop Models

### *3.1. Crop yield prediction*

a. Crop models can predict yield outcomes under different management scenarios and environmental conditions, aiding farmers in decision-making processes.

b. They provide valuable insights into the potential impacts of climate variability and change on crop productivity.

### *3.2. Crop management optimization*

a. Crop models help optimize agronomic practices by identifying optimal planting dates, irrigation schedules, fertilizer rates, and crop rotations.

b. They assist in maximizing yield potential while minimizing resource inputs and environmental impacts.

### *3.3. Climate change impact assessment*

a. Crop models are used to assess the potential effects of climate change on crop yields, phenology, and geographical distribution.

b. They contribute to developing adaptation strategies and informing policymakers about the vulnerability of agriculture to climate variability and change.

# 4. Challenges in Modeling

### *4.1. Data limitations*

a. Crop modeling requires extensive data on weather, soil, crop physiology, and management practices, which may be limited or uncertain in certain regions.

b. Addressing data gaps and improving data quality are critical challenges for enhancing the accuracy and reliability of crop models.

### *4.2. Model calibration and validation*

a. Calibration and validation of crop models require rigorous testing against observed data from field experiments and long-term monitoring sites.

b. Ensuring model robustness across different cropping systems, environments, and management practices is essential for broad-scale applicability.

### *4.3. Scaling issues*

a. Scaling crop models from plot-level simulations to regional or global scales poses challenges due to spatial heterogeneity, variability in management practices, and computational constraints.

b. Developing scalable modeling frameworks and integrating remote sensing and geospatial data are promising avenues for addressing scaling issues.

### *4.4. Incorporating uncertainty*

a. Uncertainty arises from various sources such as input data errors, model parameterization, and inherent variability in crop responses.

b. Enhancing the capability of crop models to quantify and propagate uncertainty is crucial for improving their reliability and credibility.

# 5. APSIM Model

The Agricultural Production Systems sIMulator (APSIM) stands as one of the most widely used cropping system models globally. Developed by the Commonwealth Scientific and Industrial Research Organisation (CSIRO) in Australia, APSIM is renowned for its comprehensive representation of agricultural systems, robust simulation capabilities, and flexibility in accommodating diverse cropping systems and management practices. APSIM operates on a process-based modeling approach, simulating the interactions between crops, soils, climate, and management practices at various spatial and temporal scales. Its modular structure allows users to configure and customize model components according to specific cropping systems and research objectives. The model incorporates algorithms for simulating crop growth, phenology, water and nutrient dynamics, soil organic matter decomposition, root growth, and various management operations (Raymond et al., 2021).

One of the key strengths of APSIM lies in its ability to simulate a wide range of crops, including cereals, legumes, oilseeds, and forage species, across different agroecological zones. The model captures the physiological responses of crops to environmental stresses such as drought, heat, cold, and nutrient limitations, enabling researchers and farmers to assess the resilience of cropping systems to various climate scenarios. APSIM's versatility extends to simulating diverse management practices such as tillage, irrigation, fertilization, crop rotations, intercropping and residue management, allowing users to explore the impacts of different management strategies on productivity, profitability, and environmental sustainability.

Furthermore, APSIM has been extensively validated and applied in various research and agricultural development projects worldwide, including South Asian cropping systems. Its user-friendly interface, extensive documentation, and active user community contribute to its widespread adoption and continual improvement. APSIM serves as a valuable tool for addressing complex agronomic challenges, optimizing resource use efficiency, and enhancing the resilience of agricultural systems in the face of climate change and other environmental stressors. As agricultural landscapes continue to evolve, APSIM remains at the forefront of modeling efforts, supporting evidence-based decision-making and sustainable agricultural development across the globe.

# 6. Applications of APSIM Model

### *6.1. Crop yield prediction and management optimization*

APSIM is widely used for predicting crop yields under different management scenarios and environmental conditions. Researchers and farmers utilize APSIM to optimize agronomic practices such as planting dates, planting densities, irrigation scheduling, fertilization rates, and crop rotations. By simulating the effects of various management strategies on crop growth, development, and yield formation, APSIM helps identify optimal management practices to maximize productivity while minimizing resource inputs and environmental impacts.

### *6.2. Climate change impact assessment*

This model plays a crucial role in assessing the potential impacts of climate change on agricultural productivity and food security. Researchers utilize APSIM to simulate crop responses to future climate scenarios, including changes in temperature, precipitation, and $CO_2$ levels. By integrating climate projections with crop models, APSIM helps identify regions and cropping systems most vulnerable to climate change, evaluate adaptation strategies, and inform policy decisions aimed at enhancing agricultural resilience.

### *6.3. Crop breeding and genotype evaluation*

It is employed in crop breeding programs for evaluating the performance of new cultivars and genetic traits under different environmental conditions and management regimes. Researchers use APSIM to simulate genotype-by-environment interactions, assess the stability and adaptability of new varieties across diverse agroecological zones, and identify traits contributing to yield potential, stress tolerance, and resource use efficiency. APSIM's genetic models aid in predicting the performance of breeding populations, guiding selection decisions, and accelerating the development of improved crop varieties.

### *6.4. Nutrient management and environmental sustainability*

APSIM facilitates the optimization of nutrient management practices to enhance crop productivity while minimizing nutrient losses and environmental impacts. Researchers and extension agents use APSIM to simulate nutrient cycling processes, evaluate the effects of fertilization rates, timing, and placement on crop uptake and soil fertility, and develop site-specific nutrient management recommendations. By integrating soil, crop, and management models, APSIM supports sustainable intensification of agriculture by promoting nutrient use efficiency, reducing nutrient runoff, and mitigating environmental pollution.

### *6.5. Decision support systems and policy analysis*

It serves as a decision support tool for farmers, agronomists, and policymakers by providing insights into crop performance, risk management, and policy implications. Decision support systems built on APSIM help users make informed decisions related to crop selection, land use planning, irrigation management, pest and disease control, and economic analysis. APSIM-based simulations contribute to policy analysis by evaluating the impacts of agricultural policies, subsidies, and incentives on farm profitability, land use change, and environmental outcomes.

We can summarise that APSIM is a versatile and widely used modeling platform with diverse applications in agricultural research, crop management, climate change adaptation, crop breeding, nutrient management, and policy analysis. By simulating the complex interactions within cropping systems, APSIM contributes to enhancing agricultural sustainability, resilience, and productivity in a changing world.

## 7. Other Widely Used Crop Models

### *7.1. DSSAT (Decision support system for agrotechnology transfer)*

DSSAT is a widely used crop modeling framework comprises models for simulating the growth, development, and yield of various crops, integrating modules such as CERES (Crop Environment Resource Synthesis) for crop response to weather, soil, and management practices. DSSAT assists in assessing management strategies for improved crop productivity, resource use efficiency, and sustainability (Gao et al., 2022).

### *7.2. STICS (Simulator for crop management)*

STICS, developed by INRA, France, simulates crop growth, development, and yield under different conditions. It includes algorithms for crop physiology, soil processes, water dynamics, nutrient cycling, and pest/disease interactions. STICS optimizes crop management practices, analyses climate change impacts, and designs sustainable cropping systems.

### *7.3. CROPSYST (Crop system simulation model)*

CROPSYST, from Washington State University, models multiple crop growth, development, and yield. It integrates crop and soil models, weather generators, and economic modules to simulate interactions between crops, soils, climate, and management. CROPSYST evaluates crop rotations, water and nutrient management, and climate variability impacts.

### *7.4. EPIC (Environmental policy integrated climate)*

EPIC, by the USDA, assesses environmental impacts of agricultural practices including crop growth, soil erosion, nutrient cycling, and water quality. It incorporates crop growth, soil processes, land use change, and environmental outcomes. EPIC informs land use planning, conservation practices, and policy decisions.

### *7.5. SALUS (System approach to land use sustainability)*

SALUS, simulates multi-crop growth, development, and yield under various conditions. It integrates crop physiology, soil processes, water dynamics, nutrient cycling, and pest/disease interactions. SALUS evaluates crop management, irrigation scheduling, and climate change impacts.

### *7.6. AQUACROP*

AQUACROP, developed by the FAO, focuses on rainfed and limited irrigation crop growth, development, and yield. It simulates crop water requirements, soil water dynamics, water stress responses, and yield formation. AQUACROP assesses water productivity, irrigation scheduling, and supports water management decisions (Kheir et al., 2021).

*7.7. Cool farm tool*

The Cool Farm Tool estimates greenhouse gas emissions from agricultural practices across various crops and livestock systems. It integrates data on land use, crop management, fertilizer use, energy consumption, and livestock management. It identifies mitigation options, tracks emission reductions, and improves environmental sustainability.

*7.8. DNDC (DeNitrification-DeComposition)*

DNDC, developed by the University of New Hampshire and the USDA, models carbon and nitrogen cycling in agricultural and natural ecosystems. It simulates soil organic matter decomposition, nitrogen cycling, and greenhouse gas emissions. DNDC assesses land use change, agricultural practices, and climate variability impacts on soil health and greenhouse gas fluxes.

*7.9. InfoCrop*

InfoCrop, developed by the ICAR-Indian Agricultural Research Institute (IARI) New Delhi, simulates crop growth, development, and yield under diverse environments. It integrates crop physiology, soil processes, water dynamics, and management practices. InfoCrop supports crop yield forecasting, land suitability assessment, and climate change impact analysis.

*7.10. CENTURY*

CENTURY, developed by Colorado State University, models long-term carbon and nitrogen dynamics in soils. It simulates plant residue decomposition, microbial activity, humus formation, and nutrient cycling. CENTURY assesses land use change, soil management, and climate variability impacts on soil organic matter dynamics and ecosystem sustainability.

In brief, these models serve as valuable tools for researchers, agronomists, and policymakers, providing insights into the complexities of cropping systems and supporting decision-making for sustainable and resilient agriculture.

## 8. Scope of Cropping System Models in Futuristic Research

The scope of cropping system models in futuristic research is vast and holds immense potential for addressing emerging challenges and opportunities in agriculture. As technology continues to advance and our understanding of agricultural systems deepens, cropping system models are expected to play a pivotal role in shaping the future of farming. Here are some key areas where cropping system models can contribute to futuristic research:

*8.1. Climate change adaptation*

Cropping system models will be crucial for assessing the impacts of climate change on agricultural productivity, resource availability, and environmental sustainability. These models can simulate future climate scenarios and predict how changes in temperature, precipitation, and $CO_2$ levels will affect crop growth, water availability, pest and disease dynamics, and soil health. By identifying climate-resilient crop varieties, agronomic practices, and adaptation strategies, cropping system models can help farmers mitigate risks and maintain productivity in a changing climate.

*8.2. Sustainable intensification*

Cropping system models will support efforts to intensify agricultural production while minimizing negative environmental impacts. These models can optimize resource use efficiency, reduce greenhouse gas emissions, and enhance ecosystem services by simulating diverse cropping systems, precision management practices, and conservation strategies. By integrating biophysical and socio-economic factors, cropping system models can guide the development of sustainable intensification pathways that balance productivity, profitability, and environmental stewardship.

*8.3. Digital agriculture and precision farming*

Cropping system models will integrate with emerging technologies such as remote sensing, drones, sensors, and artificial intelligence to enable precision farming and decision support systems. These models can assimilate real-time data on weather, soil conditions, crop growth, and pest/disease outbreaks to provide personalized recommendations for crop management. By optimizing inputs such as water, nutrients, pesticides, and energy, cropping system models can enhance farm efficiency, reduce costs, and minimize environmental impacts.

*8.4. Resilient crop varieties and genetic improvement*

Cropping system models will aid in the development and evaluation of resilient crop varieties through crop breeding and genetic engineering. These models can simulate genotype-by-environment interactions, predict the performance of new cultivars under different environmental conditions, and identify genetic traits associated with stress tolerance, yield potential, and nutritional quality. By accelerating the breeding process and guiding trait selection, cropping system models can contribute to the development of climate-resilient and high-yielding crop varieties.

*8.5. Integrated farming systems and agroecology*

Cropping system models will facilitate the design and optimization of diverse and integrated farming systems that harness ecological processes and promote biodiversity. These models can simulate agroforestry, intercropping, crop-livestock integration, and ecosystem services such as pollination, pest control, and soil fertility enhancement. By quantifying trade-offs and synergies between different components of farming systems, cropping system models can support the transition towards more sustainable and resilient agroecological practices.

### *8.6. Global food security and nutrition*

Cropping system models will contribute to global food security and nutrition by assessing the impacts of population growth, dietary changes, trade dynamics, and land use policies on food production and availability. These models can simulate food supply chains, market dynamics, and socio-economic factors to identify regions at risk of food insecurity and inform policy interventions. By integrating crop production with nutrition outcomes, cropping system models can promote food systems that are equitable, diverse, and nutritious.

## 9. Conclusion

The exploration of cropping system models highlights their critical role in advancing sustainable agriculture. By integrating diverse models like APSIM, DSSAT, and EPIC, researchers can gain valuable insights into complex agricultural systems. As we face challenges such as climate change and food security, these models will be instrumental in developing adaptive strategies and optimizing resource use. Continued investment in research and collaboration is essential to fully leverage these tools, ensuring a resilient and equitable food system for future generations.

## 10. References

Raymond, N., Kopittke, P.M., Wang, E., Lester, D., Bell, M.J., 2021. Does the APSIM model capture soil phosphorus dynamics? A case study with Vertisols. Field Crops Research 273, 108302.

Kheir, A.M., Alkharabsheh, H.M., Seleiman, M.F., Al-Saif, A.M., Ammar, K.A., Attia, A., Schillaci, C., 2021. Calibration and validation of AQUACROP and APSIM models to optimize wheat yield and water saving in arid regions. Land 10(12), 1375.

Gao, F., Luan, X., Yin, Y., Sun, S., Li, Y., Mo, F., Wang, J., 2022. Exploring long-term impacts of different crop rotation systems on sustainable use of groundwater resources using DSSAT model. Journal of Cleaner Production 336, 130377.

Peng, B., Guan, K., Tang, J., Ainsworth, E.A., Asseng, S., Bernacchi, C.J., Zhou, W., 2020. Towards a multiscale crop modelling framework for climate change adaptation assessment. Nature plants 6(4), 338-348.