

COMPUTER MODELS FOR AGRICULTURE: APPLICATIONS, ADVANCES AND FUTURE PROSPECTS

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ABSTRACT

Agriculture faces growing challenges from climate variability, resource scarcity, soil degradation, and emerging pests and diseases. Computer-based models support scientific decision-making by simulating agricultural processes using weather, soil, crop, water, management, and socioeconomic data. Traditional crop models, including DSSAT, APSIM, AquaCrop, and WOFOST, estimate crop growth, yield, and environmental responses. Recent advances in artificial intelligence, machine learning, remote sensing, IoT, and digital twins have expanded predictive capabilities. This article reviews agricultural modelling approaches, applications, advantages, limitations, and future prospects, emphasizing integrated, accurate, and sustainable decision-support systems.

KEYWORDS: Artificial intelligence, Computer modelling, Crop yield prediction, Decision support system, Machine learning, Precision agriculture, Remote sensing, Smart agriculture

INTRODUCTION

Agricultural production is a complex system involving interactions among soil, crop, atmosphere, water, nutrients and management practices. Farmers must make decisions regarding sowing dates, crop varieties, irrigation, fertilization, pest management and harvesting under uncertain environmental conditions. Computer models provide a systematic method for representing these interactions and evaluating different management scenarios.

Crop models have traditionally been developed using mathematical equations describing physiological and environmental processes. They can simulate crop growth and development under different combinations of weather, soil and management conditions. Recent reviews indicate that models such as APSIM, DSSAT, AquaCrop, WOFOST and ORYZA have important applications in crop production, water management and food-security assessment.

The rapid development of artificial intelligence has introduced a new generation of computer models. Machine-learning and deep-learning models can identify relationships within large datasets without requiring all relationships to be explicitly represented through mathematical equations. Consequently, computer modelling in agriculture is moving from conventional simulation toward integrated, data-driven and intelligent systems.

MAJOR TYPES OF COMPUTER MODELS IN AGRICULTURE

- 1) *Crop Simulation Models*: Crop simulation models represent crop growth and development as a function of environmental and management variables. Important inputs include temperature, solar radiation, rainfall, soil properties, crop genotype, planting date, irrigation and fertilizer application. Models such as DSSAT, APSIM, AquaCrop and WOFOST can estimate biomass production, crop phenology, yield and water-use efficiency. These models are particularly useful for evaluating alternative management practices and studying the effects of climate change. Recent research emphasizes that crop models can support decisions related to productivity, sustainability, climate adaptation and resource management. Model ensembles and coupled models can also reduce some limitations associated with individual models.
- 2) *Statistical and Machine-Learning Models*: Machine learning uses historical datasets to establish relationships between agricultural inputs and outputs. Common techniques include linear regression, decision trees, random forests, support vector machines, artificial neural networks and gradient-boosting methods. For example, a crop-yield prediction model can use rainfall, temperature, soil characteristics, fertilizer application, satellite-derived vegetation indices and historical yield data to estimate expected production. Recent reviews demonstrate the increasing use of machine learning and deep learning for agricultural yield prediction. The major advantage of ML models is their ability to handle large and nonlinear datasets. However, their reliability depends strongly on the quality, quantity and representativeness of training data.
- 3) *Deep-Learning and Computer-Vision Models*: Deep learning has become particularly important for agricultural image analysis. Convolutional neural networks (CNNs), recurrent neural networks (RNNs), long short-term memory networks (LSTMs) and transformer-based models can analyse images obtained from smartphones, drones and satellites.

These models can be used for:

- Crop disease identification
- Weed detection

- Plant counting
- Crop-stage identification
- Fruit detection
- Crop stress assessment
- Yield estimation
- Remote-sensing image classification

A major advantage of deep learning is its ability to automatically extract complex features from images and other high-dimensional datasets. Recent research also highlights the potential of advanced deep-learning architectures and vision transformers for agricultural applications.

APPLICATIONS OF COMPUTER MODELS IN AGRICULTURE

Computer models have applications throughout the agricultural production cycle.

- Crop Yield Prediction:* Yield prediction is one of the most important applications. Models can combine weather records, satellite observations, soil information and historical yield data to provide early estimates of production. Such information is useful for farmers, agricultural planners, commodity markets and policymakers.
- Irrigation Management:* Computer models can estimate crop evapotranspiration, soil-water balance and crop water requirements. These predictions can help determine when irrigation should be applied and how much water should be supplied. This is particularly important in water-scarce regions.
- Fertilizer and Nutrient Management:* Models can estimate nutrient demand and evaluate fertilizer strategies. By integrating soil information, crop growth and weather conditions, computer models can support site-specific fertilizer recommendations and improve nitrogen-use efficiency.
- Pest and Disease Management:* AI-based models can analyse crop images and environmental conditions to identify disease symptoms and estimate pest risks. Early detection allows farmers to take preventive action and potentially reduce unnecessary pesticide applications.
- Climate-Change Impact Assessment:* Crop models are widely used to evaluate the potential effects of temperature increases, changing rainfall patterns, elevated atmospheric carbon dioxide and extreme weather events. Such simulations can help identify suitable adaptation strategies, including changes in planting dates, cultivars, irrigation and crop-management practices.
- Precision Agriculture:* The combination of GPS, sensors, drones, satellites, IoT and AI enables

spatially and temporally specific agricultural management. Computer models transform these data into useful information for variable-rate irrigation, fertilizer application, crop protection and harvesting.

INTEGRATION OF AI AND TRADITIONAL CROP MODELS

An important development is the integration of process-based crop models with machine learning. Traditional models have the advantage of representing biological processes, whereas machine-learning models are effective at identifying complex patterns in large datasets. Hybrid models can therefore combine the strengths of both approaches. Remote sensing and real-time sensor data can also be incorporated to continuously update crop-model predictions. Recent research identifies model coupling, remote sensing, real-time observations, AI and digital twins as important directions for improving agricultural decision-support systems. Foundation models represent another emerging area. Recent reviews indicate that agricultural foundation models could integrate diverse agricultural datasets and support applications such as crop monitoring, disease diagnosis, agricultural knowledge services and intelligent machinery.

CHALLENGES AND LIMITATIONS

Despite considerable progress, several challenges remain. Agricultural datasets are often fragmented, geographically limited and inconsistent in quality. A model trained in one agro-climatic region may not perform equally well in another region. Model interpretability is another important issue. Farmers and agricultural scientists need to understand why a model has generated a particular recommendation. Data privacy, computational requirements, infrastructure costs and digital literacy can also restrict adoption, especially among small and marginal farmers. Therefore, model calibration and validation using independent field observations are essential. Recent research emphasizes systematic model selection, sensitivity analysis, uncertainty assessment and multi-model approaches to improve prediction reliability.

FUTURE PROSPECTS

The future of agricultural modelling will increasingly involve multimodal and hybrid systems. Weather stations, soil sensors, drones, satellites, farm machinery and historical databases will provide continuous streams of information. Digital twins could provide virtual representations of agricultural fields and allow alternative management scenarios to be tested before implementation. Federated learning may also allow models to learn from distributed datasets while reducing the need to centralize sensitive farm data. Recent research highlights federated learning, deep learning and real-time data integration as promising

developments for agricultural modelling. Agricultural foundation models and large agricultural models are also developing rapidly. A recent 2026 review reports increasing research activity in agricultural large models and applications ranging from agricultural knowledge services and disease diagnosis to livestock management and intelligent agricultural machinery.

CONCLUSION

Computer models have evolved from conventional mathematical crop simulations into sophisticated systems incorporating machine learning, deep learning, remote sensing, IoT, artificial intelligence and foundation models. They provide valuable opportunities for improving crop-yield prediction, irrigation scheduling, nutrient management, pest and disease detection, climate-risk assessment and precision agriculture. Traditional crop models remain important because they represent biological processes, while AI-based models offer powerful capabilities for analysing large and complex datasets. The most promising future direction is therefore not the replacement of conventional agricultural models by AI, but their integration into hybrid modelling frameworks. Such systems can combine biological knowledge with real-time observations and data-driven learning to provide more accurate and practical recommendations. Continued development of high-quality datasets, regional calibration, explainable AI, uncertainty analysis and farmer-oriented decision-support platforms will be essential. Properly implemented, computer models can become a major component of climate-resilient, resource-efficient and sustainable agriculture.

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