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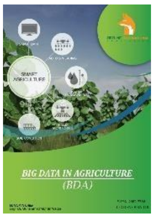

REVIEW ARTICLE

CROP SIMULATION MODELS FOR COTTON GROWTH AND DEVELOPMENT: STRENGTHS AND WEAKNESSES

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ABSTRACT

Cotton, a major global cash crop, faces diverse challenges due to changing environmental conditions and evolving agricultural practices. Crop simulation models have emerged as powerful tools for understanding and predicting cotton growth and development. These models offer farmers and researchers valuable insights and decision support. However, their effectiveness is contingent on addressing challenges related to data requirements, sensitivity to input parameters, model complexity, and validation. As technology advances and research continues, addressing these weaknesses will further enhance the utility of crop simulation models in shaping the future of cotton cultivation. Thus, this paper reviews various crop simulation models employed in studying cotton, highlighting their strengths and limitations. The paper explores the key modeling approaches, the integration of biophysical processes, and the impact of these models on decision-making in cotton agriculture.

KEYWORDS

Cotton, crop modeling, DSSAT, GOSSYM-COMAX, Cotton2K, SWAT

1. INTRODUCTION

Crop simulation models have become essential tools for optimizing input use in agricultural production. These models are useful in answering questions in policy, research, and crop management (Boote et al., 1996). However, as the old adage by Box (1979) says, "All models are wrong, but some are useful," selecting appropriate models for particular applications is critical. Hence, there is a great need to consider the performance and complexity of a particular model if it is being selected over others under local environmental conditions. Crop models generally differ in details and methods for simulating crop, soil, and management practices (Thorp et al., 2014a). Another study argued that simple models might not be appropriate if they are not robust enough to address certain phenomena (Boote et al., 1996). In contrast, complex models may not be appropriate because of excessive parameterization and numerous required inputs (Jones et al., 2017). This means a compromise that balances model complexity and accuracy is needed in model selection. Because of the increasing application of crop simulation models by non-traditional modelers, there is a need to develop models with minimum complexity and appropriate usability (Thorp et al., 2014a). This review briefly outlines some of the strengths and limitations of crop models for simulating cotton production.

2. CROP SIMULATION MODELS

2.1 Cropping System Model (CSM) CROPGRO-Cotton

The Cropping System Model (CSM)-CROPGRO-Cotton model is executed in the Decision Support System for Agrotechnology Transfer (DSSAT) (Hoogenboom et al., 2012). DSSAT is a platform that integrates the database management system (soil, climate, and management practices) and various application programs, including sensitivity analysis and spatial analysis, by integrating a wide range of crop models into a single platform (Jones et al., 2003). With the addition of the CSM, DSSAT has the added strength of simulating rotations in cropping systems. The CSM utilizes one set of computer codes for dynamic simulation of soil water, inorganic soil nitrogen, and organic carbon and nitrogen balances on a daily time step. The CSM-CROPGRO-Cotton model in DSSAT has the capacity to predict different cotton growth stages such as emergence, first leaf, first flower, first seed, first cracked boll, and 90% open boll based on the accumulation of heat units or photo-thermal time (Thorp et al., 2014a). The model can also simulate defoliation, insect and disease damage, cropping sequences, and climate change. These attributes make this model a powerful tool compared to other crop models, especially when conducting detailed studies on crop growth, such as investigating phenological stages.

Another advantage of DSSAT is its graphical user interface, which allows the user to enter data, run the crop models, and view the simulation results graphically, thereby making model evaluation easy. Several researchers have evaluated the CSM-CROPGRO-Cotton (Modala et al., 2015; Thorp et al., 2014b). Thorp et al. (2014b) reported that CSM-CROPGRO-Cotton responded appropriately to various climate change factors and crop management, including irrigation amounts, nitrogen levels, and plant populations in the arid environment of central Arizona. However, Modala et al. (2015) highlighted that the DSSAT crop models are complex because they require many input parameters to thoroughly evaluate water and nutrient dynamics and crop growth and development. In addition, the study found unsatisfactory performance of the model's ET routines in water-limited conditions. As a result, the model's ability to predict seed cotton yield under mild to arid conditions was limited. Additionally, using air temperature in crop development calculations limits the model in irrigated arid regions because evaporative cooling causes the temperature within a well-watered crop canopy to be significantly lower than that of the surrounding air (Thorp et al., 2014b). In that case, using air temperature instead of canopy temperature would more likely cause rapid crop development than reality.

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2.2 GOSSYM-COMAX

GOSSYM-COMAX uses the principles of dynamic mass balance to model water, carbon (C), and nitrogen (N) processes throughout the cotton life cycle (Liang et al., 2012). The model predicts potential growth and development rates based on air temperature under optimal water and nutrient conditions (Thorp et al., 2014). It then reduces these potential rates by accounting for the impact of environmental stresses through environmental productivity indices. GOSSYM-COMAX has a distinctive and robust soil sub-model that simulates all major soil processes and attempts to incorporate unique physical properties of individual soils into the cotton simulation. This allows the characterization and inclusion of a wide range of soil properties, providing a more accurate representation of the specific conditions of the field (Landivar et al., 2010). Some producers found the GOSSYM-COMAX model complex, occasionally inaccurate, and with limited technical support (Landivar et al., 2010). Another drawback of GOSSYM-COMMAX is that it has many parameters in excess of 85 that need to be tuned argued that this introduces significant uncertainties in simulation results, mainly when modeling climate-crop interactions. The GOSSYM-COMAX components were reported to be less comprehensive as the model formulations are primarily empirical and do not fully interact with atmospheric dynamics, which limits its performance (Liang et al., 2012).

2.3 Cotton2K

Cotton2K is a process-based crop model that was derived from the GOSSYM-COMMAX model. It was reported to be more accurate in simulating cotton production in arid and semiarid environments (Attia et al., 2016). The model simulates the processes happening in the soil, plant, and microenvironment and how these processes interact with the inputs and practices used in the field (Marani, 2004). Cotton growth and development are influenced by air temperature, water, C, and N stresses, which limit potential production under suboptimal conditions (Thorp et al., 2014a). Leaf water potential is calculated using the average soil water potential, the plant's resistance to water transport, and the potential transpiration rate. The leaf water potential is subsequently utilized to estimate empirical water-stress factors.

The water-stress factors in the model influence the growth rates of cotton plants, rate of senescence, maturity of bolls, photosynthesis, and abscission rates of leaves, squares, and bolls. Because of these robust water-stress empirical relations, Cotton2K outperforms other cotton models in predicting the relationship between applied water and yield (Attia et al., 2016). Furthermore, the accuracy of Cotton2K was improved by simulating potential evapotranspiration on an hourly basis, which allows better representation under arid and irrigated conditions (Thorp et al., 2014a). Thus, the major strength of the Cotton2K model is that it operates on hourly time-step processes such as transpiration, soil water evaporation, soil water redistribution, heat, and nitrogen fluxes, and the exchanges of energy and water at the soil-plant-atmosphere interfaces. This detailed approach has significantly enhanced the model's usefulness and applicability for irrigation in arid regions. Other strengths of the model are that it can be used to predict the timings of defoliation, apply a growth regulator, and manage irrigation (Thorp et al., 2014a).

However, the Cotton2K model is a column model that functions over time within a restricted spatial domain, typically representing a single cotton plant. Generally, a column model assumes that input values, such as soil physical and chemical properties, are uniform throughout the selected modeling domain. As such, results from column-based models used to assess irrigation management across different production scales overlook the inherent spatiotemporal variability that ultimately affects cotton lint yield (Booker et al., 2014).

2.4 Computerized Cotton Management System (COTMAN)

COTMAN is a cotton crop monitoring system that uses plant indicators to track cotton development and fruit load from initiation of squaring through effective flowering (Oosterhuis et al., 2009). It assists with in-season and end-of-season management decisions (COTMAN, 2018). The collected information includes growth patterns, historical and current weather data, and field parameters. COTMAN tracks crop maturity by monitoring the time it takes for cotton plants to reach five nodes above the white flower (NAWF = 5). The COTMAN program comprises two components, the SQUAREMAN and the BOLLMAN. The SQUAREMAN determines if early-season growth up to the time of the first flowers is acceptable and whether the squares are developing on the right track. The BOLLMAN utilizes NWAF data to assess plant stress and boll loading and to assist with end-of-season management. Overall, the COTMAN program is simpler and more useful in determining earliness and timely feedback on cotton development and plant stress using a Target Development Curve (TDC) (Oosterhuis et al., 2009). The TDC represents an ideal balance of early maturity and high yield against which actual growth patterns observed in the fields can be compared. Comparisons of the actual data and the TDC in COTMAN help monitor the impact of stress occurrences on the cotton crop. In addition, the program is useful in identifying cutout dates for individual fields, which could be useful in making insecticide termination decisions and planning defoliation and harvest schedules based on crop maturity (Landivar et al., 2010). Another strength of the program is that it generates graphs for easy analysis of the stress intensity on cotton reported that the process was inexpensive (Oosterhuis et al., 2009).

However, some weaknesses were reported in the application of COTMAN. For instance, collecting COTMAN data is labor-intensive and time-consuming (Gwathmey et al., 2010). Furthermore, researchers highlighted that the program may not be useful for timing defoliation for regions beyond Arkansas, where environmental differences and varying cultural practices may necessitate adjustments in accumulated heat unit requirements before applying harvest aids to optimize yield (Siebert and Stewart, 2006). Since COTMAN relies on specific observations of cotton development at particular locations within the field, the recommendations from each field may not be generalized for other fields or areas.

2.5 Soil and Water Assessment Tool (SWAT)

The Soil and Water Assessment Tool (SWAT) is a physically based, continuous model designed for watershed scales. It can simulate crop growth, soil water, surface water, groundwater movement, and the transport of sediment and nutrients across both large and small scales (Sinnathamby et al., 2017). This model is mainly applied to evaluate the impacts of agriculture on water quality and can simulate various agricultural practices, such as fertilization, crop rotations, tillage, irrigation, and drainage. SWAT has hydrology and crop growth modules that allow an integrated simulation of soil-crop-atmosphere processes. This ability to integrate multiple environmental processes is its major strength, particularly when evaluating the impacts of management practices on regional-specific water resources, climate, and land use change on crop production (Faramarzi et al., 2010; Glavan and Pintar, 2012). SWAT employs a streamlined version of the Environmental Policy Impact Climate (EPIC) crop growth module to predict the crop phenological stages based on accumulated heat units. The crop growth module simulates the leaf area index (LAI) until it reaches a maximum value, which will remain the same until leaf senescence, after which it declines linearly (Alemayehu et al., 2017). However, this is not always true for crops like cotton that exhibit perennial characteristics, which might cause inaccuracies in simulations of cotton production. Plant biomass in the model increases on a daily basis and is influenced by an atmospheric carbon dioxide-dependent radiation use efficiency (Sinnathamby et al., 2017). Biomass accumulation in the model is reduced by water, temperature, nitrogen, or phosphorous stressors. Harvestable yield is simulated as a product of harvest index and above-ground biomass.

The SWAT model can simulate crop growth hourly, daily, monthly, or yearly over long periods. This attribute is critical when evaluating alternatives to irrigation management or climate change. Numerous agricultural practices and structures have already been incorporated into the model, enhancing its ability to simulate crop yield. The model has also incorporated manual and auto-calibration tools to improve modeling efficiency (Glavan and Pintar, 2012). SWAT has an open-source code and a flexible framework for widespread application and worldwide research collaborations. However, it has weakness in oversimplifying reality and inconsistencies in simulating crop stresses (Gassman et al., 2007; Faramarzi et al., 2010). In that study, the model simulated crop yields at seasonal ET of less than what is possible in reality. Previous research highlighted the deficiencies in the SWAT auto-irrigation function (Chen et al., 2017a). They reported inaccuracies from continued irrigation applications after the crop matures and over-irrigation when soil water deficit triggers were less than the static irrigation level. This study reported that plant growth algorithms in SWAT were limited to predicting cotton yields expected for irrigation practices in the Texas High Plains (Marek et al., 2017). Another weakness reported is that atmospheric CO_2 concentration can only be inputted as a single value in SWAT (Chen et al., 2017b). Hence, the model does not allow input of variable concentrations over a long term. This makes it challenging to evaluate future climate scenarios with the SWAT model. SWAT requires a wide range of data to run crop simulations (Glavan and Pintar, 2012). Several parameters need to be adjusted when calibrating the model, which usually discourages modelers from using the model.

3. CONCLUSION

This study reviewed the strengths and weaknesses of DSSAT, GOSSYM-COMAX, Cotton2K, COTMAN, and SWAT in simulating cotton production. The CSM-CROPGRO-Cotton model has versatility and comprehensive environmental integration but can be complex to calibrate, particularly among non-modelers and growers. GOSSYM-COMAX offers detailed physiological simulations specific to cotton, but some studies have highlighted its complexity and lack of technical support as some of the significant drawbacks. On the other hand, Cotton2K provides user-friendly and practical outputs for growers, though it lacks depth in capturing complex interactions. COTMAN has strengths in decision support and real-time data integration but depends heavily on continuous data input. This is laborious and time-consuming, and since COTMAN relies on extensive observations of cotton growth at selected points in the field, the recommendations from each field may not be generalized for other fields or areas. SWAT is valuable for assessing environmental impacts at a watershed scale but may not address specific cotton growth and development processes. Overall, the selection of a crop model for any application should align with the specific needs of the research or management objectives, potentially incorporating multiple models to balance their individual strengths and limitations.

CONFLICTS OF INTEREST

The authors declare no conflicts of interest.

REFERENCES

Alemayehu, T., Van Griensven, A., Woldegiorgis, B.T., and Bauwens, W., 2017. An improved SWAT vegetation growth module and its evaluation for four tropical ecosystems. Hydrology and Earth System Sciences, 21(9), Pp.4449-4467.

Attia, A., Rajan, N., Nair, S.S., DeLaune, P.B., Xue, Q., Ibrahim, A.M. and Hays, D.B., 2016. Modeling cotton lint yield and water use efficiency responses to irrigation scheduling using Cotton2K. Agronomy Journal, 108(4), Pp.1614-1623.

Booker, J.D., Lascano, R.J., Evett, S.R. and Zartman, R.E., 2014. Evaluation of a landscape-scale approach to cotton modeling. Agronomy Journal, 106(6), Pp.2263-2279.

Boote, K.J., Jones, J.W., and Pickering, N.B., 1996. Potential uses and limitations of crop models. Agronomy journal, 88(5), Pp.704-716.

Chen, Y., Ale, S., Rajan, N., and Srinivasan, R., 2017. Modeling the effects of land use change from cotton (Gossypium hirsutum L.) to perennial bioenergy grasses on watershed hydrology and water quality under changing climate. Agricultural Water Management, 192, Pp.198-208.

Chen, Y., Marek, G.W., Marek, T.H., Brauer, D.K., and Srinivasan, R., 2017a. Assessing the efficacy of the SWAT auto-irrigation function to simulate irrigation, evapotranspiration, and crop response to management strategies of the Texas high plains. Water, 9(7), Pp.509.

COTMAN., 2024. Cotton Management Expert System Software. http://www.cotman.org/

Faramarzi, M., Yang, H., Schulin, R. and Abbaspour, K.C., 2010. Modeling wheat yield and crop water productivity in Iran: Implications of agricultural water management for wheat production. Agricultural water management, 97(11), pp.1861-1875.

Gassman, P.W., Reyes, M.R., Green, C.H. and Arnold, J.G., 2007. The soil and water assessment tool: historical development, applications, and future research directions. Transactions of the ASABE, 50(4), Pp.1211-1250.

Glavan, M., and Pintar, M., 2012. Strengths, weaknesses, opportunities and threats of catchment modelling with Soil and Water Assessment Tool (SWAT) model. Water resources management and modeling, Pp. 27.

Gwathmey, C.O., Tyler, D.D., and Yin, X., 2010. Prospects for monitoring cotton crop maturity with normalized difference vegetation index. Agronomy journal, 102(5), Pp.1352-1360.

Jones, J.W., Antle, J.M., Basso, B., Boote, K.J., Conant, R.T., Foster, I., Godfray, H.C.J., Herrero, M., Howitt, R.E., Janssen, S. and Keating, B.A., 2017. Brief history of agricultural systems modeling. Agricultural systems, 155, Pp.240-254.

Jones, J.W., Hoogenboom, G., Porter, C.H., Boote, K.J., Batchelor, W.D., Hunt, L.A., Wilkens, P.W., Singh, U., Gijsman, A.J., and Ritchie, J.T., 2003. The DSSAT cropping system model. European journal of agronomy, 18(3-4), Pp.235-265.

Landivar, J.A., Reddy, K.R. and Hodges, H.F., 2010. Physiological simulation of cotton growth and yield. Physiology of Cotton, pp.318-331.

Liang, X.Z., Xu, M., Gao, W., Reddy, K.R., Kunkel, K., Schmoldt, D.L. and Samel, A.N., 2012. A distributed cotton growth model developed from GOSSYM and its parameter determination. Agronomy Journal, 104(3), Pp.661-674.

Marek, G.W., Gowda, P.H., Marek, T.H., Porter, D.O., Baumhardt, R.L. and Brauer, D.K., 2017. Modeling long-term water use of irrigated cropping rotations in the Texas High Plains using SWAT. Irrigation science, 35, Pp.111-123.

Modala, N.R., Ale, S., Rajan, N., Munster, C.L., DeLaune, P.B., Thorp, K.R., Nair, S.S. and Barnes, E.M., 2015. Evaluation of the CSM-CROPGRO-Cotton model for the Texas rolling plains region and simulation of deficit irrigation strategies for increasing water use efficiency. Transactions of the ASABE, 58(3), Pp.685-696.

Oosterhuis, D.M., Bourland, F.M., Tugwell, N.P., Cochran, M.J., and Danforth, D.M., 2009. Overview of the COTMAN crop management system. Summaries of Arkansas Cotton Research, 2008, Pp.11-13.

Siebert, J.D., and Stewart, A.M., 2006. Correlation of defoliation timing methods to optimize cotton yield, quality, and revenue. Journal of cotton science.

Sinnathamby, S., Douglas-Mankin, K.R., and Craige, C., 2017. Field-scale calibration of crop-yield parameters in the Soil and Water Assessment Tool (SWAT). Agricultural water management, 180, Pp.61-69.

Thorp, K.R., Ale, S., Bange, M.P., Barnes, E.M., Hoogenboom, G., Lascano, R.J., McCarthy, A.C., Nair, S., Paz, J.O., Rajan, N., and Reddy, K.R., 2014a. Development and application of process-based simulation models for cotton production: A review of past, present, and future directions. Journal of Cotton Science, 18(1), Pp.10-47.

Thorp, K.R., Barnes, E.M., Hunsaker, D.J., Kimball, B.A., White, J.W., Nazareth, V.J. and Hoogenboom, G., 2014b. Evaluation of CSM-CROPGRO-Cotton for simulating effects of management and climate change on cotton growth and evapotranspiration in an arid environment. Transactions of the ASABE, 57(6), Pp.1627-1642.

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