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Understanding the Agricultural Systems Modeling: A Review

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ABSTRACT

These Crop modeling is an imperative tool in complex agricultural systems, which has been achieved by scientists from a broad range of disciplines, who have provided ideas and tools for more than six decades. Agricultural researchers are now focusing on the "next-generation" models and information needed to solve the issues of complicated systems faced by the farming communities. It is essential to take stock of modeling history, methodology, and its suitability under different circumstances to guarantee that we avoid re-development and endeavor to consider all elements of associated challenges. In this paper, we review the historical connectivity and the methodology of agricultural systems modeling and identify various modeling approaches to guide the design and advancement of "next-generation" modeling tools and techniques. Historical events combined with technological advancement have powerfully contributed towards the development of agricultural and dynamic models at domestic to global scales. Agricultural systems models have wide characteristics relying on the systems involved, purposes, and the broad applications that intended their development and use by scientists in numerous fields. Recently the interdisciplinary research and public-private sectors partnership trends suggest that the stage is set for key advancement in agricultural systems science which is required for the "next-generation" models, information, databases, and decision support systems. Historical events and conceptual methodologies of agricultural system modeling should be considered to avoid barricades and pitfalls as the community build up these "next-generation" crop models.

Key words: Crop modeling, phenology, food security, methodology, agricultural systems, decision support systems.

1. INTRODUCTION

Agriculture is an interdisciplinary field that deals with the behavior of complex agricultural systems. It might be helpful to evaluate these systems by using observed data that describe how a specific system performs under particular conditions but it is difficult for numerous situations. Conventional field experiments are time consuming and costly so system approach nowadays becomes a significant tool for agricultural research.

The regression and correlation analysis enable us to develop some quantitative understanding among variables and their interactions that contributed towards the advancement of agriculture [1]. These analyses provide the information that might be site specific which is only reliable for those sites which have similar conditions like edaphic, climatic and crop management practices used in developing the original functions. Regarding this, decision making on the basis of regression analysis is quite limited. Furthermore, the verification of empirical regression models on conditions where it is not grown is not possible since, the simulation is not permissible.

The physiological, biophysical and biochemical activities at subcellular, cellular or organ level are impregnated into crop growth models, so it could be difficult for crop modellers to estimate a large number of model parameters. In this way, the simple approaches like radiation use efficiency may aggravate with over parameterization might be a serious problem and cause complications in finding the solution of unique parameter (Figure 1). Thus complex judicial reform strategies may fail to resolve complicated criteria [2]. Hence, these problems might be overcome by robust and making a comprehensive crop model by impregnated it with individual sub-models.

Advancement in computer technologies enable us to study the combined impact of numerous factors in different interactions. Consequently, combining the plant, environment and soil systems for precise crop yield prediction is possible. Therefore, the powerful computer technology and growing trend of integrated systems application in agriculture start a new era of agriculture research [3]. The crop simulation modeling was started in 1960's; nowadays it entered into a real-world [4]. The use of crop models are gradually increases for evaluating the variations in management strategies and yield response. The crop simulation model can be used in research yield forecast and developing an appropriate decision strategy [3].

Technology plays an important role in development, although it seems that technology has transformed some parts of itself into areas that are difficult to develop [5]. Agriculture models are increasingly contributing to the development of sustainable land management under various collective and social-economic conditions, because experiments require huge amount of resources and not provide sufficient information for appropriate management practices [6]. In crop growth modeling, the knowledge of numerous fields, such as meteorological science, plant breeding, physiology, agronomy and soil science is used in process-oriented manner.

Decision Support Systems (DSSs) are computer based software with integrated models, make recommendations for economic planning of a farm, pest management [7, 8], crop management strategies [9] and livestock management [10]. Current trends of collaboration across disciplines, private and public sectors reflect that the present scenario is set for development in agriculture that are required for the advancement in decision support systems development [11]. Computerized systems that integrate the crop growth technical knowledge with economic and climatic considerations are now available as decision support systems. Decision support systems used by farm advisors and policymakers [12]. In addition, these models are use as decision support tool, landscaping, pest management, irrigation scheduling and specific public policy decisions and implementations. The decision support systems as Agriculture Production System Simulator (APSIM) [13] and Decision Support System for Agrotechnology Transfer (DSSAT) [14], are excellent tools for well suited management options and the most widely-used decision support system models. In addition, many other useful agriculture system models for livestock, cropping systems and for economical decision (e.g., WOFOST, EPIC, AQUACROP, CROPSYST, ORYZA, STICS, TOA, RZWQM, GTAP, IMPACT and SWAP) are developed.

Crop modeling is an emerging field of agricultural systems, required interdisciplinary research data and basic information for development. The main hindrance in the way of model application in our society is awareness about structures of models, complex agricultural systems and know-how about model operations and working. This review also designs about development methodology and various types of model.

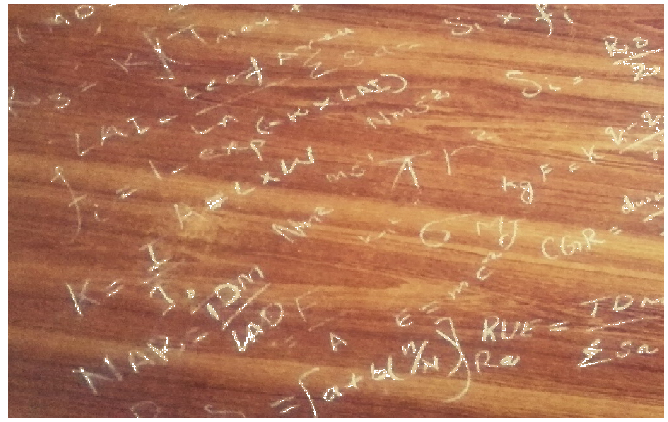

Figure 1. Agriculture systems modeling indices

2. HISTORY

The model simulates the growth of a crop component (i.e. roots, stems, leaves and grains) by simulating the crop behaviour. Moreover, a crop model not only simulates the total above ground weight or economic yield, but also contains information about plant growth and development [15]. Earlier, the crop models were developed to understand crop physiology [16].

The early work on crop modeling was started with Justus von Liebig's Law of Minimum [17], Blackman Law of Single Factor Limitation [18], the Compound Interest Law [19] and Shelford's Law of Tolerance [20]. They developed various relationships that represent the crop physiology, phenology and yield behavior in response to specific factor. [21] introduced the concept of balanced in grains and losses of plant dry matter, accounting for allocation of total gross production among plant components. He observed that actual plants have vertical inclined canopies rather than horizontal which uniformly distribute light within the leaves. These single and multi-factor researches (i.e. photosynthesis, growth and other factors) led towards the development of classic growth analysis method by British school [22].

[23] developed for the first time the classical model for the light interception and transmission of plant canopy based on the leaf area index, on the principle of Beer-Lambert optical law.

$$P = \frac{b}{ak} ln \frac{(1-m) + aKIo}{(1-m) + aKIoe^{-KF}} - rF \qquad (1)$$

Plant canopy photosynthesis calculated by [23]. Equation (1) indicates that canopy photosynthesis is calculated by leaf optical property (m), the light environment (I_0), stand structure (K and F) and leaf physiology (a, b and r).

This advances in the development of aerodynamic principles for canopy photosynthesis determination [24]. [25] develop a model for gas diffusion resistances (CO_2 and H_2O) around and inside plant canopy by using 'Ohms' electricity law, which was an innovative technique to quantify the differences in leaf gas exchange attributes among crop species [26].

The first effort to develop a model about canopy photosynthetic rates was made in 1960s [27]. An attempt was made to develop a crop growth model for cotton at Mississippi State University (MSU) and USDA/ARS in the 1960s [28, 29]. This work had opened the way towards the construction of a cotton (*Gossypium hirsutum* L.) simulation model GOSSYM, as a tool to improve crop management practices.

The outcomes acquired from this simulation model were used among others, to provide information for breeding, management and estimation of potential food production [30, 31]. The Elementary Crop Growth Simulator (ELCROS) a dynamic crop model [32] had static photosynthesis model and respiration (a fixed per day of the biomass, plus a quantity proportional to the crop growth rate. Moreover, it was integrated with a functional equilibrium between root and shoot growth [33]. Computer modeling of canopy photosynthesis, light distribution, canopy architecture and CO_2 flux was worked out [27, 34-36].

The induction of microclimatology in the models [37] and estimation of canopy resistance to gas exchanges led to advance the simulation of models about transpiration and progress into the development of “BACROS” (Basic Crop growth Simulator) [38]. Research projects were financed to develop crop models that would use with remote sensing information to simulate the production of major crops worldwide and traded internationally. These research programs led to the development of the CERES-Maize and CERES-Wheat crop models [39, 40]. In 1980s the U.S Agency for International Development signed a contract with University of Hawaii, Manoa, USA [41, 42] to help the poor farmers and a new model development project was started under the IBSNAT (International Benchmark Sites Network for Agrotechnology Transfer) [43]. The IBSNAT was resulted into the development of a research and teaching tool, the Decision Support System for Agrotechnology Transfer (DSSAT).

Meanwhile the crop growth model WOFOST [44] was developed. WOFOST is a mechanistic model that estimates crop growth on the basis of processes like respiration, photosynthesis and environmental conditions. It is also use to predict growth and production of annual field crops.

In early 1990s, a multidisciplinary research group worked on crop modeling in Australia and develops a cropping system model named as APSIM (Agriculture Production System Simulator). APSIM is one of the most extensively used cropping system model [13].

The AgMIP (The agricultural model intercomparison and improvement project) in 2010, formed an international group of modelers with the intentions of comparing and improving crop, livestock and socioeconomic models. These compared and developed models then use for climate change impact assessment and adaptation [45-47].

The growing curiosity in developing the presentation of the land area in environmental models, induced new methodologies in agricultural systems modeling [48]. Finally, the several groups developed models for water, greenhouse gases (GHGs) fluxes and CO_2 representation [49, 50].

The agricultural system models provide basic information for decision and management practices and our emphasis is on next generation model and decision support systems for agriculture.

3. MODELING METHODOLOGY

The models use ecophysiological processes to simulate plant physiology and development as a function of crop management and weather conditions which use for model input [51].

It is prerequisite to understand the methodology of that thing which we are going to develop. The development of a methodology always instigate with problem identification and its understanding. Otherwise we developed erroneous type of model and that model may failed to reach our problems [52]. In the example of Leaf area duration model our problem was to estimate the leaf area index at proper time intervals because the manual process is time consuming, difficult, tedeous and may at that time be impossible to count Leaf area duration of whole field.

According to [53] a clear and precise understanding of our problem lead to the formulation a precise conceptual model. This is the stage where we try to epitomize the real system in a generelized or an abstract form. It can be visual or narrative that clearly determines the system components and their intraction with each other. After the construction of a conceptual model it is then interpreted into the mathematical model and descibe all the inter-relationships in matematical form. All the assumptions may have refined a make mathematical model after taking a back step and revising our conceptual model. The solutions from mathematical model is obtained and interpret. It is also checked against the reality (Measured data). When the solution from the model is acceptable (accurate). The model then use for solving the problems. Different methodologies and approaches adopt for model development.

In Figure 2 summarizes the phases involved in the development and operation of a simulation model. These steps make for a logical progression but obviously do not constitute a rigid procedure. Relatively, they are a tentative outline, or a "conceptual model," of model building.

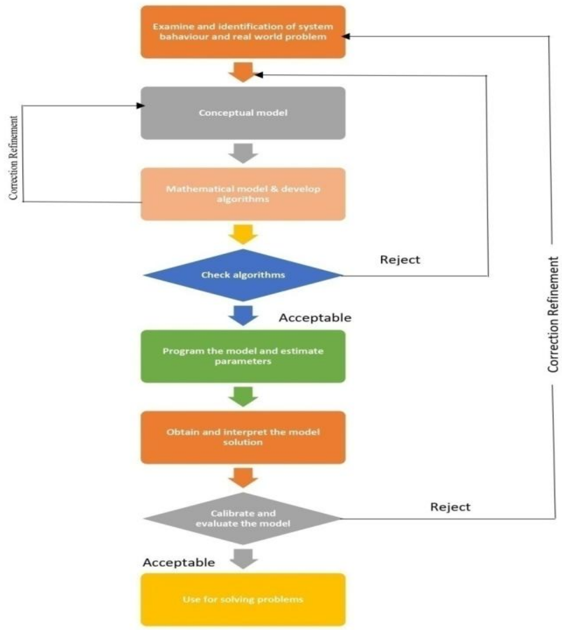

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Figure 2. Methodology for developing a model [54].

Crop model parameters are generally determined byadjusting and comparing iterative parameter with observed data; however, parameters estimated in this way are inaccurate because of the inherent experimental errors associated with field observation [55].

[56] described a model of grassland plant physiology and water used developed in the matador project of the Canadian IBP (**figure 3**). This model was designed to simulate canopy and soil microclimate, plant and soil evaporation as net assimilation and dynamics of the biomass of green and dead shoots. The model is mechanistic and has generality in the sense that it can be run for any year for which the input data are available and for any mixed grassland species for which the physical structure and physiological responses to the environment are known.

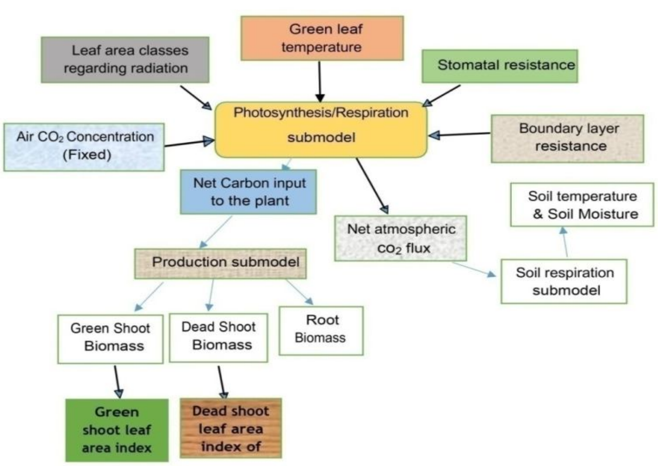

Figure 3. Model Production section diagram by [56].

[57] present an all-inclusive computer based tool that deal with the statistical and mathematical calculations in crop growth analysis **(figure 4)**. This software tool estimates up to six of the most essential growth parameters. The other growth parameters that have same statistical and mathematical expression would be calculated by manipulating the input variables for example, RGR, ULR or LAR.

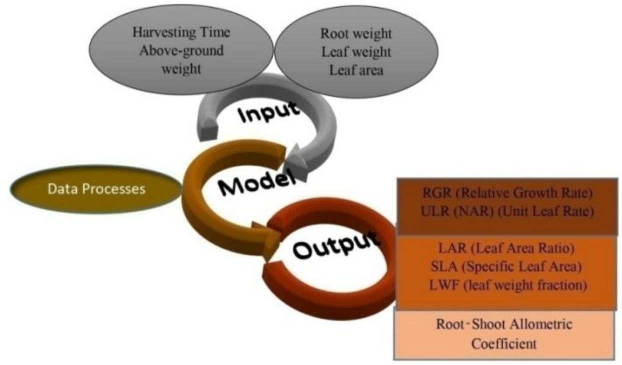

Figure 4. Tool for classical plant growth analysis, Model set for input and output data processing [57].

Practically, there are no exact lines among the stages of a simulation, as the modeler constantly interacts with his model and critically see the steps, proficiency, ingenuity, combination of trial and error, perseverance and good luck finally bring him to the point where he believes he has a satisfactory model.

4. TYPES OF MODELS

4.1. Mechanistic model

A mechanistic model determines a system behaviour regarding lower level traits [58]. These are also called explanatory models, simulate the relationship among the variables [59]. The mechanistic model of crop growth describes the crop performance by using information of growth and development processes. The knowledge of physio-chemical and biological processes is used to develop a mechanistic model known as an explanatory model because it characterizes the cause-effect interaction among the variables. The mechanistic model is more rubustic and more applicable over a broad range of climatic conditions [52]. A mechanistic model GLYCIM uses to simulate the physiology and yield of soybean [60]. It comprises of mathematical equations determining the edaphic and climatic factors, photosynthesis, respiration, canopy light interception and water uptake. The mechanistic models also forecast the system behavior outside the boundaries of its generation [61].

4.2. Empirical model

The empirical models are simple, faster and therefore required less computation than process-based model and represent the interactions among variables without the correlated processes, sometimes known as statistical or correlative models [59, 62]. An empirical crop model which simulating the yield of wheat crop as a function of weather conditions [63], estimating the yield as a function of water stress [64, 65] was observed. The leaf area index (LAI) of sugarcane is estimated by an empirical model equation in which the Growing Degree Days (GDD) is the only variable [66, 67].

$$LAI_n = \left(\sum_{i=1}^{n} GDD_i\right)^b e^{a+c\sum_{[v]}^{n} GDD_i}$$

Where
LAI_n = leaf area index, GDD_i = growing degree days (°C day) and *a*, *b* and *c*= fitting constant.

4.3. Descriptive models

Descriptive models consist of state variables, describe the system behavior in a simple way which is significantly used in comparison of land use and greenhouse climate control [68, 69]. Descriptive models represent little or none of the mechanisms that are the reason of the behavior. Building and using the descriptive models is quite easy [70].

4.4. Deterministic models

The deterministic model predicts the qualities like rainfall, crop performance without any associated variance, probability distribution and indirect land use changes impact [71]. Though, the agricultural systems are inherent with heterogeneities and inaccuracies that may cause variations [72]. Sometimes, deterministic models performed satisfactory even with these variations however, in certain cases they performed unsatisfactory e.g. prediction of rainfall. The increase in uncertainties causes low performance of deterministic models.

4.5. Dynamic Models

Dynamic models estimate the variability in crop behavior with time as a function of exogenous parameters. This model correlates the growth as a function of time and use to predict temperature [73, 74]. For example changing number of wheat crop leaves trough out the growing season are dynamic crop model. The Basic Crop Growth Simulator (BACROS) and Elementary Crop growth Simulator (ELCROS) are dynamic models [32, 38].

4.6. Static Models

The static model does not contain time as a variable. In 1960s, efforts to calculate the canopy photosynthesis rate resulted in development of various explanatory models [27]. These models were not included the time as a variable. The results of these static models were used to estimate the emergence of cover crop, food production, breeding and crop management practices [30, 31, 75]. The quantitative research on leaf photosynthesis was results of these attempts [76].

4.7. Stochastic models

A stochastic model contains some elements of randomness or probability distributions within the model. The higher the uncertainty in the behavior of the system, the more important it may be to construct a stochastic model [77]. The development of stochastic model is often difficult. Therefore, it is recommended to resolve the problem first with deterministic approach and only try to solve the problem through the stochastic model if the results are unsatisfactory [59].

4.8. Simulation models

A crop simulation model (CSM) used to simulate crop phonological phenophases, physiology and yield as a function of edaphic, climatic variables and management operations [78]. The simulation model mimics the behaviour of a system at short time intervals, and integrated with change soil and weather conditions [79]. These models provide decision support and provide a wide range of crop management strategies.

A real system is often described by many alternative models. This is because one model may focus on one aspect of the system, not covered or covered with insufficient depth by the other models. These models also differ from each other in terms of their model simplicity and accuracy. Consequently, there is no one model that is suitable for all circumstances. The best model is one that meets our interests and purpose of study, not necessarily always being the most accurate or simplest model. Depending on our objectives, one model could be chosen over the others because the chosen model best meets our conditions and requirements.

5. CONCLUSION

An interdisciplinary systems approach to research and development will assist in capturing our ever-increasing understanding of the physical and biological systems components. Models are amongst the most significant tools in agriculture that facilitates objective evaluation of alternative decisions at the farms, marketing or policy level. It is prerequisite to understand the framework and methodology of models for its development. The complete knowledge and understanding of agriculture system is mandatory for development of crop growth model. No one model is best under all circumstances. The best model is one that meets our objectives, interest and conditions.

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