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APSIM and DSSAT models as decision support tools

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ABSTRACT

Climatic variations, continuously increasing population pressure and market infrastructures are driven forces to reduce agricultural productivity. New management options and appropriate genotypes are need of the day to be considered for sustainable production. Crop simulation models are complementary tools in field experiments to develop innovative crop management systems. In this perspective, two crop growth models viz., APSIM (Agricultural Production System Simulator) and DSSAT (Decision Support System for Agro Technology Transfer) were calibrated and validated to predict growth and yield of wheat under rainfed conditions for Pothwar region of Pakistan. Five wheat cultivars; Tatara, NARC-2009, Sehar-2006, SKD-1 and F-Sarhad were planted in plot size of 5 m x 3 m with row spacing of 25 cm arranged in Randomized Complete Block Design (RCBD) replicated thrice during 2008-09 and 2009-10 at Islamabad. Both the models were parameterized using different agronomic parameters (phenological development, drymatter accumulation, leaf area index, physiological indices and grain yield) and climatic data. Efficiency of both models was tested using model validation skill scores including d-stat, RMSE and R^2. RMSE between observed and predicted value by APSIM for drymatter for Tatara genotype was 0.34 t ha^{-1} as compared to DSSAT with RMSE 1.40 t ha^{-1}. Similarly, results observed for grain yield and other agronomic parameters generated by APSIM were more precise while less accurate results were depicted by DSSAT. Poor simulations were observed for Sehar-2006 by both models. While, predicted results for NARC-2009 were close to Tatara, whereas, SKD-1 and F-Sarhad showed similar behaviour. Findings of the study highlighted that crop models as a decision support tool to design agricultural production and crop management system, select suitable crop and genotypes under changing climatic scenario, fertilizer management, weeds management and appropriate sowing time. Similarly, these models are helpful in the managements of biotic and abiotic stresses. Meanwhile, this study will introduce both models under rainfed conditions of Pakistan which will further help to assess the constraints that influenced the model parameterization and validation. A set of validation skill scores were used to evaluate the models to examine their usefulness, representativeness and robustness. Similarly, the focus of the models comparison was based upon crop, soil and climatic data, technique and model outcomes. The results generated by the models will help in evaluating strengths and weakness of each of the modeling approaches, and based on these outcomes recommendations about managements could be made.

The results led to the conclusion that APSIM model was more efficient and suitable to simulate wheat growth and development for arid area of Pakistan. Therefore, it can further be used for decision making to mitigate climatic risk, selection of suitable genotypes and management options for agricultural sustainability. Similarly, climatic scenarios analysis might be performed in the APSIM model to mitigate future problems related to climatic extremes, therefore, it’s important to design future strategies based upon models outputs.

Keyword: Crop Simulation Modeling, APSIM, DSSAT, Climate, Arid Region

1. INTRODUCTION

Climatic variability, moisture stress, continuously increasing population and market infrastructures are driving forces to alter agricultural productivity. Changes in climatic scenarios are of vital importance for rainfed agriculture as a change in one climatic variable alters other variables which include temperature, precipitation and solar radiation. Associated impact of increasing temperature, changing rainfall pattern and intensity has led to reduced agricultural productivity and yield over the world. Pakistan is developing country. Water availability through rainfall has become a limiting factor for crop productivity due to lack of decision support and management strategies like suitable sowing time, appropriate genotypes and cropping systems under changing climate. Global earth temperature may increase up to 0.6-2.5 oC in the coming fifty years and by 1.1 – 6.4 ^{o}C during the next century as temperature has been boosted up by 0.6 to 0.9 ^{o}C over the last 20th century on global scale (IPCC, 2007). The climate is being changed abruptly due to variation in rainfall pattern, dry spells, intermittent droughts and floods. Reduction and failure in crop production was projected due to these seasonal variations (Mishra et al., 2008). Peterson et al. (1993) suggested that a systematic approach to the study of soil and crop management problems is useful for testing present research knowledge to answer practical agricultural problems and simultaneously identify gaps in basic research knowledge. Finding the best management options and mimic climatic degradation are two key factors under contemplation in agronomic research to enhance crop productivity. Crop simulation models proved to be efficient substitute for agricultural systems under diverse climatic conditions. These models aid in decision making tools for better and sustainable agriculture (Amanullah et al., 2007).

Crop simulation models consider the complex interactions between weather, soil properties and management factors which influence crop performance. Crop simulation modeling has developed over many years in recital with advances in crop physiology, crop ecology and computing technology. Modeling performance had been envisaged with several opportunities in future including scientific investigation, decision making by crop managers and key contributor in understanding and advancing the genetic regulation of plant performance and plant improvement. An important task in experimenting with models is the testing their performance in a wide range of circumstances to identify their scope of validity and limitations. As crop simulation models are site and crop specific in nature and cannot be used in other areas until and unless validated under local conditions. For simulating yield and biomass of maize, Clemente et al., (2005) compared CERES-Maize and CropSyst modeling approach. Similarly, CERES-Wheat and CropSyst models were parameterized to simulate water-nitrogen interaction in wheat (Singh et al., 2008). Comparison of different modeling approaches is beneficial to select suitable crop model for a specific locality and climate so that it could be further used to predict and simulate agricultural productivity under changing climatic scenarios.

Various models are being used around the world as a tool for yield forecasting. The same has been initiated in Pakistan too, but requires testing of various models to identify their scope and limitations. It has been observed that comparative evaluation of DSSAT and APSIM models has not been undertaken for wheat growth and development in Pakistan yet. Based on this, the present study was carried out with the objectives to compare the performance of APSIM and DSSAT models to simulate wheat growth and yield for forecasting of wheat crop in high rainfall zone of Pakistan under different climatic scenarios.

2. APSIM (Agricultural Production System Simulator) overview

Agricultural Production Systems Simulator (APSIM) is a software tool that enables sub-models (or modules) to be linked to simulate agricultural systems (McCown et al., 1996). APSIM has various modules grouped and categorised as Plant, Environment and Management. It simulates the mechanistic growth of crops, soil processes, and range of management options considering cropping systems perspective. APSIM-Wheat module simulates the growth and development of a wheat crop in a daily time-step on area basis (per square meter, not single plant). APSIM module required inputs including weather, soil and crop data along with management options (Fig. 1). Wheat growth and development in this module responds to climate, soil water supply and soil nitrogen. The module returns information on its soil water and nitrogen uptake to the Soilwat and SoilN modules on a daily basis for reset of these systems. Information on crop cover also be provided to the Soilwat module for calculation of evaporation rates and runoff. Wheat stover and root residues were 'passed' from wheat to the surface Residue and SoilN module respectively at harvest of the plant crop. The SoilWater module is a cascading water balance model that owes much to its precursors in CERES (Jones and Kiniry, 1986) and PERFECT (Littleboy et al., 1992). SoilWater in APSIM is on daily basis, and typical of such models the various processes are calculated consecutively. The SoilN module describes the dynamics of both carbon and nitrogen in soil. The APSIM Met module provided daily meteorological information to all modules within an APSIM simulation.

2.1 Model Parameterization and Evaluation

The data collected from the field experiments was used for model evaluation. Model calibration and validation were described as different ways of model evaluation by Otter-Nacke et al. (1987). Specific cultivar coefficients for the genotypes used in this experiment was not in the list of genotypes available with the model, therefore, evaluation was done using basic information for the cultivar coefficients provided with the model. The cultivar coefficients were adjusted, until main growth and development stages were simulated within 10% of the measured values. Simulated observed comparisons were made for growth and development parameters, the purpose being sensitivity analyses of the model and improvement of the coefficients. Coefficients were increased or decreased using a small step if needed.

2.2 APSIM Model Utilization

APSIM was used to study the rainfall variability in rainfed areas of Islamabad in relation to global mechanisms of El Niño Southern Oscillation / Southern Oscillation Index (ENSO/SOI) and its impact on weather changes in Pakistan. To study the impact of ENSO/SOI phases on rainfall variability in this area, attempt was made to establish a relationship between rainfall variability during October-November (wheat sowing time) and monthly SOI phase in July (selected on the basis of rainfall data analysis). A probabilistic approach was used to describe the chances of exceeding median rainfall. The median rainfall calculated from the long term (1961-2010) actual rainfall data. Rainfall data (1961 - 2010) was analyzed using STATISTICA version 8 by plotting the total monthly actual rainfall received over that period of time to get the pattern in Islamabad during summer (locally called as kharif season starting from May extended until September) and winter (locally known as rabi season, the duration of which is from October to April) seasons (1961-2010). Actual rainfall data was aggregated over a span of 3 years. Range of deviation from 3 years' mean was calculated against each aggregated value. APSIM-wheat module used to simulate wheat crop using long term (1961-2010) climatic data. The averaged yield data partitioned on the basis of July SOI phase. The purpose of this partitioning was to explore the use of seasonal climate forecasting based on SOI phase for the selection of suitable cultivar. The APSIM, when parameterized in this pattern, was further used to explore farmer cropping decision options given the variable climate to enhance the resilience in wheat based cropping system of the area. A scenario analysis was done using a long term historical weather data to explore the feasibility of wheat based cropping system in the area as proposed by Asim et al. (2006). Similarly, use of APSIM model to study long term data of Pothwar from 1961-2010 revealed an obvious trend of increasing summer rainfall and decreased winter rainfall. The observed trend also indicated a significant tendency toward increased rainfall in July-September and decreased rains in September. Based on information generated the analysis revealed an opportunity of early sowing and hold true for selection of optimum sowing time in the mid of October as the selection of sowing time in this rainfed area depend on moisture availability.

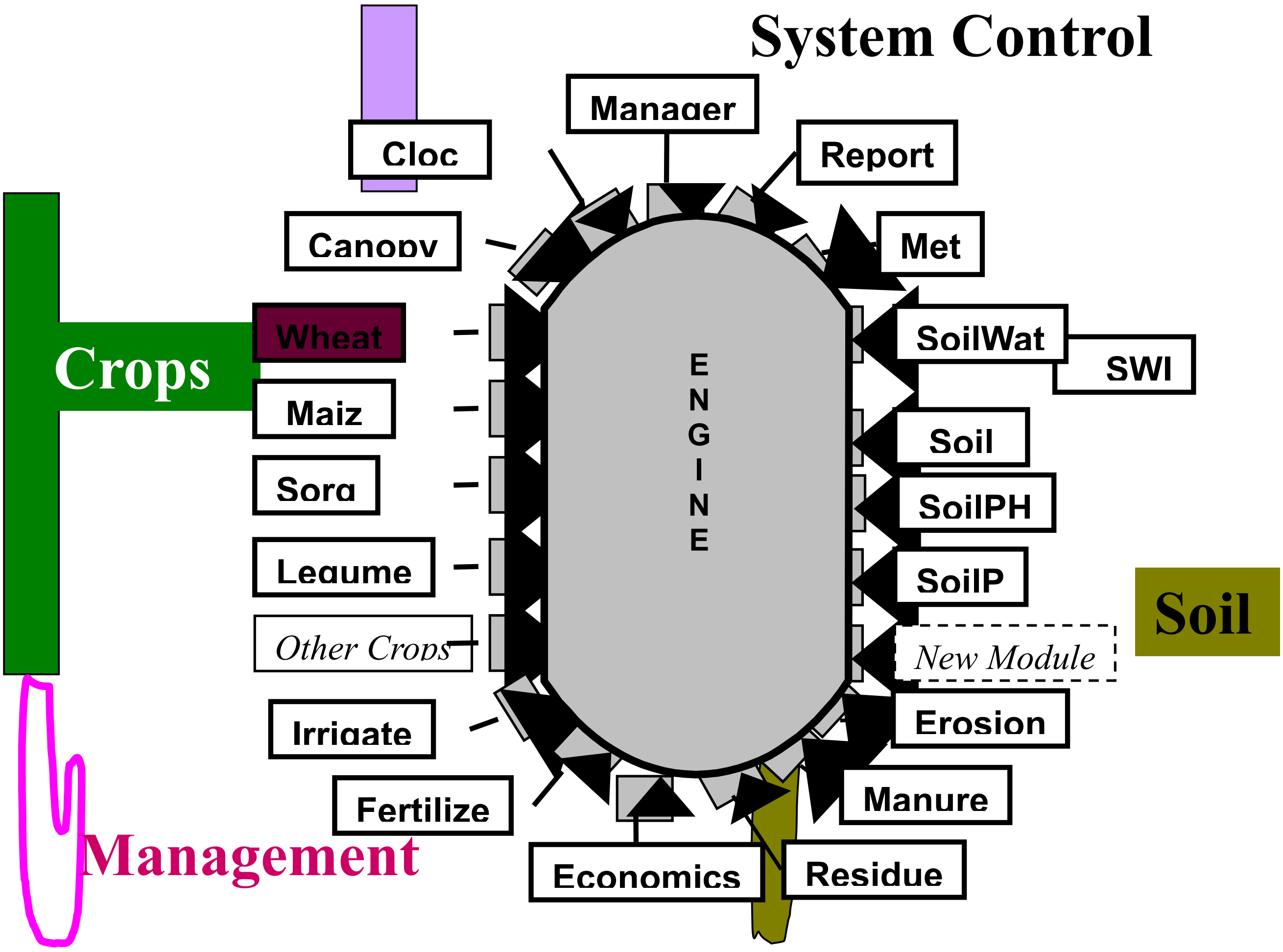

Fig.1. Working mechanism of APSIM model

3. DSSAT (Decision Support System for Agrotechnology Transfer) Overview

The DSSAT cropping model simulates growth, development and yield of crop growing under described managements over the time. The DSSAT is structured using modular approach as reported by Jones et al., (2001). It permits easy incorporation of diverse application packages because of well defined and documented interface to modules. DSSAT is collection of independent programs which then operated together. Databases include weather, soil, experimental conditions and genotypes to apply the models for different situations. These application softwares aid to prepare these databases and to compare simulated results with observed values and to improve model's efficiency and accuracy. DSSAT crop model allows users to simulate options for crop management to assess risks.

3.1 DSSAT Parameterization and calibration

A soil input file required with detailed hydraulic and physical properties of soil to simulate DSSAT. It does not offer automated procedure for its calibration and validation. Changes in its input parameters must be done to validate it under local conditions of a locality. In application of DSSAT for precision agriculture, different files need to be generated for various management zones. Several types of modules are generated for DSSAT to get simulated results which includes soil module, weather module, soil plant atmosphere module and crop module. Several genetic coefficients generated for DSSAT parameterization. These coefficients includes

P1D (Photoperiod sensitivity coefficient), P1V (Vernalization sensitivity coefficient), P5 (Thermal time from the onset of linear fill to maturity), G1 (Kernel number per unit stem/spike weight at anthesis), G2 (Potential kernel growth rate), G3 (Tiller death coefficient. Standard stem/spike weight when elongation ceases) and PHINT (Thermal time between the appearance of leaf tips). Afterward, model evaluation being done by comparing observations and simulated results and measuring its efficacy and suitability for specific predictions and locality (Jones et al., 2003).

4. Implementation era

Simulation model testing consists of two main activities (i) establishing the source codes representing the models performance as intended, and (ii) confirming that simulation models accurately reproduce empirical data (Meinke, 1996).These two activities were referred as model verification and validation (V & V) (Kleijnen, 1995). In the present study, APSIM and DSSAT module were tested for wheat phenology, days after sowing, leaf area index, drymatter accumulation (t ha-1) and grain yield (t ha-1) as these are major constituents to determine optimal productivity of crop. Both the models were calibrated under local weather conditions to simulate wheat genotypes of diverse origins under rainfed conditions. The data collected proved to be beneficial and useful to evaluate both the tactical and modeling approaches. Models were tested by validation skill scores including root mean square error (RMSE), normalized mean square error (NMSE), d-stat and R^2 which allow comparative assessment of model performance at particular location whereas, linear regression line expressed model stability across variable climatic conditions. Both the models performed well to simulate wheat growth. However, predicted results derived from APSIM model were much better to observed ones for all parameters as compared to DSSAT. APSIM model predicted all the parameters with significant R^2 than DSSAT for all wheat genotypes. However, both simulation approaches showed better and precise results for zadok phenology and days after sowing as predicted and observed values were close. Simulated results by APSIM for leaf area index, drymatter accumulation and grain yield were close to observed ones with more R^2 and RMSE than observed for DSSAT which highlighted the performance of APSIM module. From the results, it was observed that APSIM module gave unbiased and precise predictions of zadok phenology, leaf area index, drymatter accumulation and grain yield for five genotypes as close association was demonstrated between observed and predicted values. In the same way, Zhang et al., (2008) reported that yield simulation might be improved if model could simulate more accurate days after sowing under variable climatic scenarios. Simulated results for leaf area index depicted that leaf area at different zadok growth stages was close to predicted values by APSIM which was near to 1:1 line as compared to DSSAT (Table 1 (a)).

Both simulation approaches were parameterized to simulate wheat drymatter accumulation from three leaf upto maturity and results highlighted that APSIM model simulated better results for drymatter accumulation with higher R^2 and results closely associated to 1:1 line (Table 1 (b)). The use of models to simulate above ground biomass was reported with good accuracy by Chen et al., (2010) who concluded that APSIM-wheat module can simulate biomass and model was able to explain more than 90% variation in crop biomass. Grain yield is of more and vital importance as all experimental studies focused upon yield. Likewise, other attributes, APSIM module performed efficiently for grain yield with R^2 more than 0.90 % while, observed and predicted values by DSSAT were not closely related and far away from 1:1 line (Table 1 (c)). APSIM model proved to be more efficient and reliable to simulate wheat crop under rainfed conditions. The overall prediction of grain yield by model was reported satisfactory by Singh et al., (2008) with R^2 values (0.88). The results depicted that APSIM model performed well and its efficacy can be determined by validation skill scores.

5. Conclusion

Crop modeling is becoming a valuable tool to understand and mimic climatic constraints and yield gaps. The outcomes of the study clearly depicted that APSIM module predicted wheat crop growth and yield with more accuracy than DSSAT. So, it is more appropriate and can be parameterized to simulate crop growth under changing climatic scenarios to select suitable genotypes, sowing time, cropping pattern, fertilizer and weed management strategies enabling crop to cope with environmental hazards. Therefore, studies have clearly depicted crop simulation model as potential agronomic and decision making tool to understand wheat crop biodynamism under variable climatic conditions of dryland agriculture. Furthermore, the evaluation of models all over Pakistan will enhance our knowledge to pick variability and build resilience in various temperature and rainfall regimes and prove a better tool for crop yield and rainfall forecast of the region.

Table 1. Model Validation Skill Scores for (a) Leaf Area Index, (b) Drymatter accumulation (t ha^{-1}) and (c) Grain Yield (t ha^{-1})

(a)

Genotypes	APSIM				DSSAT			
	R2	d-stat	RMSE	NMSE	R2	d-stat	RMSE	NMSE
Tatara	0.99	0.98	0.34	0.02	0.56	0.70	1.40	0.39
NARC-2009	0.97	0.97	0.38	0.02	0.51	0.81	1.11	0.29
Sehar-2006	0.94	0.94	0.48	0.05	0.48	0.62	1.30	0.59
SKD-1	0.93	0.94	0.51	0.06	0.59	0.61	1.30	0.55
F-Sarhad	0.91	0.92	0.65	0.08	0.51	0.52	1.63	0.91

(b)

Genotypes	APSIM				DSSAT			
	R2	d-stat	RMSE	NMSE	R2	d-stat	RMSE	NMSE
Tatara	0.99	0.99	1.13	0.05	0.81	0.76	4.58	0.91
NARC-2009	0.97	0.96	1.70	0.09	0.83	0.80	3.80	0.62
Sehar-2006	0.89	0.96	1.86	0.12	0.83	0.79	3.72	0.67
SKD-1	0.87	0.99	0.96	0.03	0.78	0.85	2.87	0.46
F-Sarhad	0.90	0.98	1.12	0.04	0.81	0.83	3.22	0.54

(c)

Genotypes	APSIM				DSSAT			
	R2	d-stat	RMSE	NMSE	R2	d-stat	RMSE	NMSE
Tatara	0.95	0.97	0.26	0.00	0.62	0.65	0.73	0.03
NARC-2009	0.92	0.82	0.48	0.02	0.56	0.69	0.70	0.03
Sehar-2006	0.83	0.88	0.48	0.02	0.51	0.66	0.70	0.03
SKD-1	0.87	0.87	0.49	0.02	0.54	0.68	0.68	0.03
F-Sarhad	0.84	0.85	0.49	0.02	0.58	0.69	0.44	0.03

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