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Application of Crop Growth Simulation Models in Agriculture with special reference to Water Management Planning

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Abstract

Crop growth simulation models are developed to show the complex interaction of agronomic, environmental and hydrologic factors on crop growth. A number of these models especially EPIC, DSSAT and CROPWAT models have been widely used in agriculture since 1970s. The main applications of these models is to show the crop growth under different types of soil fertility, water availability and variations of different inputs use in agricultural crop production. The climatic, agronomic and environmental factors are also included in these models to simulate the long-term impacts of different cropping systems and management practices on crop growth. It is difficult to fit any particular model in every situations as most of the models has some limitations. However, the EPIC and DSSAT models are found used in different geographical locations and in various agro-environmental conditions with limited data availability. Furthermore, these models are found applied in estimating soil moisture, crop water requirements and crop evapotranspiration but the use of these two models are limited in planning irrigation water management. The CROPWAT has advantage over EPIC and DSSAT models for estimating scheme water requirements and planning of irrigation scheduling and water management planning in irrigation scheme.

Keywords: ***EPIC model, DSSAT model, CROPWAT model, crop growth, water management***

Introduction

Agro-ecosystems comprise a complex interaction among the components and systems of soil, crops, the atmosphere and farming practices (Zhang, Li, Zhou, & Moore III, 2002). An understanding of the complex interaction of soil-water-atmosphere and crop yield is important for sustainable water use. Several empirical models related to crop growth have been developed to show the complex interaction of crop growth with various climatic, hydrologic, atmospheric and agronomic factors. These empirical models were developed based on regression analyses. The regression model assumes that the variability of crop yields can be explained by a few independent variables. The regression models have many shortcomings due to errors attending some assumptions. Some regression models, when dealing with multiyear time series, usually include a technology trend factor, thus lumping everything other than climatic factors into one regressor (Singh, n. d.). Furthermore, this type of regression analysis can often be misleading when a large number of hydrologic, agronomic, soil and environmental factors that influenced the crop growth are not included in the model.

On the other hand, crop simulation models are computer-based mathematical models representing the interaction of crop growth and the environment (Graves, Hess, Matthews, Stephens, & Middleton, 2002). The crop simulation models play an important role in resource management in the agricultural field, and have been used to understand, observe, and experiment with crop systems for the last four decades (Cheeroo-Nayamuth, 2001; Graves et al., 2002). Crop growth simulation models are used as research tools for assessing the relationships between crop productivity and environmental factors (Adejuwon, 2005). These models use one or more sets of differential equations over time, normally from planting to final harvest, to estimate agricultural production as a function of weather and soil conditions, as well as crop management (Murthy, 2004).

The use of crop models and their application in the agricultural field started in the 1970s, but different types of models are increasingly accessible for practitioners with different levels of exposure and expertise (Cheeroo-Nayamuth, 2001). The most commonly used models are the Environmental Policy Integrated Climate (EPIC) model (Williams, 1990), Decision Support System for Agro-Technology Transfer (DSSAT) model (Jones et al., 2003; Jones et al., 1998; Ritchie, Godwin, & Otter-Nacke, 1985), and CROPWAT model (M. Smith, 1992). In most cases, the models have been developed for specific localities and are not always applicable for other regions (Adejuwon, 2005). Therefore, when introducing such crop models into new regions, their applicability needs to be evaluated. The main aim of this paper is to review the applications of different crop growth simulation models in different regions and to assess their suitability for water management planning in agriculture. Judicious use of agricultural models is possible only if the user has a sound understanding of the model structure, scope

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and limitations; however these models are nonetheless only rough representations of complex real systems (Cheeroo-Nayamuth, 2001).

Environmental Policy Integrated Climate (EPIC) model

The EPIC model was developed in 1981 to determine the relationship between soil erosion and soil productivity throughout the U.S.A. The model was ready for use in the Soil and Water Resources Conservation Act (RCA) analysis by 1985. Although model refinement and development has been applied to the RCA analysis, the EPIC model has been applied to a number of agricultural management problems (Williams, 1990). For example, the EPIC model is capable of dealing with decisions involving drainage, irrigation, water yield, erosion (wind and water), weather, fertiliser and lime application, pest control, planting dates, tillage, and crop residue management. The EPIC model has been applied in different countries in different situations, such as the 1988 drought assessment, global climate change analysis and farm level planning.

A number of studies found that the EPIC model was used in different geographical locations and in various agro-environmental conditions (Bulatewicz et al., 2009; Costantini, Castelli, Raimondi, & Lorenzoni, 2002; Gassman et al., 2009; Hilger et al., 2000; Ko, Piccinni, & Steglich, 2009; Schlüter, Savitsky, McKinney, & Lieth, 2005; Wriedt, Van der Velde, Aloe, & Bouraoui, 2008). The EPIC model has also been used in estimating soil moisture, crop water requirements and crop evapotranspiration for the last three decades. Ko et al. (2009) applied the EPIC model as a decision support tool to manage irrigated cotton and maize in South Texas. They performed the simulation by using the EPIC model to determine crop yield, crop water use, and the relationships between the yield and water use parameters, such as crop evapotranspiration (ETc) and water use efficiency (WUE). They also used the EPIC model to simulate the variability in crop yields under different irrigation regimes. In addition, the EPIC model was used to simulate yield responses in various irrigation regimes using data at the farm field level. Ko et al. (2009) concluded that the EPIC model can be used as a decision support tool for the crops under full and deficit irrigation conditions in South Texas. Finally, they suggested that using the EPIC model can be effective in making long-term and pre-season decisions for irrigation management of crops, but in the case of in-season irrigation management, evapotranspiration and phonologically-based crop coefficients are likely to be more useful.

Since 2000, a number of studies have shown the application of the EPIC model with other agricultural models, crop models, Geographic Information Systems (GIS), and mathematical optimisation models to calculate crop water requirements at different geographical locations, with simulated crop yields, and alternative sustainable water resource management strategies (Hilger et al., 2000; Wriedt et al., 2008).

Soil moisture stress and soil water deficit can effect crop yields unless offset by irrigation, thus increasing water use. Hilger et al. (2000) examined the potential of the EPIC model by coupling it with the Agricultural Land Management Alternatives with Numerical Assessment Criteria (ALMANAC) model to estimate crop yields under erratic rainfall in northeast Brazil. The objective of their study was to examine the potential of both models to simulate growth and yield performance of annual crops under these conditions. The structures of both models are appropriate for simulating crop production. However, both models partly failed to simulate crop growth and yield performance with increased planting density and input uses on less favorable sites.

Optimisation of the use of limited irrigation water based on crop requirements at the farm level can help inform sustainable use of water resources. Bulatewicz et al. (2009) applied the calibration of the EPIC model on irrigated water use in the Kansas High Plain area using a genetic algorithm. This study explored utilisation of the EPIC model to serve as a decision support system for sustainable usage of groundwater for irrigated agriculture in the High Plains aquifer. The study estimated the bootstrap probability distributions for ten model parameters for each crop by entropy maximisation via the genetic algorithm. The results of the study demonstrated that, given sufficient data, the EPIC model applies reasonable total amounts of water on a county-wide basis, but appeared to do so in fewer, larger applications. Schlüter et al. (2005) conducted a study on optimising long-term water allocation in the Amudarya river delta by using a water management model for ecological impact assessment. To assist in the evaluation of trade-offs in water allocation and the determination of ecological restoration goals, they developed a simple water management model for the Amudarya River and its delta region using the EPIC modelling system. Optimal water allocations in the irrigation network, through multi-objective optimisation in monthly time steps, were determined by the water management model. The model results were compared with the current water allocation for the entire basin, as well as higher resolution for the delta region. They calibrated and tested the model using a high-water and a low-water year.

The Agricultural Policy Extender (APEX) model, coupled with the EPIC model, can be used to simulate the long-term impacts of different cropping systems and management practices, which can be helpful for making policy aimed at reducing environmental degradation. Gassman et al. (2009) reviewed the historical development and applications of the EPIC model and the APEX models. The APEX model is essentially a multi-field version of the

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EPIC model that was developed in the late 1990s to address environmental problems associated with livestock and other agricultural production systems on a whole-farm, or small watershed, basis. The EPIC model and the APEX are most effective at simulating the long-term impacts of different cropping systems and management practices; however, it also revealed that both models are less accurate at replicating the effects of single climatic events on erosion and other losses or inter-annual variability between crop yields and pollutant losses.

The EPIC model is widely used in calculating crop water requirement, simulating crop growth under different water management and climatic conditions. The model is also suitable to combine with optimisation techniques. The EPIC model uses simplified crop growth functions that respond to climate, environment and management and has also been used in some climate impact assessment (Dinar & Mendelsohn, 2011). One of the main constraints of applying the EPIC model in climate change assessment is that it cannot calculate specific yields for individual crops and it does not consider the positive effect of CO_2 fertilisation (Dinar & Mendelsohn, 2011). The DSSAT model is a decision support system used to simulate crop growth in response to crop management and is specifically developed for climate impact studies.

Decision Support System for Agro-Technology Transfer (DSSAT) model

Identifying the optimum level of management for attaining economically efficient yields remains problematic in agricultural production, and crop simulation models are often found to be useful in this context (Sarkar & Kar, 2006; Yadav et al., 2012). Crop simulation models can be used as decision support systems to assess the risk and economic impacts of management strategies in agriculture. The decision support system for agro-technology transfer (DSSAT) model is a collection of models that connects the decision support system to crop simulation models (Jones et al., 2003). The DSSAT model is a software application program that comprises crop simulation models for over 28 crops (as of version 4.5) and is used to simulate growth, development and yield as a function of the soil-plant-atmosphere dynamics (DSSAT.net, 2013). The DSSAT model is composed of various crop simulation models which include the CERES models for cereals (barley, maize, sorghum, millet, rice and wheat); the CROPGRO models for legumes (dry bean, soybean, peanut and chickpea); and models for root crops (cassava, potato) and other crops (sugarcane, tomato, sunflower and pasture) (Ines et al. 2001). These models have been used extensively by researchers, educators, consultants, extension agents, growers, and policy and decision-makers. Applications cover over 100 countries worldwide with a history of more than 20 years (DSSAT.net, 2013).

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A number of applications for the DSSAT model exist, including crop management at the farm and regional levels and assessment of the impact of climate variability and climate change. Kapetanaki and Rosenzweig (1997) applied a simulation study with CERES-Maize to show the impact of climate change on maize yield in central and northern Greece. Climate change scenarios were developed by doubling the CO_2 from three general circulation models (GCMs). A consistent increase in air temperature, small increases in solar radiation and precipitation changes were added to these scenarios. The study results showed that the maize yield would likely decrease under present management practices, due to the reduced duration of the growing period at all sites. They also conducted adaptation analyses and concluded that climate change effects may be potentially offset through earlier sowing dates and the use of new maize varieties.

Saseendran, Singh, Rathore, Singh, and Sinha (2000) conducted a study on the effects of climate change on rice production in the tropical humid climate of Kerala, India. The plausible climate change scenarios were developed for the Indian subcontinent by using a coupled atmosphere-ocean model experiment performed at Deutsches Klimarechenzentrum, Germany. The study results showed that the rice maturity period was projected to shorten by 8 per cent and yield increase by 12 per cent over the state, due to the effects of climate change. This study also showed an increase in yield due to the fertilisation effect of elevated CO_2 but there were also negative impacts on the rice yield due to the temperature rise.

The effect of climate change on rice yields in diverse agro-environments in India and China are found in studies undertaken by Aggarwal and Mall (2002) and Yao, Xu, Lin, Yokozawa, and Zhang (2007). Aggarwal and Mall (2002) found that the direct effect of climate change on rice crops in different agro-climatic regions in India would always be positive even under pessimistic scenarios and in optimistic scenarios. They also discussed the effect of uncertainties in scenarios and crop models. They used two popular crop simulation models - Ceres-Rice and ORYZA1N – to simulate the impact of various climate change scenarios on the yields of irrigated rice with different levels of nitrogen management. Their results point to the need to take caution in using the impact assessment results based on the average simulated grain yields and mean changes in climatic parameters. The impact of climate change on irrigated rice yields using the High Emission (B2) climate change scenario from the Regional Climate Model (RCM) and the CERES-rice model for the period of 2071-2090 are assessed in Yao et al. (2007). They selected eight rice growing stations in China and found that there will be direct negative effect from the B2 scenario on rice yields compare to the baseline scenario. They concluded that impacts under the B2 scenario could pose a threat to rice yields at most selected stations in the main rice areas of China. The DSSAT model is

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suitable for simulating the effects of changing climatic variables on any particular crop yields presented in the above study. However, the DSSAT model cannot be used to show the effect on cropping patterns.

In Bangladesh, some studies have used the DSSAT model to simulate the effects of climate variability and change on crop production (Basak, 2012; Basak, Ali, Islam, & Alam, 2009; Karim, Hussain, & Ahmed, 1996). These studies were conducted mainly at the farm level of analysis.

The role of soil water availability in potential rain-fed rice productivity in Bangladesh is investigated by Mahmood, Legates, and Meo (2004). They used the CERES-Rice model to examine the major rice growing regions of Bangladesh. They compared the potential average yield per hectare with yields from model applications and found rice yield to be 7218kg and 6077kg respectively, in Bangladesh. Moreover, they determined from the modelling results that the loss of potential yields are 39, 57, and 70 per cent due to high levels of water stress during the maturing, flowering, and concurrent flowering and maturing stages, respectively. These types of findings are useful in farm planning but the DSSAT models are limited in planning for water management in an irrigation project.

The effects of micro nutrients on crop yields by applying the DSSAT model are found in different studies. Sarkar and Kar (2006) conducted a simulation study in West Bengal, India from 2001 to 2003 using the seasonal analysis program of the Decision Support Systems for Agro-technology Transfer (DSSAT 3.5) suite of models. The weather scenarios used were generated from a weather generator in the seasonal analysis program to run each treatment combination with 20 replications. They conducted both biophysical and economic analyses. Their study found that the seasonal analysis program predicted an application of 120kg of nitrogen per hectare for both rice and wheat to be optimal, but the economic analysis showed an application of 80kg of nitrogen per hectare for both rice and wheat to be preferable. The study revealed that future crop yields under different management practices can be predicted by using the generated future weather data.

Bordey (2010) studied the impacts of research on Philippine rice production. The CERES-Rice simulation model of the Decision Support System for Agro-technology Transfer (DSSAT) was used to show the shift in individual rice supply when a hybrid rice variety was adopted. The yield responses of hybrid and inbred rice varieties to different levels of nitrogen, potassium, and water applications were also determined by using the DSSAT model. The study results revealed that adopting the hybrid rice variety would lead to a pivotal and divergent shift in the individual supply, but it is far from being used on an aggregate scale.

Porter et al. (2010b) conducted a study on modelling organic carbon and carbon-mediated soil processes in the cropping system model (CSM) within the Decision Support System for Agro-technology Transfer (DSSAT). The CENTURY soil organic matter model was also adapted for the DSSAT-CSM modular format for better modelling of the dynamics of soil organic nutrient processes. Details of the DSSAT-CSM model architecture and the DSSAT-CENTURY module, as well as the more complex soil organic matter modelling capability, are described in their paper. Another limitation of using the DSSAT model is that it can only be used to show the effects of nitrogen application and deficiency. However, plant nutrients are fulfilled by more than nitrogen, as crop yields are affected by other micro nutrients.

In sum, the applications of DSSAT model are common for agronomic and field experimental problems. Calculation of relative yields based on different inputs is often reported and the simulated effects of weather and changing crop management also appear in some studies. Economic analysis based on estimating crop water requirement at an irrigation project level using DSSAT is largely absent from this strand of literature.

CROPWAT model

The CROPWAT model is used as a decision support tool to help agro-meteorologists, agronomists and irrigation engineers calculate water requirements. Calculations are based on crop evapotranspiration. The CROPWAT model is specially designed for water management planning in irrigation schemes. It is used for the planning of irrigation scheduling for rain-fed or irrigated crops under different water supply conditions and in the context of irrigation deficits. Importantly, using the CROPWAT model has resulted in improved irrigation practices. Crop water requirements are calculated from the input data on climate, crop and soil. The CROPWAT model contains built-in standard crop information. In addition to the standard data found in the CROPWAT model, the CLIMWAT-database can be used to obtain climatic data for 144 countries. Irrigation scheduling and scheme water requirements can be calculated for rain-fed or irrigated crops using soil-water balance and by following a pre-specified cropping pattern. The procedures for calculating crop water and irrigation requirements are based on methodologies presented in FAO Irrigation and Drainage Papers No. 24 ‘Crop water requirements’ (Doorenbos & Pruitt, 1977), and No. 33 ‘Yield response to water’ (Doorenbos & Kassam, 1979). The CROPWAT model includes a revised method for estimating reference crop evapotranspiration, adopting the approach of Penman-Monteith as recommended by the FAO Expert Consultation held in May, 1990 in Rome (Allen, Pereira, Raes, & Smith, 1998).

A number of studies have employed the CROPWAT model for calculating crop water requirements, irrigation water requirements, irrigation scheduling and total water withdrawal for irrigation. The wide ranges of applications for the CROPWAT model are briefly reviewed below.

Kuo, Ho, and Liu (2006) conducted field experiments at the HsuehChia Experimental Station from 1993 to 2001. They estimated the irrigation water requirements of paddy and upland crops at the ChiaNan Irrigation Association, Taiwan, by calculating the reference and actual crop evapotranspiration, deriving the crop coefficient, and collecting the input data for the CROPWAT model. They found the estimated crop coefficients for corn were 0.40, 0.78, 0.89 and 0.71 in the initial, development, mid-season and late-season stages, respectively. Meanwhile, they also estimated crop coefficients for sorghum and soybean in the four growth stages. They experimented by using the single and double cropping patterns and estimating the peak water requirements in a year.

Research on the water requirements of major crops for different agro-climatic zones of Balochistan, Pakistan, was conducted by IUCN (2006). Historical meteorological data such as maximum-minimum temperatures, relative humidity, wind speed, sunshine hours and rainfall were collected from 15 stations in Balochistan for a period of 44 years (1961-2004). This data was used to determine reference evapotranspiration at seven zones in the province by applying the CROPWAT model. The crop water requirements for 13 crops were estimated for seven agro-climatic zones of Balochistan and recommendations for specific crops in different locations were made based on crop water requirements.

Nazeer (2009) used a simulation of maize under irrigated and rain-fed conditions with the CROPWAT model. The field experimental data of maize was collected from the Mardan district of the NWFP, Pakistan, and used as an input in the CROPWAT model. The evapotranspiration and crop water requirements were calculated for improved irrigation practices and the planning of irrigation schedules under varying water supply conditions. Yield changes were also explored under various conditions. The study results suggest that the application of adequate irrigation scheduling can markedly reduce the yield losses.

Thimme Gowda, Manjunaththa, Yogesh, and Sunil (2013) conducted a study on water requirements of maize using the CROPWAT model in the northern transitional zone of Karnataka, India. They conducted an experiment to consider the water requirements of maize under rain-fed conditions during the monsoon season at the main agricultural research station in Dharwad. They collected and analysed the field experimental data with the two sowing dates, June 16, 2010 and July 30, 2010, and found that the total water requirement of maize sown at the earlier date was 116.0 millimetres, while that of the maize sown at the later date was 183.8 millimetres. Needless to add, they concluded that the water requirements of maize differed.

The main application of the CROPWAT model is to calculate scheme water requirements in irrigation projects or in any irrigation regions. Nonetheless additional insights can be gained by combining CROPWAT with other data. Cornejo (2003) used the evapotranspiration concept embodied in CROPWAT and a geographic information system (GIS) to estimate the irrigation potential of the Trasvase irrigation system on the Santa Elena peninsula in Guayas, Ecuador. Data on air temperature, relative humidity, solar radiation, and wind speed was used to calculate evapotranspiration. The potential area under irrigation was calculated from the total available water divided by the crop water requirements. Nine scenarios were tested to cover a wide range of possible variations in irrigation technology and crops planted in the area. The results offer useful guidelines for irrigation planning.

Estimates of water requirements and consideration of irrigation scheduling of spring maize using the GIS and CROPWAT models are also found in Feng, Liu, and Zhang (2007) in Beijing-Tianjin-Hebei Region. The data on irrigation withdrawals, soil types and climatic conditions in the study area was used to obtain information about crop water requirements for spring maize and to achieve effective planning. The GIS data were also used to extend the capabilities of the crop models at a regional scale. The study found that two or three times the amount of supplementary water irrigated to spring maize at the right time under different scenarios improved yields compared to that of the rain-fed control. Precise supplementary irrigation schedules were recommended to fulfil the water deficits during its critical growth.

Cavero, Farre, Debaeke, and Faci (2000) conducted a comparative evaluation of EPIC-phase and CROPWAT model to simulate yield reduction of maize due to water stress under semi-arid conditions. They also evaluated simulated evapotranspiration (ET), harvest index (HI), leaf area index (LAI), and plant biomass by using the data from three field experiments. They found that even when different amounts of water were applied a continuous water deficit resulted in one sprinkler-irrigated experiment; however, the other two experiments were subject to flood-irrigation and water stress was intermittently imposed at different development stages of maize.

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The CROPWAT model is a valuable tool for irrigation planning in maize because it can adequately calculate the yield reduction caused by water stress. However, more data is required to find a better simulation of crop evapotranspiration with the EPIC-phase model. The CROPWAT model is usually assembled with simulation and optimisation models for irrigation and crop planning (Darshana, Pandey, Ostrowski, & Pandey, 2012). However, the evolutionary algorithm (GANetXL) can subsequently be used to consider the optimal cropping patterns by maximising net benefits while irrigation water requirements act as a constraint. This model was applied in the Holeta catchment in Ethiopia as a case study. The simulation results of the CROPWAT model showed that crop water requirements at the farm level for apple was the highest (993mm), followed by peach (908mm), tomato (470mm), potato (443mm) and wheat (294mm). Unsurprisingly, the study reveals that fruit crops have greater water requirements than cereals but the study also showed that the total benefit from the study area could be increased by $34 US per hectare through modified water allocation.

Scheme irrigation planning and irrigation scheduling based on surface and groundwater sources by using the CROPWAT model have also been studied. Rajput and Patel (n. d.) applied the FAO CROPWAT model to determine the optimal date for sowing wheat in canal-irrigated areas of a small Noorpur distributary of the Western Yamuna Canal system. They found that the CROPWAT model adequately predicted the effects of water stress on yields. They applied the model in a canal operation area in the north Indian plains to find the expected yields of wheat with different sowing dates spread across the sowing season. They concluded that the CROPWAT model is a powerful tool to simulate different crop water needs under different planting dates in canal operating areas. Moreover, this type of analysis helps to select the optimal sowing date for higher yields and enhance water use efficiency.

Endalamaw (2009) conducted a study on the optimum utilisation of groundwater in Kobo Valley, Eastern Amhara, Ethiopia. The CROPWAT model was used to determine crop evapotranspiration and the water requirements of onion, tomato and pepper in the dry season. The study results indicate that the current irrigation rate, if extended across all of the irrigable land, would reduce the water table by 2 metres per year. In contrast, the water table depth will not be depleted if irrigation followed the crop water requirement of different vegetables. Capturing the flood water and using it to recharge the groundwater, whilst adopting more judicious watering, was suggested as measures to protect the declining water table.

More recently, the CROPWAT model has been found useful for showing the effects of climate change on crop yields and optimal water use (Antonellini et al., 2014; Blanc et al., 2013; Deressa, Hassan, Ringler, Alemu, & Yesuf, 2009; Döll, 2002). Most of these types of studies use GCMs as well as the MAGICC-SCENGEN model developed by the IPCC, with the CROPWAT model then used to estimate climate change impact on cropped areas and adaptive measures for the agricultural sector. The climate change scenarios and the inputs on precipitation and temperature are usually developed in accordance with the IPCC. Overall, these studies suggest that the CROPWAT model can be used as a decision-making tool for contemplating adaptation to climate change with respect to water use in agricultural crop production.

CROPWAT versus EPIC and DSSAT models

During the last four decades crop models have been increasingly used to estimate crop water requirements and to account for the complex interaction of soil, water, atmosphere, and crop growth. Early models were primarily used for yield gap analyses, but crop models are increasingly focused on complex yield-water relationships, including nutrient and water deficiencies, infestation of pest and disease and soil nutrient dynamics (Aggarwal & Mall, 2002; Bhatia et al., 2008; Porter et al., 2010a). Moreover, these models have been shown to be effective in presenting the impacts of changes in weather and climate. Notwithstanding significant refinements, it should be noted that there are some limitations to crop models. For example, in most cases, models have been developed in particular localities and are not always applicable in other regions without modification (Adejuwon, 2005). Some variation also exists in the performances of crop models and the predictions of any of these models cannot unequivocally be termed robust and accurate (Palosuo et al., 2011).

Farmers can use crop simulation models as decision-making tools to enhance profitability and improve ecological outcomes (Jacobson, Jones, & Welch, 1995). One of the main advantages of using simulation models is their ability to create data rapidly and inexpensively for making choices. Nonetheless, not all models follow the same development processes. The main difference between crop growth models and simplified crop water-yield models is that crop growth models, such as the EPIC and DSSAT models, simulate the most relevant physiological and hydrologic processes. In contrast, the simplified crop water-yield models, such as the CROPWAT model, have been developed for irrigation scheduling that does not explicitly simulate crop growth. The upshot is that the EPIC model is used for the estimation of total crop production within a given land area or territory; assessment of the impacts of climate variability and climate change on crop yields; and crop production and assessment of the vulnerability of cropping systems to climate variability and climate change (Adejuwon, 2005). In addition, the EPIC model can be used to calculate soil moisture and temperature regimes at the national scale; however, its consistency is not clear (Costantini et al., 2002).

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The EPIC crop simulation model can be used to simulate water and nitrogen effects on crop growth. Ko et al. (2009) note that the model has been used extensively in the US and other counties. The major biotic and/or abiotic factors, such as interactions of nutrients, weed or pest infestations and field variations of soil chemical and physical properties, have significant effects on crop growth, but the EPIC model fails to biophysically simulate these effects on crop growth (Ko et al., 2009).

In addition to the EPIC model, the DSSAT models is widely used for crop simulation (Aggarwal & Mall, 2002; Ma, Hoogenboom, Ahuja, Ascough Ii, & Saseendran, 2006; Thorp, DeJonge, Kaleita, Batchelor, & Paz, 2008). The DSSAT model includes only a few crops in the system and the models are not specified to respond to all environment and management factors. As such, the same limitations for the EPIC model is applicable for the DSSAT model (Ko et al., 2009).

The advantage of using the CROPWAT model is its ease of use compared to other models, such as the DSSAT (Durand, 2006). Monthly climatic data is the only requirement to estimate crop water needs. The standard built-in data can be easily adjusted and new data can be effortlessly inserted. In addition, climatic data from 144 countries can be imported from CLIMWAT.

According to M Smith, Kivumbi, and Heng (2002) “an important attribute of the CROPWAT model is that it allows extension of the findings and conclusions from studies to conditions not tested in the field”. The model can also be used to identify inconsistencies and shortcomings in data. In sum, the CROPWAT model offers a parsimonious means of generating recommendations on irrigation scheduling, scheme water requirements under various water supply situations and conditions of crop production.

Conclusion

The planning of agricultural production can minimise water use and ultimately to increase the total area under irrigation. Planning of irrigation water use in irrigation projects can improve agricultural production with limited water availability under different climatic conditions. Crop simulations models are used to determine crop yield, crop water use, and the relationships between the yield and water use under different crop management at the farm and regional levels. Some features are common in crop simulation models that are estimating water requirements, determining crop growth and generating future weather data. The DSSAT model is improved over EPIC model in estimating crop yields considering impact of climate variability and climate change. Application of EPIC and DSSAT models are brought positive outcomes in crop management in different agro-environmental conditions. However, CROPWAT model is specifically developed for planning irrigation scheduling and determining scheme water requirements in irrigation projects with limited availability of data. These advantages are accentuated in different regions specially developing countries where the availability of data is a common problem.

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