Potential of crop models for improving and sustaining crop production in Ghana

D. K. ASARE & H. M. AMOATEY
Department of Plant and Soil Sciences, Biotechnology and Nuclear Agriculture Research Institute, Ghana Atomic Energy Commission, P. O. Box LG80, Legon, Ghana

ABSTRACT
Attainment of food security depends on the productivity and sustainability of food production. In Ghana, crop production is predominantly carried out under rainfed and low-resource input conditions. Strategies are, therefore, required to optimise the use of available resources and minimize the adverse effects of the weather pattern on crop productivity and sustainability. Crop models can be used to map out strategies for improving and sustaining crop productivity. This paper highlights some of the areas in which crop models can be used to boost crop production and improve food security in Ghana. Logistic requirements for effective use of crop models in the country are also discussed.

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RÉSUMÉ
ASARE, D. K. & AMOATEY, H. M.: *Potentiel des modèles végétaux pour améliorer et soutenir la production végétale au Ghana.* La réalisation de l'autosuffisance alimentaire dépend de la productivité et la durabilité alimentaire. Au Ghana la production végétale se déroule principalement sous des conditions pluviales et de peu de resource d' intrants. Les stratégies sont donc exigées pour optimiser l'utilisation des resources disponibles et réduire les effets défavorables de l'orientation climatique sur la productivité et la durabilité végétales. Les modèles végétaux peuvent être utilisé pour élaborer des stratégies pour améliorer et soutenir la productivité de culture. Cet article met en lumière quelques zones dans les quelles les modèles végétaux peuvent être utilisé pour accroître la production végétale et améliorer l' autosuffisance alimentaire au Ghana. Les exigences logistiques pour l'utilisation efficace des modèles végétaux dans le pays, sont également discutées.

Introduction

Ghana's agriculture is largely managed by resource-poor, peasant farmers with small holdings. Food crop production as carried out by these farmers is characterized by unreliable weather pattern and declining soil fertility. Additionally, financial constraints limit the use of vital resources such as water and fertilizers. Consequently, agricultural productivity and food security are proving difficult to sustain over a long period in this environment. In view of these, an effective means of improving and sustaining food crop production in the country will require that production be based on improved management strategies that can result in better use of the available resources. For example, selecting the appropriate crop to match the total amount and pattern of seasonal rainfall, and managing efficiently available resources are potential avenues through which crop production under rainfed conditions can be improved in Ghana.

Crop models simulate the growth, development, and productivity of crops as a function of weather, soil, and resource input management strategies. Therefore, they are valuable tools for the analysis of agricultural systems (Probert *et al.*, 1998) and for better crop management. Consequently, crop models have the potential to play an important role in providing the necessary direction for improving the productivity and sustainability of crop production, particularly under rainfed environment.

The objectives of this paper are to highlight the potentials of crop models for improving and sustaining crop productivity, and to identify logistic requirements for effective use of crop models in Ghana.

Crop models

Crop models currently available include the Decision Support System for Agrotechnology Transfer (DSSAT) (IBSNAT, 1989) and Agricultural Production Systems Simulator (APSIM) (McCown *et al.*, 1996). These models are physiologically based and comprise modules for different crops including cowpea/bean, groundnut, maize, millet, and sorghum. These are staple crops that are produced under rainfed conditions in Ghana. Both DSSAT and APSIM simulate growth, development, and productivity of crops at a daily time-step resolution. Other processes simulated by these models include moisture and nitrogen dynamics in soils, while APSIM also simulates the soil erosion process. These models can be used to complement strategies designed to improve and sustain the productivity of staple crops in Ghana.

Potential uses of crop models

Crop models are developed to provide better understanding of the interactive effects of soil, crop, weather, and management factors on the growth and productivity of crops (McCown *et al.*, 1996). Consequently, they have potential use in several key areas.

Strategy evaluation

Several workers have acknowledged the usefulness of crop models for evaluating strategies for managing scarce resources and for adopting appropriate practices to improve crop productivity in a sustainable manner. Typical areas for strategy evaluation include the evaluation of planting or sowing date (Swaney *et al.*, 1983; Egli & Bruening, 1992; Asare *et al.*, 1992; Vanderlip, Hammer & Muchow, 1996), and the scheduling and management of irrigation and fertilizer application (Sinclair, Muchow & Monteith, 1997) to identify the most promising and least risky management practices for the most efficient use of resources and high crop productivity. In rainfed agriculture, as practised in Ghana, crop models can be used to evaluate different planting or sowing dates to identify the best opportune time to plant or sow for effective use of store soil water and seasonal rainfall. How much supplemental nutrients and water to apply, when to apply them, and the maintenance of a balance among inputs also have to be addressed for sustainable and high crop productivity.

Crop models can also be used to evaluate crop yield response to graded levels of fertilizers in different agro-ecological zones in Ghana to establish the fertilizer levels and fertilizer scheduling strategy that could result in optimum crop yield and economic returns.

Farmers' management practices can also be evaluated with crop models. For instance, they can be used to assess whether crop yields of farmers differ significantly from those under improved practices. The evaluation process provides an avenue for the critical analysis of farmers' practices to identify key areas needing attention for improving the productivity at the farm level. In addition, crop models linked with long-term historical weather data can be used to assess benefits and risks associated with different management strategies. This approach could be used to assess the effectiveness of the current management strategy in relation to others, and the subsequent adoption of appropriate management practice to suit the prevailing environmental conditions.

Experimental tool

Simulation modelling has become an important tool for researchers to study complex agricultural systems (Timlin, Pachepsky & Acock, 1996). Specifically, crop models can be used to complement and explain field experiments (Elwell, Curry & Keener, 1987; McCree, Fernandez & Ferraz de Oliveira, 1990), in which case the models are used to investigate which plant characteristics, soil, management, or environmental processes are responsible for the observed crop response. Consequently, crop models can serve as an experimental tool to understand the complex rainfed agriculture mostly practised by Ghanaian farmers. Thus, the models can be used to identify possible causes of observed phenomena on the experimental plots or farmers' fields.

Crop models can also be used to interpret results of long-term field research and identify key constraints of agricultural production systems. The models can typically be used to evaluate the contribution of seasonal weather variations to the year-to-year variation in crop yield (Acock & Acock, 1991). Hypothesis can subsequently be developed to test the possible causes of the yield variation and then verified by using model simulations. This approach was used by Reddy & Baker (1990) to show that the continuous yield decline of cotton in USA over a 20-year period was unrelated to the weather deterioration but to changing soil conditions.

The advantage of using crop models to evaluate and plan field experiments is that results that are difficult or time consuming to obtain experimentally on the field can be produced in a relatively short time (Whistler *et al.*, 1986; McCree *et al.*, 1990). Additionally, the approach has the potential of isolating important research areas for field experimentation, thereby reducing costs associated with several field experiments and shortening the time for obtaining research results.

Potential crop productivity estimation

Knowledge about the potential productivity of major crops will provide an avenue for determining the gap between the observed and potential yield across agro-ecological zones. Management practices can, subsequently, be designed to bridge this gap. Generally, time and resource constraints do not allow potential crop productivity to be estimated from field experiments. However, a crop model can conveniently be used for this purpose. This approach has been used by Meinke & Hammer (1995a) for estimating regional production potential of groundnut.

Linking crop models with long-term historical weather data provides an avenue for estimating climatic risk associated with crop production in a region. Such an approach has been used to evaluate the risk associated with sorghum production in water-limited, subtropical environments in Australia (Hammer & Muchow, 1994), groundnut production in Australia (Meinke & Hammer, 1995b), and citrus and potato production in USA (Rosenweig *et al.*, 1996). Linking crop models with historical weather data can also be used to determine if actual crop productivity levels reflect the potential supported by the growing environment. In Ghana, the approach can be used to estimate yield variation and stability of crops as a measure of evaluating the sustainability of the crop production systems in the country. This should yield relevant data for policy makers and agricultural extension workers for sound decision making.

Logistic requirements

Weather and soil define the environment to which crops respond. Consequently, weather and soil data are vital inputs required by crop models to simulate the true response of crops to the environment. The effective use of crop models in Ghana, therefore, will depend on the availability of weather and soil input data and trained personnel in agricultural system modelling and model applications.

Weather data

Weather data required by crop modelling include daily values of maximum and minimum air temperatures, relative humidity, average wind speed, solar radiation, and the amount of rainfall for the crop-growing period (IBSNAT, 1989; McCown *et al.*, 1996). Such data must be collected at or as close to the site of interest as possible.

In Ghana, the Meteorological Services Department (MSD) is mandated to collect and keep in archives, records of climate/weather data collected countrywide. Individuals and organizations that require weather data may have to approach MSD if such data cannot be collected at the site of interest. Generally, MSD maintains Rainfall, Climatological, Agromet, and Synoptic Stations for collecting different sets of weather variables. Table 1 shows the network of different meteorological stations maintained by MSD countrywide.

The data collected at the different weather stations ranged from a single variable of daily rainfall at Rainfall Stations to about 10 variables at Synoptic Stations (Table 2). Even though Agromet and Synoptic Stations are the only stations which record weather data required for crop-modelling studies, they are relatively few and not extensively distributed in the country (Table 1).

For sites or locations where appropriate weather data are unavailable, either weather-generating models such as WEATHERMAN (Pickering *et al.*, 1994) and WGN (Richardson & Wright, 1984) could be used to obtain the required data, or data for nearby sites may be used. Even though rainfall is invariably one of the major determinants of crop productivity, especially in rainfed crop production systems, it varies greatly over short distances. Therefore, rainfall data produced by weather-generating models can deviate considerably from actual data. The use of such data in crop-modelling studies could lead to erroneous model predictions. Therefore, it is suggested that rainfall data must be collected at the site of interest.

Soil data

Soil is a reservoir for water and nutrients which are made available for crop use during the cropping season. Consequently, the soil at the site of interest has to be characterized by its water and nutrient status and supply potential. Typical soil data required by most crop models include field capacity, permanent wilting point of the crop, hydraulic conductivity, soil bulk density, saturated soil water content, soil profile depth, thickness of major soil horizons, organic matter or

TABLE 1

Network of Different Meteorological Stations Maintained by the Meteorological Services Department in Ghana

Regions	*Types of station*									
	Rainfall		*Climatological*		*Agromet*		*Synoptic*		*Total*	
	[1]*EXTG*	[2]*FUNC*	*1*	*2*	*1*	*2*	*1*	*2*	*1*	*2*
Ashanti	45	42	9	7	5	5	1	1	60	35
Brong-Ahafo	42	18	5	4	4	4	2	2	53	28
Central	44	5	11	6	7	7	1	1	63	19
Eastern	72	19	20	13	10	9	4	4	106	45
Greater Accra	31	13	2	0	7	4	3	3	43	20
Northern	43	12	5	3	4	3	3	3	55	21
Upper-East	25	4	1	0	7	7	1	1	34	12
Upper-West	21	11	0	0	1	1	1	1	23	13
Volta	96	9	9	8	7	5	3	3	115	25
Western	49	7	16	11	3	3	3	3	71	24
Total	468	120	78	52	55	48	22	22	623	242

Source: Meteorological Services Department, Ghana (November, 1999)
[1] Stations already existing, but not necessarily functioning
[2] Stations are functioning

TABLE 2

Weather Variables Measured at the Different Weather Stations Maintained by the Meteorological Services Department in Ghana

Rainfall station	*Climatological station*	*Agromet station*	*Synoptic station*
Rainfall amount	Rainfall amount	Rainfall amount	Rainfall amount
	+ Max. air temperature	+ Max. air temperature	+ Max. air temperature
	✞ Min. air temperature	✞ Min. air temperature	✞ Min. air temperature
	Dry bulb temperature	Dry bulb temperature	Dry bulb temperature
	Wet bulb temperature	Wet bulb temperature	Wet bulb temperature
		++ Rainfall intensity	++ Rainfall intensity
		++ Rainfall duration	++ Rainfall duration
		++ Pan evaporation	++ Pan evaporation
		Sunshine hours	Sunshine hours
		*Soil temperature	*Soil temperature
		**Wind speed	**Wind speed
		***Wind speed	***Wind speed
		[a]Ambient air temperature	[a]Ambient air temperature
		Relative humidity	Relative humidity
		Atmospheric pressure	Atmospheric pressure

Source: Meteorological Services Department, Ghana (November, 1999)
+ Daily maximum ambient air temperature
✞ Daily minimum ambient air temperature
++ Measured at selected stations
* Soil temperature measured at 5, 10, 20 and 30 cm soil depths
** Wind speed measured at 2 m above soil surface
*** Wind speed measured at 10 m above soil surface
[a]Ambient air temperature

organic carbon content in each of the soil horizons (IBSNAT, 1989; McCown *et al.*, 1996). Additionally, residual soil water and nutrient at planting for each of the soil horizons are required.

The Faculties/Schools of Agriculture of the universities and the Soil Research Institute of the Council for Scientific and Industrial Research (CSIR) in Ghana have some records on soils in the country. These institutions may be approached for data on soils or their services sought to characterize soils in Ghana.

Trained personnel

Agricultural system modelling is an interdisciplinary endeavour. Trained personnel are required from disciplines such as soil science, crop breeding, crop physiology, agronomy, economics, agro-climatology/climatology, and computer programming. Some of the trained personnel will undertake model set up and develop protocols for estimating input parameters for the model calibration process. For example, a climatologist will develop protocols for using weather-generating models to predict reliable weather data for sites with no capacity to record measured weather data, whilst some of the trained personnel will incorporate needed changes in the crop models to reflect local conditions.

Universities and research institutions such as the Biotechnology and Nuclear Agriculture Research Institute of the Ghana Atomic Energy Commission, the Crops Research Institute and the Soil Research Institute of the CSIR in Ghana have trained personnel in various fields in agriculture whose expertise could be harnessed to develop crop-modelling work in Ghana. There is a clear need to constitute a team comprising researchers from these institutions. Training courses may be required to re-orient and equip these researchers in crop-modelling studies, and to develop protocols for incorporating crop-modelling studies in strategies designed to enhance and sustain crop production in Ghana.

Conclusion

Crop production is a dynamic process which is affected by several factors such as management strategies, availability of resource inputs, seasonal weather patterns, and soil properties. Crop models can be used to enhance food production in Ghana, as they integrate the effects of management factors, weather and soil characteristics on the productivity of crops. Specifically, these models can provide research direction, assist in guiding decision making, and identify crop production constraints. They can also be used to develop management strategies for efficient use of resource inputs to enhance crop production.

As crop modelling is an interdisciplinary endeavour, the effective use of crop models in Ghana will depend on trained personnel in fields such as soil science, crop science, agronomy, agro-climatology/climatology, computer science, and economics. Even though the required manpower is available at the universities and research organizations in the country, it is imperative to form an agricultural modelling group. The objectives here are to equip the group to develop the following: effective modelling strategies that are suitable for the country's need, protocols for appropriate weather and soil input data collection, and protocols for incorporating crop modelling in national programmes designed to enhance and sustain food security in Ghana.

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