African Crop Science Conference Proceedings, Vol. 11. pp. 943 - 954
Printed in Uganda. All rights reserved
ISSN 1023-070X/2013 $ 4.00

Maize cultivar specific parameters for Decision Support System for Agrotechnology Transfer System (DSSAT) application in Tanzania

S.K. MOURICE[1], C.L. RWEYEMAMU[1], S.D. TUMBO[1] & N. AMURI[1]
[1]Sokoine university of Agriculture, P. O. Box 3005, Morogoro, Tanzania
Corresponding author: siza.tumbo@gmail.com

Abstract In order to develop basis for tactical or strategic decision making towards agricultural productivity improvement in Tanzania, a new approach in which crop models could be used is required. Since most crop models have been developed elsewhere, their adaptation, improvement and/or use outside their domain of development requires a great deal of data for estimating model parameters to allow their use. Cultivar specific parameters for maize varieties in Tanzania have not been determined before and consequently, crop modelling approaches to address biophysical resource management challenges have not been effective. An overall objective of this study was to evaluate DSSAT (v4.5) Cropping System Model (CSM) using four adapted maize cultivars namely *Stuka*, *Staha*, *TMV1* and Pioneer HB3253. The specific objectives were; to determine maize crop growth and development indices under optimum conditions, to estimate maize cultivar parameters, and to evaluate DSSAT CSM for simulating maize growth under varied nitrogen fertilizer management scenarios. The results indicate that maize cultivars did not differ significantly in terms of the number of days to anthesis, maturity, or grain weight except final aboveground biomass. Also there was no difference between variables with respect to growing seasons. The cultivar specific parameters obtained were within the range of published values in the literature. Model evaluation results indicate that using the estimated cultivar coefficients, the model simulated well the effects of varying nitrogen management as indicated by the agreement index (*d*-statistic) closer to unity. Also, the cultivar coefficients which are difficult to measure physically were sensitive to being varied indicating that the estimated values were reasonably good. Therefore, it can be conclude that model calibration and evaluation was satisfactory within the limits of test conditions, and that the model fitted with cultivar specific parameters that can be used in simulation studies for research, farm management or decision making.

Key words: CERES-Maize, crop system model, , Morogoro, nitrogen, phenology

Introduction

Crop models are mathematical representation of the current understanding of biophysical crop processes and of crop responses to environment (van Ittersum & Donnateli, 2003). Crop models have been developed and used worldwide as operational or strategic research and decision support tools in crop production or resources management. For example, in the Netherlands, average farmers' wheat yield were below 5 t ha^{-1} in 1960's while the crop had a predicted potential yield of 10 t ha^{-1}. By 1993, the yields had exceeded 9 t ha^{-1} (van Ittersum *et al*., 2013). Crop models are also being used to evaluate the impact of climate change on crop production as a result of increased green-house gases (Rosenzweig & Liverman, 1992; White *et al*., 2011). In resource management optimisation, crop models have played important role. Mupangwa *et al*. (2011) used APSIM to understand long term effects of conservation agriculture on the productivity of smallholder systems in Zimbabwe.

Tanzania has had several initiatives geared towards agricultural intensification country-wide, dating back to independence times (e.g. *siasa ni kilimo*, (of 1972), "*kilimo cha kufa na kupona*" (of 1974/75) and recent *Kilimo Kwanza* (*of* 2010), which have had little or no impact in as far agricultural productivity is concerned. For instance, maize which is the most important staple grain in Tanzania, grown on 44% of total cultivated area and accounting for 62% of total cereal production (Ministry of Agriculture Food Security and Cooperatives-MAFSC, 2013) have seen its yields declining (FAOSTAT, 2012), despite the fact that area under maize cultivation has on average been increasing, at an average rate of 8 percent per year for the past 20 years. Generally, maize yields are very low, averaging 1.2 t ha^{-1} (MAFSC, 2013), suggesting that maize production has not matched with population growth as evidenced by a surge in maize grain imports (FAOSTAT, 2012) to address the deficit.

To be able to develop basis for tactical or strategic decision making to improve agricultural productivity in Tanzania, a new approach in which crop models could be used is required.

To date, there have been some efforts in evaluating or adapting some dynamic crop models in Tanzania. However, the progress has been slow. Since most models have been developed elsewhere in Europe and USA, their use outside their domain of development requires a great deal of data for their calibration and validation, which is not readily available or difficult to obtain. The most important aspects in evaluating crop models include determination of cultivar specific parameters or coefficients (Hunt & Boote, 1998). Cultivar coefficients for maize varieties in Tanzania are not known and are not included in the cultivar database of DSSAT version 4.5 (Hoogenboom *et al*., 2010). As a result, it is difficult to understand underlying processes that impact on crop yield, and therefore, it is inefficient in designing appropriate strategies to improve crop productivity as well as efficient resource use. Previous studies using crop models have succumbed to serious shortfalls due to lack of crop cultivar parameters and either opted for generic models or used surrogate maize cultivars, the result of which would be more uncertainty in the results. Mwandosya *et al*. (1998) reported countrywide maize yield decline by 33% should temperature rise between 2 - 4°C due to climate change. The setback encountered in their study was that the maize cultivar used in CERES-Maize simulations had few data to warrant its sufficient calibration, thus chances for erroneous output. Lack of crop cultivars whose genetic parameters are known, has led IFPRI (2010) to using surrogate crop cultivars for rice, wheat and maize in predicting yields under the influence of climate change at continental scale for Africa. Moreover, generic models which need few crop data, for example CLICROP, haev also been used in Tanzania for climate change studies (Arndt *et al*., 2011). Model predictions would have been greatly improved had there been sufficient information over crop cultivar coefficients.

Several approaches for estimating cultivar coefficients have been documented. However, these approaches require key information regarding a particular crop cultivar such as planting dates, anthesis and physiological maturity dates and final grain yield, which in most cases are not available. Anothai *et al*. (2008) used genetic coefficient calculator (GENECALC) which is a sub module in the Decision Support System for Agrotechnology Transfer (DSSAT v4.5) to determine cultivar coefficients for new peanut lines in Thailand from standard varietal trials. Bannayan & Hoogenboom (2009) employed pattern recognition technique, which is based on similarity measures to estimate crop cultivar coefficients for maize. He *et al*. (2010) used generalized likelihood uncertainty estimation (GLUE) method to estimate maize cultivar coefficients. Also DSSAT v4.5 has GLUE module for estimating crop cultivar coefficients. All of the above mentioned approaches to estimate crop cultivar coefficients for use in dynamic crop models need some degree of information on a particular cultivar. Therefore, in situations where there is paucity of data from standard variety trials or other dedicated experiments, repeated field experimentations would be the only option.

Accurate estimation of crop cultivar coefficients is the entry point into dynamic crop model use (for research as well as decision making) and improvement for identification and consequently narrowing gaps in our knowledge over crops and biophysical aspects for improved agricultural productivity. Calibrated crop models with cultivar parameters can be used to optimise crop management (e.g. MacCarthy *et al*., 2012), to evaluate the impacts of climate change (Jones & Thornton, 2003), develop options to optimise resource use (e.g. Mupangwa *et al*., 2011) or to develop new crop genotypes (Craufurd *et al*., 2013).

Since maize cultivar coefficients for use in DSSAT CSM have not been investigated under Tanzanian environment, an overall objective of this work was to quantify the maize cultivar coefficients for four maize cultivars adapted to the basin. Specific objectives were i) to determine maize crop growth and development indices under optimum conditions (ii) to estimate maize cultivar parameters and calibrate DSSAT CSM using the same, and (iii) to evaluate DSSAT CSM for simulating maize growth and yield under WRB conditions.

Materials and methods

The study site was within Morogoro region, characterised by a unimodal rainfall pattern between the months of March and June. The site receives annual precipitation of 850 mm (of which 65-75% fall between March and June) and an average daily temperature of 24°C. The soils of the study site are characterised as isohyperthermic, Ultic Haplustalfs, with good natural drainage, a slope of between 1-2% and a clayey texture.

CERES CSM description. CERES (Crop–Environment–Resource– Synthesis) - Maize module (Jones & Kiniry, 1986) within the DSSAT v (4.5) requires minimum data sets (MDS) (Hunt & Boote, 1998) to compute daily growth of vegetative and reproductive components as a function of daily photosynthesis, growth stage, and water and nitrogen stresses. A detailed account on MDS and data for evaluation of crop models has been documented elsewhere (e.g. Hunt & Boote, 1998; Jones *et al*., 2003; Hoogenboom *et al*., 2012). CERES-Maize requires a set of six cultivar specific parameter for its calibration (Table 1).

The model computes a complete daily soil water balance, and water is distributed through the soil based on a tipping bucket principle (Jones & Kiniry, 1986). Because soils are not homogeneous with depth, soil inputs are needed for several soil layers. Runoff is calculated using the USDA–Soil Conservation Service (SCS) curve number method. Drainage is computed based on the amount of water that exceeds the drained upper limit (DUL) for a layer, and how much water the next layer can hold. Perched water tables can be created by setting the saturated hydraulic conductivity (K_{sat}) in a deep soil layer

Table 1. Maize cultivar coefficients.

Coefficient	Unit	Definition
P1	°C day	Thermal time from seedling emergence to the end of the juvenile phase
P2	Days	Extent to which development (expressed as days) is delayed for each hour increase in photoperiod above the longest photoperiod at which development proceeds at a maximum rate (which is considered to be 12.5 h).
P5	°C days	Thermal time from silking to physiological maturity
G2	Number	Maximum possible number of kernels per plant.
G3	mg/day	Kernel filling rate during the linear grain filling stage and under optimum conditions
PHINT	°C day	Phyllochron interval; the interval in thermal time between successive leaf tip appearances

in the profile to a very small value. Root water uptake is calculated using a "law of limiting factors" approach in which the larger resistance, soil or root, determines the flow rate of water into roots. Daily increase in rooting depth is a function of soil temperature and is restricted by either excess or deficit soil water contents. A maximum depth increase per day is reduced under cool temperatures. In addition to this, when soil water content approaches the saturated limit, oxygen depletion reduces root growth into a layer. This allows a water table defined by a saturated layer to limit root growth. Soil hydrological properties namely drained upper limit (DUL) (m/m), drained lower limit (DLL) (m/m), soil water content at saturation (m/m), saturated hydraulic conductivity (KSAT) (cm/hr) and root growth factor (SRGF) were estimated using pedo-transfer functions. This approach was adopted because physical determination (measurement) of hydrological properties tried earlier by Rweyemamu (1995) within the same experimental site did not yield better results, than pedo-transfer functions did.

Field experiments for model calibration. Two field experiments were carried out at Sokoine University of Agriculture within the crop museum site (6°50'58"S and 37°39'56"E, 540 m above sea level) during 2011/2012 and 2012/2013 growing seasons. The soils of the study site are characterised as isohyperthermic, *Ultic Haplustalfs*, with good natural drainage, a slope of between 1-2% and a clayey texture. The site was previously planted to rice but at the time of the experiment, it was bare with little or no surface organic matter, dominated by slight sheet erosion. Four adapted maize cultivars; Pioneer Phb 3253, *Situka*, *Staha* and *TMV1* were selected for use in this experiment following a key-informants interview in Morogoro, Kilosa, Kongwa Kiteto and Kilindi districts. The respondents included District and Ward Agricultural Officers, farmers and Agro-Input Stockists. *Pioneer phb* 3253 is a full season hybrid cultivar with dented type of grain with yield potential ranging from 5 to 6.5 t ha^{-1}. It is a new introduction in Morogoro area by DUPONT Company from Zambia. *Situka* is an open pollinated cultivar (OPV) yielding between 4.0-6.0 t ha^{-1}. *TMV1* is also an OPV with yield potential of 4.0 t ha^{-1} while *Staha* yields between 4-5 t ha^{-1} (MAFSC, 2012). Plant population for each cultivar was 44000 plants/ha. The maize cultivars were planted in a completely randomised block design with three replications. Sowing was done on March, 07 for the 2011/2012 season and on similar date for the 2012/2013 season. In both growing seasons, each plot had 5 rows, with 10 plants each. Diammonium phosphate (DAP) fertilizer was applied during planting to supply 25 kg P ha^{-1} and 40 kg/ N ha^{-1}, placed at approximately seven centimeters below the soil surface and covered and compacted with a soil layer, above which three seeds were placed to make a seeding depth of 2-3 cm. Another round of N fertilisation was done by applying 40 Kg N ha^{-1} as urea at 45^{th} day after planting. Sowing was done following 43 mm of precipitation at the site in the first season when the soil was at near field capacity, while sowing was done in dry soil in the second season, followed by fallow irrigation till rains started. Gap filling was done immediately after 90% of the plants had emerged. Thinning was done after the third true leaf had emerged to leave one plant per hill. Supplemental irrigation water was applied in the event that there was no rain for three consecutive days. Standard agronomic practices were followed including weed and insect control.

Data collection

Soil characterisation. Soil samples from the site were obtained one week before planting at an interval of 15 cm to a depth of 120 cm for gravimetric water determination and mineral N analysis. Additional soil information was obtained from a report by Balthazar & Msita (2009) (unpublished) (Table 2).

Soil from each corresponding layer was immediately mixed thoroughly and composited in the laboratory and weighed. Composited samples were oven dried at 105°C till no weight change. Gravimetric soil moisture content determination was done as per procedure described by Motsara & Roy (2008).

Soil samples from each layer for mineral Nitrogen (Ammonia and Nitrate N) were immediately stored in the cool box. Soil samples for corresponding soil layers were composited in the laboratory and immediately prepared for analysis. The inorganic nitrogen was extracted using 0.01M calcium chloride solution at 20°C for two hours. Nitrate and Ammonium N was determined colorimetrically and quantified in ìgg^{-1} as per procedure described by Wilke, (2005).

Weather information. Daily weather data for both growing seasons, including precipitation (mm), minimum/maximum air temperature (°C), and global solar radiation (W/m^2) were collected using sensors mounted onto automated data loggers (Umwelt - Geräte – Technik, GmbH, Müncheberg, Germany) installed at the experimental site. The amount of weather information was in line with minimum data sets requirement by the DSSAT CSM (Hunt & Boote, 1998)

Phenology. Crop growth and development was evaluated by observing phenological events and recording the length of time in terms of number of days for a particular phenological event to occurl. Eight central plants from each cultivar (plot) in each replication were tagged with red oil paint for observation of phenological stages. End of juvenile stage was determined through destructive sampling by dissecting the plants and observing the apical meristem using a stereo dissection microscope for any development of floral buds at the 2-3 days interval starting from the 10^{th} day after emergence. The end of juvenile stage was recorded when the male flowers were visible under the microscope in two thirds of plants examined. Days to 50% tasseling was recorded when tassels were noticed on 50 percent of the tagged plants. For observation of the physiological maturity, grains were removed from the base, middle and distal end of each marked ear, at an interval of 2-3 days after browning of the husks had started. Days to physiological maturity was recorded when 50%

Table 2. General soil physical and chemical characteristics of the study site, SUA crop Museum.

Depth (cm) / variable	0-30	30-55	55-77	77-100	100-130	130-190+
Horizon	Ap	Bt1	Bt2	Bt3	Bt4	Bt5
Clay %	47	61	61	67	71	69
Silt %	9	9	11	9	9	7
Texture class[1]	C	C	C	C	C	C
pH $_{H2O}$	5.63	5.21	5.47	5.58	5.34	5.19
Organic Carbon (%)	1.4	0.9	0.83	0.73	0.67	0.6
Avail. P mg kg^{-1} (Bray)	5.74	4.33	4.8	4.91	9.5	3.96
CEC NH_4OAc (cmol(+)kg^{-1})	16.6	17.4	16.6	17.6	16.2	17
Exch. Ca (cmol(+)kg^{-1})	4.31	3.83	2.76	2.17	1.74	1.14
Exch. Mg (cmol(+)kg^{-1})	2.99	3.42	4.22	4.9	4.59	2.94
Exch. K (cmol(+)kg^{-1})	0.62	0.12	0.09	0.06	0.05	0.04
Exch. Na (cmol(+)kg^{-1})	0.28	0.32	0.31	0.37	0.40	0.61

[1]C = Clay.

of the grains in each ear had formed a black layer (Daynard & Duncan, 1969), indicating that no further accumulation of assimilates was possible.

Plant growth analysis. The total number of leaves was recorded at tasseling. To ensure accuracy on data of total leaf number, a fifth leaf of eight plants per plot per replication was marked with permanent red paint before the cotyledons (primary leaves) had senesced. Leaf area was calculated by multiplying the leaf length (L) (measured from leaf tip to the point of attachment to the collar), leaf width (W) (at the widest point) and by a factor of 0.75

$$LA = L \times W \times 0.75$$

To determine plant biomass, four samplings were conducted during vegetative, anthesis, grain filling and physiological maturity stages, where four plants within a one-meter strip in a row were cut at the ground level (Ogoshi *et al*., 1999). Leaves were separated from the stem, chopped and dried in the shade for three days. Both stems and leaves were separately oven dried at 70°C for 36-48 hours until the sample had attained constant weight.

Yield and yield components. A subsample of six plants was selected in which case the plant components were separated into stover husks and ears. Because leaf senescence had progressed, the leaf blades were not separated from individual stems. Plant samples were oven dried at 70°C over varying durations (depending on the component) till there was no further weight change. The variables that were determined include the number of seed per unit area (seed no. m-^{2}), seed weight (dry, gm-^{2}) cob weight (dry, gm-^{2}) husks weight (g m-^{2}) and stover weight (dry, g m-^{2}). Procedures and formulae described by Ogoshi *et al.* (1999) were adopted to collect data on yield components and final yield.

Experiment for model evaluation. Four maize cultivars and three nitrogen treatments were laid out in a completely randomised block design experiment under a 4x3 factorial structure with three replicates in the 2012/2013 growing season at Sokoine University of Agriculture crop museum. The site had been earlier grown to maize crop under irrigation. Soil samples were collected five days before sowing at a depth of 35 cm for important chemical and physical characterisation (Table 3).

Maize varieties namely *Staha, Situka TMV1* and *Pioneer* were tested under three nitrogen levels (0, 15 and 80 kg N ha^{-1}) under rainfed conditions. Planting was done on 8th March 2013. For the 15kg N ha^{-1} treatment, DAP fertilizer was applied once after crop establishment, 28 days after sowing (DAS) whereas for the 80 Kg N ha^{-1} treatment, N fertilizer was applied in two rounds, the first one during planting to supply 40 Kg N ha^{-1} (as Di-Ammonium Phosphate -DAP) and the second round at 45 DAS as Urea, to supply the remaining 40 kg N ha^{-1}. Phosphorus was supplied as triple super phosphate (TSP) at a rate of 40 kg P ha^{-1}. Other management practices were carried out accordingly. No nitrogen was added in a control treatment. Number of days to anthesis, number of days to physiological maturity, 50% anthesis, grain filling and physiological maturity information were collected. Moreover, grain yield and total plant biomass was measured at physiological maturity.

Model calibration. Model calibration procedures were as described by Hoogenboom *et al*. (2010). Soil files, Weather files and experimental files were created using data measured from experimental sites (Jones *et al.,* 1994; Wilkens, 2004; Uryasev *et al*., 2004). Simulation controls of the DSSAT CSM to simulate water and nitrogen balance and other crop management options were handled as described by Hoogenboom *et al*., 2010). In this study, water and nitrogen balance simulations were switched off, based on assumptions that these were sufficiently supplied in the course of experimentation. The United Republic of Tanzania (URT, 1993) recommends that 80 kg N ha^{-1} to be the optimum for economic maize production with the site of the study, hence this rate was adopted in this study. Supplemental irrigation was applied whenever there was three consecutive days without rain. Also, insect pests and diseases option was switched-off since they were all sufficiently controlled. Proxy cultivars were created within the genetic file (MZCER045.CUL) of the DSSAT-CSM initially using cultivar coefficients for *Katumani*

Table 3. Chemical and physical properties at the site for model evaluation experiment.

Depth	Organic carbon (%)	Total N(%)	pH (H2O)	P (Bray 1)(mg kg^{-1})	Exchangeable Potassium (cmol kg^{-1})
0-10	1.8	1.2	5.70	13.6	0.8
10-25	1.6	0.9	5.63	9.2	0.2
25-35	0.8	0.8	5.6	4.8	0.1

cultivar after which adjustments were iteratively done observed values were closer to simulated values for all variables, by minimising the root mean square error (RMSE) (Wallach, 2006):

$$RMSE = \sqrt{\frac{1}{N}\sum\left(\hat{Y}_i - Y_i\right)^2}$$

Where $\hat{Y}_i$ and Y_i are, respectively, the simulated and observed values and N is the number of observations. The variables over which iterations were done include days to 50% anthesis, days to 50% physiological maturity, leaf area, grain yield (kg ha^{-1}), by-product weight (kg ha^{-1}) and total above ground biomass (kg ha^{-1}).

Model evaluation. Model performance was evaluated by comparing the simulated vis-à-vis observed values where an agreement index or d-statistic (Wilmott, 1981) was used.
,

$$d = 1 - \left[\frac{\sum_{i=1}^{n}\left(\hat{Y}_i - Y_i\right)\left(\hat{Y}_i - Y_i\right)}{\sum_{i=1}^{n}\left(\left|\hat{Y}_i - \overline{Y_i}\right| + \left|Y_i - \overline{Y_i}\right|\right)}\right]$$

Where $\hat{Y}_i$, Y_i and $\overline{Y_i}$ are, respectively, the simulated, observed and mean of the observed values and n is the number of observations. For good agreement between model simulations and observations, *d*-statistics should approach unity.

Sensitivity analysis. Sensitivity analysis was performed to evaluate the influence of the cultivar parameters variation on model response with respect to number of days to anthesis, number of days to maturity, grain yield and by-product biomass. Parameters tested include P1, P3 and PHINT. The basis for choice of these crop parameters was the difficulty inherent in their physical measurements in the field, hence their uncertainties in the model. One cultivar parameter was tested at a time while others were fixed at their normal values. For each cultivar parameter, the values were reduced and also increased by 5 and 10 per cent from their normal values.

Statistical analyses. Analysis of variance to evaluate the varieties growth and development and the effects of nitrogen levels and varieties on growth and yield was done. Test of significance between the 2011/2012 and 2012/2013 experiments and simulated and measured quantities was done using a paired t-test. Analysis of variance (ANOVA) for evaluation experiment was performed using GENSTAT (v. 15) software (VSN international Ltd., Hempstead, England) whereas paired t-test was performed using Microsoft Excels' Data analysis Tool Pack (Microsoft Corporation, Redmond, Washington, USA).

Results and discussion

Weather conditions and soils. There was more precipitation during 2012 season than 2013 season, although the rains were not statistically different (P=0.12) (Fig. 1). In the 2012, sowing was done when the soil was wet; unlike in the 2013 season when sowing took place in dry soil. Moreover, during the 2012, dry spells were experienced (between 10th and 30th day after sowing) before crop establishment in which case supplemental irrigation was applied. During the 2013 season, a dry spell was experienced towards the middle of the season just during silking and grain filling, so supplemental irrigation was implemented.

Seasonal temperature and hence degree days between 2012 and 2013 seasons were not statistically different (P<0.05) (Fig. 2). However, total heat units received during 2013 season were slightly higher than those in the 2012 season.

Regarding net solar radiation for the 2012 and 2013 growing seasons, pairwise t-test showed there was no significant difference (P = 0.1) with respect to solar energy received (Fig. 3). Although there was no significant difference in weather elements between the two seasons, it was still important to test calibrate the model using two seasons since even the slightest difference matters for sound model calibration.

Soils within the study sites are highly weathered containing highly weathered clays and highly acidic. Special management including drainage during heavy downpour or irrigation during dry spell was important due to higher clay contents. Due to acidity, phosphorus fixation was expected, hence phosphorus fertilizers were added.

Crop growth and development

Duration for major phenological events. Although there was significant difference (P<0.05) between varieties with respect to number of days to emergence and 50% anthesis, these phenological events did not differ significantly (P<0.05) between 2012 and 2013 seasons. Days to physiological maturity between the seasons differed significantly (P= 0.002), with 2013 season having more number of days to physiological maturity than the 2012 season. The reason to this may be the undetected stresses which occurred in 2013 but not in 2012 growing season. Although the experiments were conducted under assumptions of optimality, it is often difficult to remove completely all stresses under field conditions.

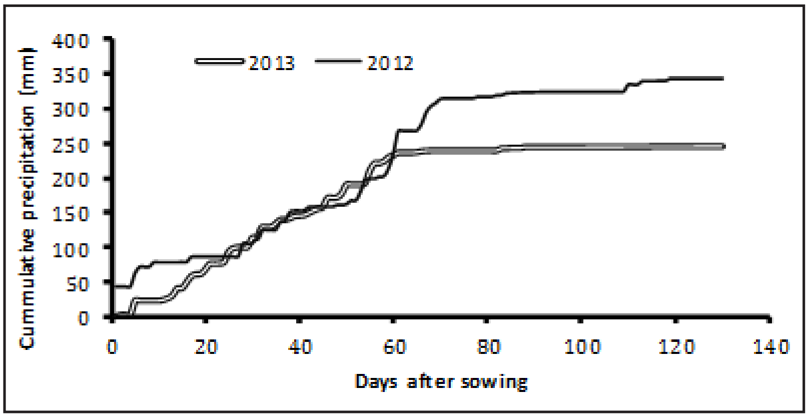

Figure 1. Cumulative quantities of precipitation for 2012 and 2013 seasons.

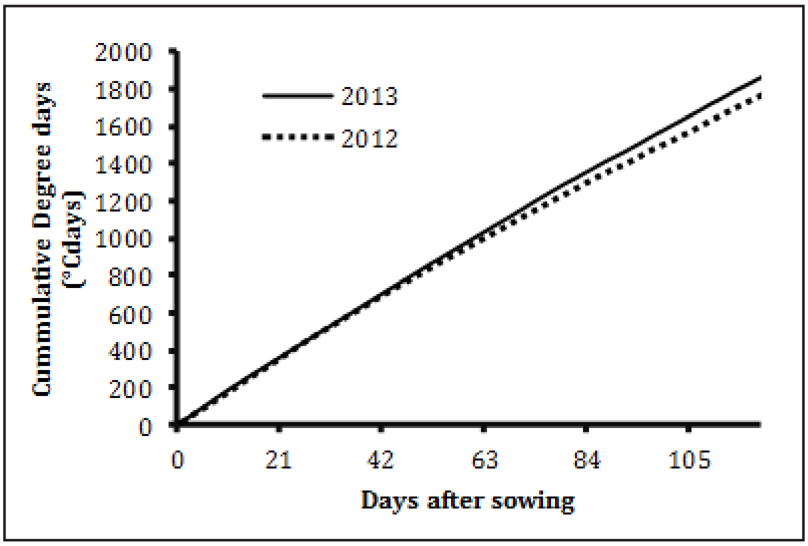

Figure 2. Cumulative thermal time for 2012 and 2013 growing seasons.

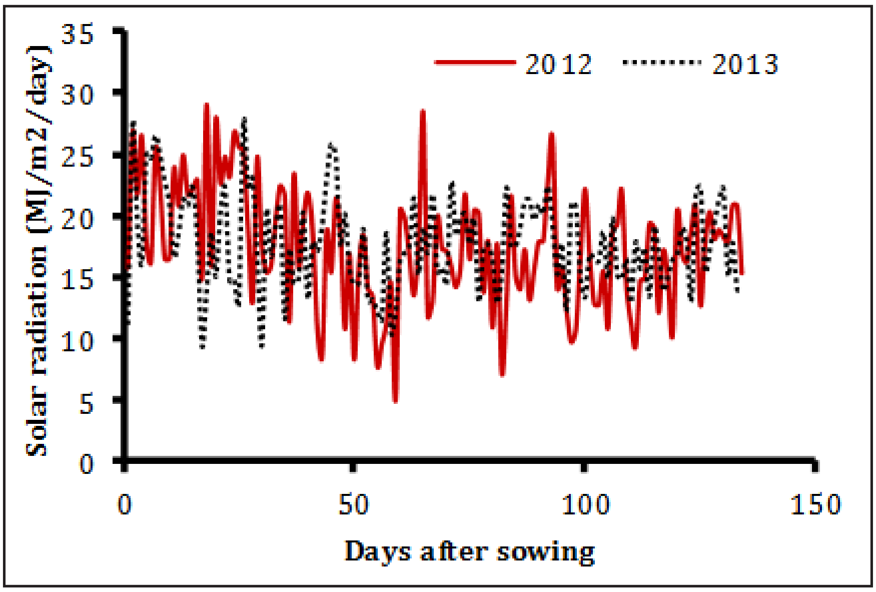

Figure 3. Net solar radiation for 2012 and 2013 growing seasons.

Biomass and yield. Except for the tops weight at physiological maturity which varied significantly ($P<0.05$) during 2012 season, all other variables in did not vary. Likewise, there was no significant variation among varieties in the 2013 season with respect to biomass and yield (Table 4). Also, there was no inter seasonal variation in the tested variables of plant biomass at 50% anthesis, grain yield and tops weight at harvest as indicated by the t-statistic (Table 4).

The equality in the parameters for the 2012 and 2013 growing seasons suggests that growing conditions of water, nutrient and other management were uniform across the seasons. For instance, the date of sowing for both seasons was the same, March, 08, and because weather elements were more or less similar in both years, then the similarity may be anticipated.

CERES maize calibration. Observed and simulated days to anthesis and physiological maturity, grain yield, by-product biomass and total above-ground biomass converged for all cultivars (Table 5), indicating that cultivar specific parameters within the model were reasonably adjusted. Also, there was a good relationship between observed and simulated variables such that r^2 values were 0.96, 0.98, 1.0, 0.99 and 0.99 for days to anthesis, days to physiological maturity, grain yield, by-product biomass and total above-ground biomass, respectively. *Stuka* showed high RMSE with respect to both the number of days to anthesis and physiological maturity than others. TMV1 had higher RMSE with respect to grain yield and tops weight by 29 and 11% of the measured yield, respectively.

The results indicate that S*taha* cultivar was high yielding and the yield is associated with the growth duration since it took longer than others to attain anthesis and physiological maturity.

Cultivar specific parameters. Results on cultivar specific parameters indicate that *Stuka* required few thermal units to complete juvenile stage (P1) while more thermal units were required for *Staha* to attain the same (Table 6). This allows *Staha* more time to accumulate photosynthates before silking, and hence higher yield in turn. *Stuka* which was originally bred for drought conditions indicates here that few heat units or short duration is just required to attain end of juvenile stage. This could be used as a drought escaping mechanism breeders had in mind. Although *Staha* seems to give higher yields compared to other cultivars, it may be prone to water stress in case the growing season is short due to dry spells towards the end.

TMV1 required few heat units from anthesis to physiological maturity (P5), unlike *Staha* with highest thermal time requirement. Number of grains/ear (G2) also was high in *Staha* and lower in Pioneer. This corresponds to differences in ear size between the two cultivars. The rate of grain development was high in *Stuka* as compared to other cultivars perhaps since this could be a drought avoidance mechanism for which this cultivar was developed. Phyllochron interval (PHINT) for the cultivars ranged from 30°Cdays for TMV1 to 47.25°Cdays for *Staha.*

There were no cultivar parameter values from the literature for comparing the values in this study. However, Tumbo *et al.* (2012) estimated some cultivar parameters for use in APSIM model. Thermal time to end of juvenile stage (P1) for *Stuka* was estimated to be 160°Cdays whereas P5 was estimated to be 800°Cdays. Difference between the values reported in this study and theirs could be that the parameters were merely estimated from little information or e.g. days to tasseling, days to maturity and range of possible grain yields obtainable from varietal catalogue by MAFSC (2009), since growing conditions of soils, weather and management are not specified. This is one of the setbacks to estimate cultivar coefficients for modeling application or improvement in Tanzania because, while yield information may exist, there are no records on planting dates, maturity dates, or total final biomass.

Model evaluation. The cultivar specific parameters obtained from experiments reported above were used to evaluate CERES-Maize CSM for simulating different nitrogen treatments under rainfed conditions. The model simulated well the average number of days to anthesis and maturity with high degree of agreement as indicated by the agreement index (*d*-statistics) (Table 7). This is an indication that the model calibration and resulting cultivar specific parameters were reasonably accurate. Generally there was significant differences ($P<0.05$) between observed and simulated quantities at all nitrogen treatments and in all variables.

Particularly, simulated yields increased consistently as N levels increased in both model simulations and experimental observations. This suggests that the CERES-Maize model is sensitive to environmental variables such as nutrient supply. Grain yield for all varieties may not have been as high as that obtained in the calibration experiment due to water stress since evaluation experiment was carried out under rain dependent conditions. Also, plants under high nitrogen supply tend to face water stress since they have large leaf area from which more water loss takes place than in plants under sub optimal nutrient supply. Moreover t-test revealed significant difference

Table 4. F values for the cultivars comparison and t-statistics for 2012 and 2013 seasons.

Variable	2012	2013	t-statistic
Biomass at 50% anthesis	0.99 ns	1.25 ns	0.64 ns
Grain yield at harvest	2.76 ns	1.75 ns	1.58 ns
Tops weight at physiological maturity	4.86*	2.44 ns	0.13 ns

*significant at $p<0.05$; ns = not significant.

($P<0.05$) between simulated and observed yields at all N levels (Table 8).

Sensitivity analysis. The model was sensitive in terms of the number days to 50% anthesis whenever the length of juvenile stage (P1) was varied, and the sensitivity was consistent to the direction of variation but with exceptions. Stuka and TMV1 cultivars were not sensitive to 5% increase in P1 (Fig. 4). This suggests probably that *Stuka* and *TMV1* have range of P1 which does not affect the days to attain 50% anthesis.

The model was sensitive for all maize cultivars tested to changes in heat units from flowering to physiological maturity (P5). The variation of the number of days to physiological maturity was consistent with the direction of P5 variation, being lower when P5 was reduced and vice versa (Fig. 5). Since P5 is associated with the crops ability to fully utilise environmental resources, at low P5, probably due to increased temperature, the number days to attain physiological maturity would decline. Conversely, when P5 increased due to low daily average temperatures, the number of days to physiological maturity increased.

In the same line, when the number of days to physiological maturity increases, the crop has more time to carry out photosynthetic processes and accumulate biomass; hence the yield would increase (Fig. 6). However, since the maize cultivars varied from one another with respect to change of P5, *Staha* would be more affected either way than other cultivars (Fig. 3). Thus, of the maize cultivars tested, *Staha* would gain up to more than 1000 kg ha^{-1} if it were grown under similar management but in medium altitudes where daily average temperatures are low. *Stuka*, *Staha* and *TMV1* are well adapted to wide range of altitudes (500-1500 m above sea level for *Stuka*, 0-900m for *Staha* and up to 1500 for *TMV1*) (MAFSC, 2013).

By-product biomass was sensitive to changes in Phyllochron (or the inverse of the rate of successive leaf tip appearance (Tollenaar and Lee, 2002) (PHINT), being higher at low PHINT and vice versa (Fig. 7). PHINT is critical in determining the duration of vegetative growth and in maize, it is lower in temperate but higher in tropical climate. Birch *et al.* (1998) reported that phyllochron is influenced by temperature, increased by 1.7°Cday per °C increase in daily mean temperature when daily mean temperature increased from 12.5 to 25°C prior to tassel initiation. From the results, it is apparent that by-product biomass was favoured by reduced phyllochron as a result of reduced daily mean temperature prior to tassel initiation. However, other environmental variables such as nitrogen (Hokmalipour, 2011) have been reported to affect the phyllochron. Furthermore, reduced phyllochron means that the crops' vegetative stages would take longer time and thus; accumulate more photosynthates than they would in increased phyllochron as is the case when plants are grown in high temperatures or other environmental stresses.

A ten per cent decrease in PHINT only resulted in yield increase for *Stuka* cultivar and as the parameter was set to 5% less, the yield increased significantly (Fig 8). For other cultivars, decreasing or increasing PHINT

Table 5. Comparison between simulated and observed values for four maize cultivars. Observed values are the average of two growing seasons and three replications for each cultivar.

Cultivar	Days to anthesis			Days to maturity			Grain yield (kg ha^{-1})			Byproduct (kg ha^{-1})			Tops weight (kg ha^{-1})		
	Obs.[‡]	Sim.[§]	RMSE	Obs.	Sim.	RMSE	Obs.	Sim.	RMSE	Obs.	Sim.	RMSE	Obs.	Sim.	RMSE
STUKA	57	58	8.6	105	106	8.5	6598	6604	86.67	7204	7416	211	13802	13978	200
STAHA	62	62	4.0	114	114	6.5	7712	7712	715	8040	8080	105	15752	15746	812
TMV1	60	60	3.5	108	108	0.0	6568	6579	1636	8612	8672	85	15180	15199	1701
Pioneer	58	58	7.0	107	107	0.5	6318	6321	231	7700	7770	95	14018	14046	171

‡Obs. = Observed values. §Sim. = Simulated values.

Table 6. Cultivar coefficients for the four maize varieties

Cultivar	P1 (°C)	P2 (day)	P5 (°C day)	G2 (#grains/ear)	G3 (mg/day)	PHINT (°C day)
STUKA	199.5	0.5	671.7	672.9	10.03	42.80
STAHA	230.5	0.5	735.0	700.0	8.80	47.25
TMV1	215.0	0.5	635.0	650.0	7.55	38.00
PIONEER	210.0	0.5	700.0	645.0	9.07	43.50

Table 7. Observed and simulated values for variables as affected by three nitrogen levels under rainfed conditions at Sokoine University of Agriculture site; Values in parentheses indicate standard deviation.

Variable name	Mean observed	Mean simulated	r-Square	RMSE	d-Stat.	Number of Obs.
Anthesis day	57 (2.4)	57 (2.2)	0.94	0.9	0.96	12
Byproduct (kg ha^{-1})	4391 (1756)	3828 (1904)	0.98	644.358	0.97	12
Tops weight (kg ha^{-1})	7225 (2974)	5952 (2993)	0.98	1324	0.95	12
Mat yield (kg ha^{-1})	2834 (1249)	2154 (1159)	0.95	735	0.91	12
Maturity day	104 (5.3)	104 (4.5)	0.91	1.5	0.98	12

Table 8. Simulated vs. observed grain yields at different nitrogen levels. Values in parentheses indicate standard deviation for the observed treatment effects.

Cultivar	Grain yield (kg ha^{-1})					
	N-0		N-15		N-80	
	Sim.	Obs.	Sim.	Obs.	Sim.	Obs.
STUKA	1235	1626 (288)	1879	2548 (409)	3999	4453 (502)
STAHA	1264	1814 (345)	1656	2275 (1016)	3856	4655 (759)
TMV1	839	1570 (426)	1214	1882 (155)	3064	4572 (455)
PIONEER	1151	1607 (354)	1732	2506 (428)	3956	4496 (428)

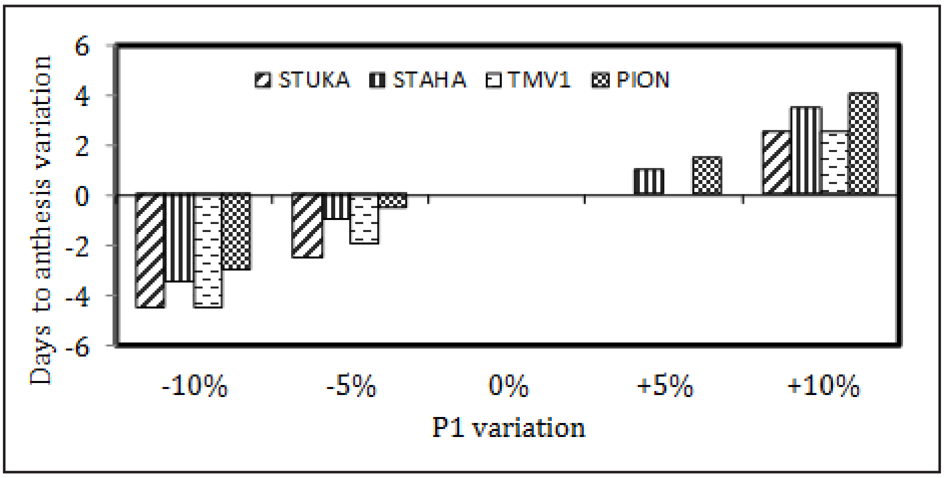

Figure 4. CERES-Maize CSM sensitivity analysis of days to 50% anthesis due to variation in P1 cultivar specific parameter.

resulted into reduced yields with significant variation among them. The variation among cultivars is probably due to the genetic differences, indicating that some cultivars such as Stuka can perform better in environments with aspects which reduce PHINT (increase rate of leaf appearance) than those which increase PHINT (reduce rate of leaf appearance). For TMV1, Pioneer with constraints that reduce or increase phyllochron at 5% PHINT increase, grain yield increased only slightly but decreased further when PHINT was increased by 10% (Fig. 5). Therefore, varieties such as TMV1 and Pioneer seem to have adapted range of environmental variables below

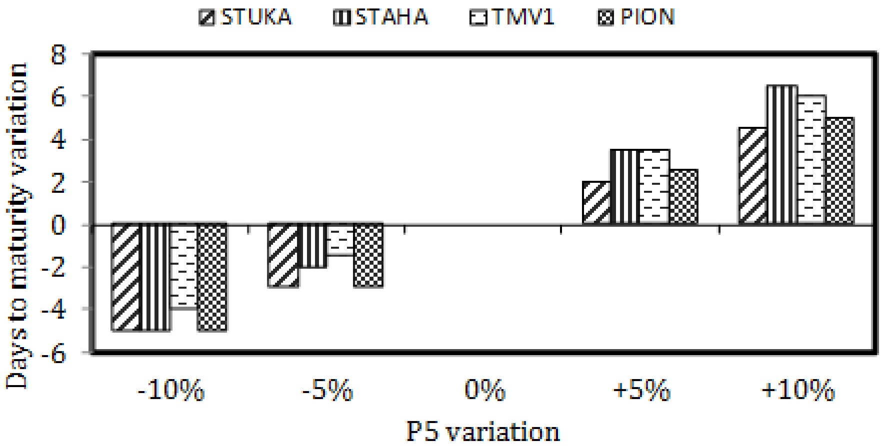

Figure 5. Variation of days to physiological maturity due to variation in P5 .

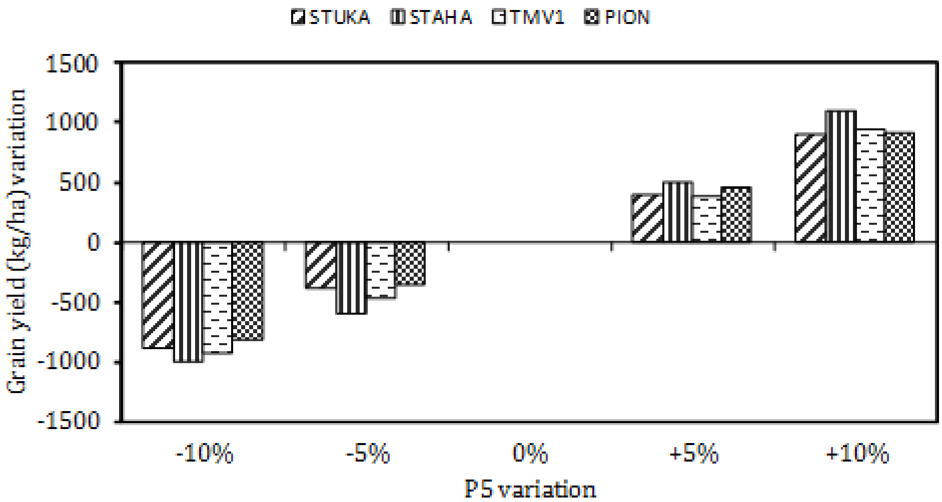

Figure 6. Variation of grain yield due to changes in P5.

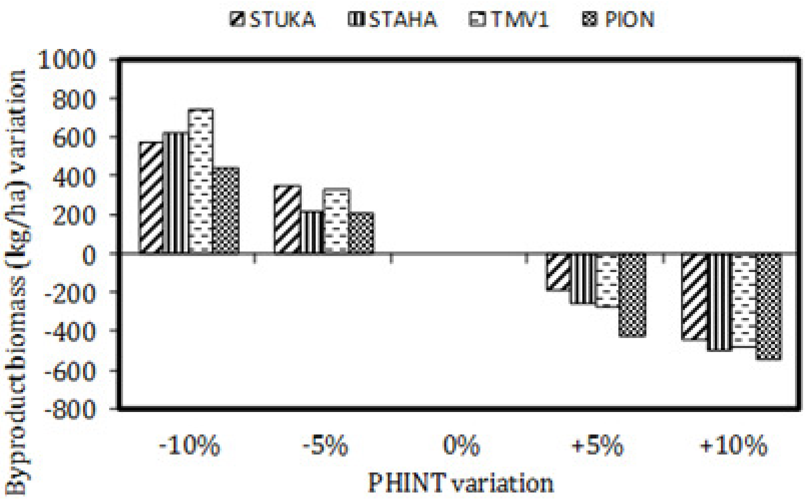

Figure 7. Changes in by-product biomass due to variation in PHINT.

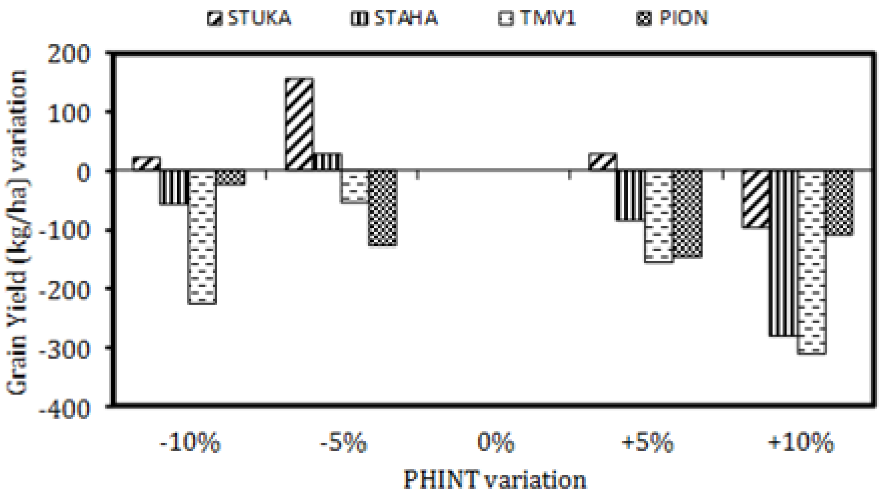

Figure 8. Changes in grain yield due to variation in PHINT.

or above which PHINT affects grain yield. The yield reduction was more pronounced when PHINT was increased by 10% from normal, implying that leaf appearance rate would be below permissible limits, leading to yield decline. This can be used to explain why crops grown under stressful conditions of water or nutrients give low yields. Generally, the model sensitivity may indicate that cultivars used in this study are adapted to environments which favour moderate leaf appearance rate, (not too cold where temperature reduces PHINT or too hot where higher temperature increases PHINT.

Conclusions

The cultivar specific coefficients estimated for CERES-Maize CSM were within the range of published parameters for tropical maize cultivars. The simulations made to test the acceptability of the parameters indicated good agreement between observed and simulated values for selected variables as exhibited by the d-statistics, therefore, the model simulations were reasonably close to observations. The model was sensitive to selected parameters change, suggesting that it can be validly used in modeling application for the cultivars used.

Acknowledgement

This study was funded by the Alliance for Green Revolution in Africa (AGRA - Soil Health Program).

References

Anothai, J., Patanothai, A., Jogloy, S., Pannangpetch, K., Boote, K. J. & Hoogenboom G. 2008. A sequential approach for determining the cultivar coefficients of peanut lines using end-of-season data of crop performance trials. Field Crops Research **108,**169-178.

Arndt, C., Farmer, W., Strzepek, K. & Thurlow, J. 2011. Climate change, agriculture and food security in Tanzania. Working Paper No. 6188. United Nations University-World Institute for Economic Development Research (UNU-WIDER). 26 pp.

Bannayan, M. & Hoogenboom, G. 2009. Using pattern recognition for estimating cultivar coefficients of a crop simulation model. Field Crops Research **111,** 290-302

Birch, C. J., Vos, J., Kiniry, J., Bos, H. J. & Elings, A. 1998. Phyllochron Responds to Acclimation to Temperature and Irradiance in Maize. Field Crops Research **59 (3),** 187-200.

Craufurd, P. Q., Vadez, V., Jagadish, S. V. K., Vara-Prasad, P. V. & Zaman-Allah, M. 2013. Crop science experiments designed to inform crop modeling. Agricultural and Forest Meteorology **170,** 8-18.

Daynard, T. B. & Duncan, W. G. 1969. The black layer and grain maturity in corn. Crop Science **9,** 473-476.

FAOSTAT. 2012. Food and Agriculture organization of the United Nations. Food and Agricultural commodities production. http://faostat.fao.org/site/339/default.aspx

Hokmalipour, S. 2011. The Study of Phyllochron and Leaf Appearance Rate in Three Cultivar of Maize (*Zea mays* L.) at four Nitrogen Fertilizer Levels. World Applied Sciences Journal 1**2(6),** 850-856.

Hoogenboom, G., Jones, J. W., Traore, P. C. S. & Boote, K. J. 2012. Experiments and data for model evaluation and application. In: Kihara, J. Fatondji, D. Jones, J. W., Hoogenboom, G., Tabo, R. and Bationo, A. (Eds.). Improving soil fertility recommendations in Africa using the Decision Support System for Agrotechnology Transfer (DSSAT). Springer Science + Business Media, Dordrecht, the Netherlands. pp. 9-18.

Hoogenboom, G., Jones, J.W., Wilkens, P. W., Porter, C. H., Boote, K. J. & Hunt, L. A. 2010. Decision Support System For Agrotechnology Transfer (DSSAT) Version 4.5. Honolulu, University Of Hawaii. HI. CD ROM

Hunt, L.A. & Boote, K.J. 1998. Data for model operation, calibration and evaluation. In: Tsuji, G. Y., Hoogenboom, G. & Thornton P. K. (Eds.). Understanding Options for Agricultural Production. Kluwer Academic Publishers/ ICASA, Dordrecht, the Netherlands. pp. 9-40.

Jones, C.A. & Kiniry, J. R. 1986. CERES-Maize. Texas A&M University Press, TX. 194 pp.

Jones, J. W., Hunt, L. A., Hoogenboom, G., Godwin, D. C., Singh, U., Tsuji, G. Y., Pickering, N. B., Thornton, P. K., Bowen, W. T., Boote, K. J. & Ritchie, J.T. 1994. Input and Output Files. In: Tsuji, G.Y., Uehara G. & Balas, S. (Eds.). DSSAT V3. University of Hawaii, Honolulu, Hawaii. pp. 1-94.

Jones, J.W., Hoogenboom, G., Porter, C. H., Boote, K. J., Batchelor, W. D., Hunt, L. A., Wilkens, P. W., Singh, U., Gijsman, A.J. & Ritchie, J. T. 2003. The DSSAT cropping system model. European Journal of Agronomy **18,** 235-265.

Jones, P. G. & Thornton, P. K. 2003. The potential impacts of climate change on maize production in Africa and Latin America in 2055. Global Environmental Change **13,** 51-59.

MacCarthy, D.S., Vlek, P.L.G. & Fosu-Mensah, B.Y. 2012. The response of maize to N fertilization in a sub-humid region of Ghana: Understanding the process using a crop simulation Model. In: Kihara, J., Fatondji, D., Jones, J. W., Hoogenboom, G., Tabo, R. & Bationo, A. (Eds.). Improving soil fertility recommendations in Africa using the Decision Support System for Agrotechnology Transfer (DSSAT). Springer Science + Business Media, Dordrecht, the Netherlands. pp. 61-75.

MAFSC. 2012. Tanzania variety catalogue. Ministry of Agriculture, Food Security and Cooperatives. http://www.kilimo.go.tz/publications/publications.htm

MAFSC. 2013. Ministry of Agriculture, Food security and Cooperatives, Agricultural basic data 2005/2006-2009/2010. http://www.kilimo.go.tz/agricultural/statistics/Basic/Chapter4.pdf.

Motsara, M.R. & Roy, R.N. 2008. Guide to laboratory establishment for plant nutrient analysis. Fertilizer and Plant Nutrition Bulletin 19. Food and Agriculture Organization of the United Nations, Rome, Italy. pp. 204.

Mupangwa, W., Dimes, J., Walker, S. & Twomlow, S. 2011. Measuring and simulating maize (*Zea mays* L.) yield responses to reduced tillage and mulching under semi-arid conditions. Agricultural Sciences **2(3),** 167-174

Mwandosya, M.J., Nyenzi, B.S. & Luhanga, M.L. 1998. The assessment of vulnerability and adaptation to climate change impacts in Tanzania. Centre for Energy, Environ. Sci. Technol. CEEST), Dar-es-Salaam, Tanzania.

Ogoshi, R.M., Cagauan, B.G. & Tsuji, G.Y. 1999. Field and laboratory methods for collection of minimum data sets. In: Hoogenboom, G., Wilkens P.W. & Tsuji G.Y. (Eds.). DSSAT version 3, Vol.4. IBSNAT-ICASA, University of Hawaii, HI, USA. Pp 217-286

Rosenzweig, C. & Liverman, D. 1992. Predicted effects of climate change on agriculture: A comparison of temperate and tropical regions. In: Majumdar, S.K. (Ed.) Global climate change: Implications, challenges, and mitigation measures. The Pennsylvania Academy of Sciences, PA. pp. 342-361.

Rweyemamu C.L. 1995. A system assessment of phosphorus fertilizer for use in *Phaseolus vulgaris* L. production in Tanzania. PhD dissertation, Michigan State University, USA. 218 pp.

Tollenaar, M. & Lee, E. A. 2002. Yield potential yield, yield stability and stress tolerance in maize. Field Crops Research **75,** 161-170

United Republic of Tanzania. 1993. Review of fertilizer recommendation in Tanzania. Soil Fertility Report no. F6. National Soil Service, Tanga Tanzania. 71pp.

Uryasev, O., Jones, J. W., Hoogenboom, G. & Porter, C. H. 2004. DSSAT v4 Crop Management Data Editing Program (Xbuild). In: Wilkens, P.W., Hoogenboom, G., Porter, C.H., Jones, J.W. & Uryasev. O. (Eds.). 2004. Decision Support System for Agrotechnology Transfer Version 4.0. University of Hawaii, Honolulu, HI. pp. 47-75.

Tumbo, S.D., Kahimba, F.C., Mbilinyi, B.P., Rwehumbiza F.B., Mahoo, H.F., Mbungu, W.B. & Enfors, E. 2012. Impact of projected climate change on agricultural production in semi-arid areas of Tanzania: A case of Same district. African Crop Science Journal **20(2),** 453 -463.

van Ittersum, M.K. & Donatelli, M. 2003. Cropping system models: science, software and applications. European Journal of Agronomy **18,** 187–393.

van Ittersum, M.K., Cassman, K.G., Grassini, P., Wolfa, J., Tittonell, P. & Hochmand, Z. 2013. Yield gap analysis with local to global relevance: A review. Field Crops Research **143,** 4-17

Wallach, D. 2006. Evaluating crop models. In: Wallach, D., Makowski, D. and Jones, J. W. (Eds.) Working with Dynamic Crop Models Evaluation, Analysis, Parameterization, and Applications. Elsevier, Amsterdam. pp. 11-54.

White, J.W., Hoogenboom, G., Kimball, B.A. & Wall, G.W. 2011. Methodologies for simulating impacts of climate change on crop production. Field Crops Research **124,** 357–368

Wilke, B.M. 2005. Determination of chemical and physical soil properties. In: Margesin, R. & Schinner, F. (Eds.). Manual for Soil Analysis - Monitoring and Assessing Soil Bioremediation. Springer-Verlag, Berlin. Germany. pp. 47-96.

Wilkens, P.W. 2004. Weather Data Editing Program (Weatherman). In: Wilkens, P.W., Hoogenboom, G., Porter, C.H., Jones, J.W. & Uryasev, O. (Eds.). Decision Support System for Agrotechnology Transfer Version 4.0. Volume 2. University of Hawaii, Honolulu, HI. pp. 92-151.

Wilmott, C.J. 1981. On the validation of models. Physical Geography **2,**184-194