Chapter 5

Computer Simulation of Cassava Growth

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Additional information is available at the end of the chapter

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Abstract

To achieve higher productivity in a shorter time, growth simulation models are used in countries like Thailand to provide agro advisory to cassava farmers. Crop model helps to study the response of the crop to any environmental change. Computation of yield potential is important to adopt proper management practices to maximize the yield. Many simulation models of cassava have been developed in different parts of the world. Most of the deficiencies in earlier models were well taken care of in the cassava simulation model GUMCAS [40]. Latest process model, SIMulation of CASsava (SIMCAS), describes cassava growth and yield with good accuracy. This model emphasizes working out the sink capacity and source potential of the plant because the balance between them is a critical requirement for determining the final economic yield of the plant SIMCAS was developed with the aim of applying it for agro advisory purposes. The location- and variety-specific potential tuber yield under given weather conditions are calculated by the model. The most suitable planting time to achieve maximum yield from cassava in a particular locality can also be found out from this model.

Keywords: crop model, crop simulation, SIMCAS, cassava, simulation model

1. Introduction

The problem faced by developing world agriculture is often described as the need to produce more from less and solutions to this problem are aimed at producing more rather than reversing the trend that causes less. While the production of more is important, global efforts must focus on halting and reversing the trends that lead to diminishing agricultural lands and related natural resources. To achieve this, a greater understanding of cross sectional impacts must be achieved at all levels of agriculture and therefore the spread of information must be wider. Crop production must be increased to meet the rapidly growing food demands through sophisticated agricultural process, while it is important to protect other natural resources and the environment. New agricultural research is needed to provide additional information to farmers, policy makers and other decision makers on how to accomplish sustainable agriculture over the wide variations in climate change around the world. Therefore many researchers have over the years shown interest in finding ways to estimate the yield of crops before harvest [1]. In this context plant growth and development models should be elaborated to supply a basis for planning and managing crop production [2].

Dynamic crop growth simulation is a relatively recent technique that facilitates quantitative understanding of the effect of these factors and agronomic management factors on crop growth and productivity. Crop models are computer program that mimic the growth and development of crops [3] or is a simple representation of crop [4] used to study crop growth and to calculate growth responses to the environment [5]. Model simulates or imitates the behavior of the real crop by predicting the growth of its components or organs or parts. A crop growth simulation model not only predicts the final state of the production or harvestable yield, but also contains quantitative information about major processes involved in the growth and development of the crop.

Crop model is a simple mathematical representation of the crop, helps to study the response of the crop to any environmental change. Simulation is the study of the behavior of a system represented by a dynamic model. A particular growth model can be suitable for a particular crop but may be inappropriate for another crop. The user and developer must carefully formulate the model before using, adapting and refining it. SIMulation of CASsava (SIMCAS) is the cassava growth simulation model which describes growth and yield of cassava with good accuracy.

2. SIMCAS

Cassava (*Manihot esculenta* Crantz) is the world's fourth most important source of energy [6] and is a climate resilient crop which is likely to be the best bet under the changing global climatic condition. It is the primary staple food for more than 800 million people in the world and represents a household food bank [7]. By achieving higher productivity in a shorter time, poverty alleviation efforts can be hastened. To achieve this target, growth simulation models are used in countries like Thailand to provide agro advisory systems to cassava farmers [8]. Computation of yield potential is important to adopt proper management practices to maximize the yield. Several studies have been reported on the relationship of environmental factors on plant parts and tuber yield of cassava.

Many simulation models of cassava have been developed in different parts of the world. The model developed by Cock et al. [9] helps to predict the performance of the crop under different combinations of parameters such as branching time, leaf age, etc. This model is of great importance to breeders to determine parameters having maximum influence on tuber yield. Crop Growth Rate (CGR) is assumed to be a constant function of Leaf Area Index (LAI) and it is a serious limitation of this model that the performance of the crop under different solar radiation and temperature conditions cannot be studied. Other assumptions of fixed life span and maximum leaf size add further restrictions to this model in its use under different environmental conditions. Fukai and Hammer [10] developed a model based mainly on empirical relationships derived from datasets collected under Australian conditions. To use this model under different environments, the relationships in the model itself must be recalculated. Most of the deficiencies in earlier models were well taken care of in the cassava simulation model GUMCAS [11]. Maximum potential CGR, a varietal character, is included in this model for calculating dry matter production. The effect of stress due to solar radiation, temperature and water deficit on CGR has been computed with the help of multipliers, as in the case of the Fukai and Hammer model. Diffused and direct components of solar radiation and its differential entrapment by leaves are not included in the model. Although leaf size is one of the most important plant parameters determining dry matter production and final tuber yield, it is computed as a function of time. Thus, the environmental influence on final tuber yield is considerably restricted in this model. The fraction of dry matter allocated to the stem and leaves is calculated as a linear function of developmental time. Hence, this model cannot predict a drastic reduction of tuber yield, which sometimes happens under conditions of excessive vegetative growth. To predict branching, optimum photoperiod and photoperiod sensitivity were derived from the datasets of Keating et al. [12], which were collected for the variety M Aus 10 under Australian conditions. To use this model for a different variety or under a different environment, these values should be recalculated empirically. Dynamic partitioning of dry matter into shoot and storage roots is very important to reflect real field conditions, but has not been done in previous cassava models [13]. In the latest process model, SIMulation of CASsava (SIMCAS), most of the shortfalls observed in the earlier models were rectified and adopted some concepts and methodologies used in them. This model describes cassava growth and yield with good accuracy. This model emphasizes working out the sink capacity and source potential of the plant because the balance between them is a critical requirement for determining the final economic yield of the plant [6].

SIMCAS was developed with the aim of applying it for agro advisory purposes. The location- and variety-specific potential tuber yield under given weather conditions are calculated by the model. The most suitable planting time to achieve maximum yield from cassava in a particular locality can also be found out from this model. For this purpose, historic weather data for the locality should be analyzed to find out the general weather situation of the locality. The model can be run using known weather data and different dates of planting to find out the most suitable planting time. Once the potential yield is found out, proper management practices should be followed to maximize the yield. This model helps to reduce moisture, nitrogen and potassium wastages, and to maximize yield by applying the required amounts at the proper time. The model also calculates stresses due to shortages of moisture, nitrogen and potassium on crop growth and yield.

3. Model description

The driving variables of the models are weather parameters, crop parameters and nutrient parameters.

Crop phenology: In this model phenological development of cassava was calculated on each day in terms of growing degree days (GDD). The optimum temperature (TOPT), base temperature (TBASE) and maximum temperature for the growth of cassava were computed to be 28.5–30, 13.0 and 36–40°C, respectively [14].

Cassava is a long-day plant [4]. Photoperiod influences different processes in cassava like time of root initiation [15], leaf area and branching [12]. Photoperiodic effect in this model is calculated using the method followed in GUMCAS. *P_GDD* is calculated, by multiplying this photoperiodic effect with GDD, to simulate leaf growth, branching, fibrous root growth, etc., which are reported to be influenced by photoperiod [16, 17].

Sprouting: In cassava, sprouting is influenced by temperature. Under conditions of constant and alternating temperatures, sprouting response is found to be the same [18]. A minimum soil temperature of 12–17°C, optimum soil temperature of 28.5–30°C and maximum soil temperature of 36–40°C are required for the sprouting of cassava stems [14]. In this model the varietal parameter Temergence, is defined as GDD at which sprouting begins.

Stem growth: The number of lateral branches and sympodial branches (forks) on each lateral branch are important characters in determining the source potential of cassava. Leaves formed on these parts are major components of the source potential. Cassava forms new leaves and stem simultaneously with filling of storage roots. Stem growth has priority over tuber growth under the conditions of limited carbohydrate supply [9, 19]. Cock et al. and Fukai et al. observed a direct relationship between assimilate supply and stem growth. Among the weather factors, higher temperature favors stem and branch growth [20]. Increase in stem length is calculated in terms of GDD in this model [18].

Leaf area: Leaf Area Index (LAI) is an important component determining the final yield of cassava. It is determined by the parameters like number of active apices, rate of leaf formation per apex, leaf size, and leaf life. Leaf formation per apex is decreased at lower temperatures and increased over the temperature range 20–28°C. Time to reach maximum leaf size also increases at lower temperature. Similarly, leaf life decreases as temperature increases, but it remains more or less constant at 28°C [21]. Keating et al. [12] reported that a longer photoperiod promotes the production of leaf area and thereby a high LAI. Shading is an important factor reducing LAI by its role in enhancing leaf shedding [19]. Leaf shedding plays a key role in determining the LAI and is related more to leaf aging and mutual shading than to temperature [20]. Tan and Cock [22] reported that plants with single stem have large leaf area and that the leaf life increased when number of apices reduced. Short days increase leaf life and long days promote rate of leaf formation and thereby high LAI [17]. In this model leaf formation ($dLFi/dt$) on i DAP is computed as a function of TMEAN. Potential life of cassava leaf ($\mathrm{Life_{POT}}$) in days is a cultivar character [23]. This model calculates the number of days (Life) left in the life of individual leaves on each day since its formation, as a function of *TMEANi*. Leaf shedding is simulated in this model as a function of mutual shading. An algorithm to calculate mutual shading is developed and used in this model. The algorithm is described below.

a. Calculate the number of days left in the life of leaf ‘k’ on i DAP ($Life_{k,i}$)

b. In cassava, leaves are arranged on the stem spirally. Five leaves complete one circle and the sixth leaf and first leaf will be in the same line. The five leaves, which complete one circle, will occupy part of the area of a circle with radius (PLLN), which is equal to the sum of petiole length and the length of the mid rib of each leaf.

Light received by the first circle of leaves are not shaded and receive full sunlight, i.e., $light\_leaf_1 = 100$.

$$shade\_leaf_c = \frac{\sum_{k=n-(5c+1)}^{n-(5c-3)} LA_k}{\pi.PLLN^2}.100, \tag{1}$$

Where,

n is the total number of leaves retained, c is the circle in which the leaf exists, LA_k is the area of the leaf k, $shade\_leaf_c$ is the shade on the leaves of the circle c.

Light received by the leaves are calculated as:

$$light\_leaf_c = light\_leaf_1.\left(1 - \prod_{k=1}^{c-1} \frac{shade\_leaf_k}{100}\right) \tag{2}$$

Life k,i is modified by incorporating the effect of shading as:

$$Life_{k,i} = \frac{28.0.Life_{POT}}{TMEAN_i}.\frac{(light\_leaf_c - shade\_leaf_c)}{light\_leaf_c} \tag{3}$$

Branching: Branching has important role in terms of canopy development and dry matter partitioning [9, 22]. New branches are produced under a good supply of carbohydrates [19]. Long photoperiod conditions are found to promote branching [24]. Temperature is also important in determining the branching habit of cassava. Irikura et al. reported that branching is a varietal character and is delayed by reduced temperature or high temperature [21]. For cassava, the critical threshold value of photoperiod that promotes branching is 12–13 h [12]. The number of nodes produced before the first fork in cassava has genotypic character [24]. Under low fertility conditions, branching is very poor. Similarly, lateral branching occurs under conditions of good illumination and soil fertility. In this model, two conditions are set for emerging branches:

a. There should be a fixed number of nodes before forking stems

b. If total dry matter produced by the plant should be more than the potential requirement

Fibrous roots: Fibrous roots are very important in determining the capacity of the plant to absorb water and nutrients. Short day length and reduced light adversely affect fibrous root growth. Fibrous root growth is sensitive to reduced carbohydrate supply [16]. In this model, initiation of fibrous roots is simulated when P_GDDi reaches a fixed value, which is variety specific. Number of fibrous roots (***n_Froots***) is also set as varietal parameter in this model.

Tubers: Tubers are storage organs and are an economically important part of cassava in most parts of the world. Time of storage root initiation is determined by the interaction of photoperiod and temperature, and is delayed by low temperature conditions, which generally prevail in the subtropics [15]. Boerboom [25] proposed that the plant should attain a dry weight before the storage root initiation happens. This concept is adopted in this model to simulate tuber initiation.

Solar radiation absorbed by the plant is calculated using the method suggested by Johnson et al. [26].

Calculation of photosynthesis: Rate of leaf photosynthesis (PLi, g CO_2 m^{-2} of leaf area day^{-1}) on i DAP, gross canopy photosynthesis (Pci, g CO_2 $m^{-2}$of leaf area day^{-1}) and total dry matter (Pn′i, g m^{-2} of leaf area $plant^{-1}$), is calculated using standard methods Penning de Vries et al. [4] and Johnson et al. [26].

Partitioning of dry matter: Storage roots, stem and growing leaves constitute the sink portion of cassava and active leaves constitute the source portion [23]. In cassava, leaf area and tubers develop simultaneously. Hence, there always exists competition for assimilates between different plant parts [6]. Aboveground plant organs always have a preference over root growth [9] and, hence, in this model dry matter is first partitioned between stem, leaves and fibrous roots and whatever is remaining will be stored in the tuber. In this model the dry matter produced on i DAP (Pn'_i) is calculated using leaf area on previous day. Before tuber initiation, whatever dry matter remaining after allocating to leaves and stem will be partitioned to fibrous roots and after tuber initiation this will be transported to tubers. In this model it is assumed that after tuber initiation, fibrous roots do not receive any dry matter.

4. Stress estimation

Under field conditions, stress due to shortage of many factors essential for the growth of the crop limits the crop from achieving its potential yield. Moisture, nitrogen and potassium are the three most important factors essential for the growth of cassava. This model calculates the stresses due to shortages of moisture, nitrogen and potassium on growth and yield of cassava as well as the uptake of N and K.

4.1. Effect of drought stress on crop growth

Reduction in dry matter production due to drought stress (WS) is depending on the stage at which the crop experiences stress. Alves [23] reported that for cassava first 5 months after planting (MAP) are the most critical periods of drought stress. The effect of drought stress on crop growth is computed using the method suggested by Allen et al. [27]. Since the data on wind speed is not commonly available, Priestly-Taylor method [27] is used in this model for calculating reference evapotranspiration (ET_0), which is used in the calculation of drought stress.

4.2. Effect of nitrogen deficit on crop growth

From the change in biomass, crop demand for nutrients during a given time period can be calculated [28]. In this model stress experienced by the crop due to the shortage of nitrogen

(N_{stress}) is the ratio of Npot (nitrogen required to produce the dry matter at potential rate) and the actual nitrogen uptake (N_{uptake}) [18].

4.3. Effect of potassium deficit on crop growth

Potassium is an important nutrient for cassava because of its role in photosynthesis and the translocation of photosynthates [29]. Stress experienced by the crop due to the shortage of K (K_{stress}) is calculated in this model as the ratio of K_{pot} (potassium required to produce the dry matter at potential rate) and the actual potassium uptake (K_{uptake}) [18].

5. Growth simulation with SIMCAS model

The model requires three data files for simulating the growth and to predict the phenology, dry matter production and distribution of cassava crop.

5.1. Plant parameters required to run the model

Plant parameters required to run the model are:

a. ***n_leaf***: leaves at the time of emergence

$$\boldsymbol{n\_leaf} = \frac{LF_n{}^{*}28}{\sum_{i=1}^{n} 28 - |Tmean_i - 28|} \tag{4}$$

Where,

LF_n is number of leaves on n DAP,

$Tmean_i$ is mean temperature on ith DAP

b. ***n_stem***: Describes growth rate of stem (0C.cm^{-1})

$$n\_stem = \frac{GDD_i}{HT_i} \tag{5}$$

Where,

HT_i is the height of the stem on ith DAP

GDD_i = GDD on ith day after planting

c. ***d_roots***: P_GDD at the time of initiation of fibrous roots

d. ***dwt_rt_MAX***: It is the maximum dry weight, which the fibrous root of cassava can attain (g)

e. ***dwt_rt_EMERG***: The dry weight of fibrous roots of cassava at the time of their emergence (g)

f. ***n_F roots***: the number of fibrous roots of cassava

g. ***SLA***: Describes the specific leaf area(g*(cm^2)$^{-1}$)

h. ***stwt_MAX***: Describes the maximum dry matter that can be apportioned to the unit length of the stem (g/cm^{-1})

i. ***$LAREA_{MAX}$***: Describes the maximum area that an individual leaf can attain (cm^2)

j. ***$LAREA_{START}$***: Describes the area of individual leaves at the time of its full emergence (cm^2).

k. ***$life_{POT}$***: Describes potential life of cassava leaf (days).

l. ***node_branch***: Describes number of nodes, which should be produced on the stem since last branching to production of new branch

m. ***st_rt_plant weight***: Describes initial plant weight, i.e., the weight of the stem, leaves, and fibrous root together, at which tuber initiates.

n. ***n_S_tubers***: Describes number of tubers produced by a variety

o. ***n_shoots***: Describes the number of shoots produced by the variety. The user can set its value so that the software will do the simulation for that number of shoots. If its value is set as −99 the software will find out the actual number of shoots produced by the plant under the experimental conditions.

5.2. Weather parameters required to run the model

a. Maximum temperature (°C)

b. Minimum temperature (°C)

c. Solar radiation (MJ/day) or Sunshine hours (h)

d. Maximum relative humidity (%)

e. Minimum relative humidity (%)

f. Precipitation (mm)

Daily weather data of the cropped area is required.

5.3. Fertilizer parameters required to run the model

a. Nitrogen (kg ha^{-1})

b. Phosphorous (kg ha^{-1})

c. Potassium (kg ha^{-1})

These data files should be prepared in CSV format to run the model.

The estimated values of the crop parameters for the two varieties, Sree Vijaya, and H 226, are given in **Table 1**.

Plant parameters	Sree Vijaya	H 226
n_leaf	1.121636	1.10964
n_stem	12.53228	12.817006
d_roots	85.7309	109.13437
dwt_rt_MAX	7.762	14.065
dwt_rt_EMERGENCE	0.053832	0.0694762
n_F roots	23.64993	21.597397
SLA	0.002288	0.0024023
stwt_MAX	0.553091	0.42715
Larea MAX	467.3508	305.10788
Larea START	3.206739	2.1434482
Life POT	95	115.66667
node_branch	76.6	102.66667
st_rt_pltwt	285.561	134.967
n_S_tubers	9.373267	9.76
shoots	2.2	2

Table 1. Mean plant parameter values of Sree Vijaya and H 226.

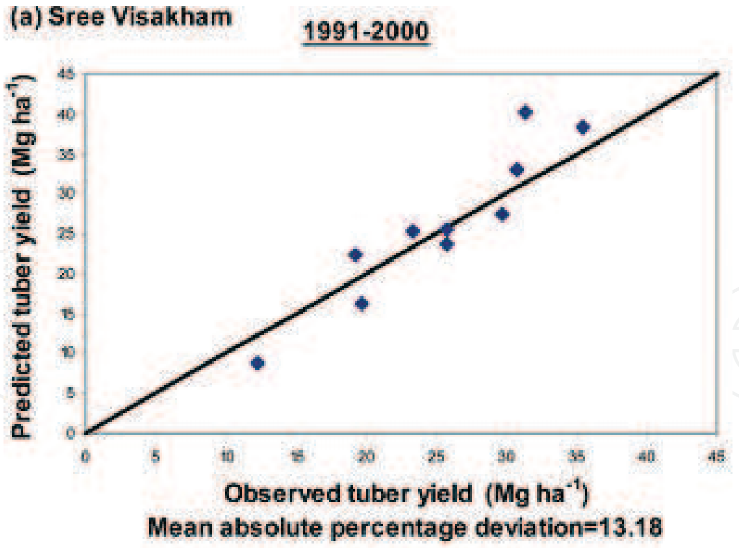
6. Evaluation of the model

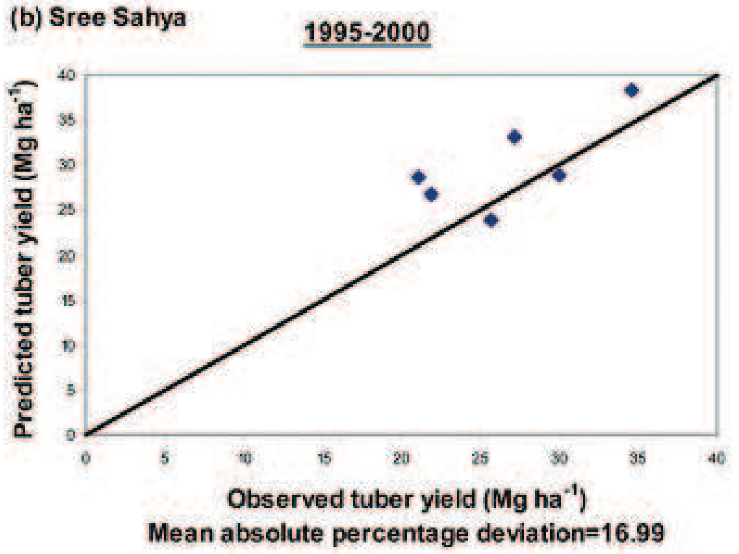
The model accuracy could only be tested against limited datasets. To evaluate the accuracy of predictions, simulated tuber yield for the varieties Sree Visakam, Sree Shya and M4 were collected from different locations and compared with the observed values. It is observed that the predicted values are reasonably close to the observed values. Mean absolute percentage deviations between observed and predicted values for the said varieties were 13.2, 17.0 and 3.4%, respectively. This shows that model's predictions are very close to the real field situation (**Figure 1**).

7. Sensitivity analysis

The sensitivity of the final output (t ha^{-1}) of the three varieties to the perturbations in each plant parameter was computed. Sensitivity (β) (**Table 2**) was estimated as the ratio of the fractional change in yield to the fractional change in a particular parameter [11].

An average 5% change on either side of the parameter value was used to compute the β (**Table 2**). Leaf area is the most sensitive parameter in determining tuber yield. The parameters, ***$Life_{POT}$*** and ***node_branch***, which play a major role in determining the canopy size of the plant and thereby are important in determining the source potential of the plant, show high β values. High β values of these parameters for all three varieties confirm the importance of vegetative growth in determining the final yield.





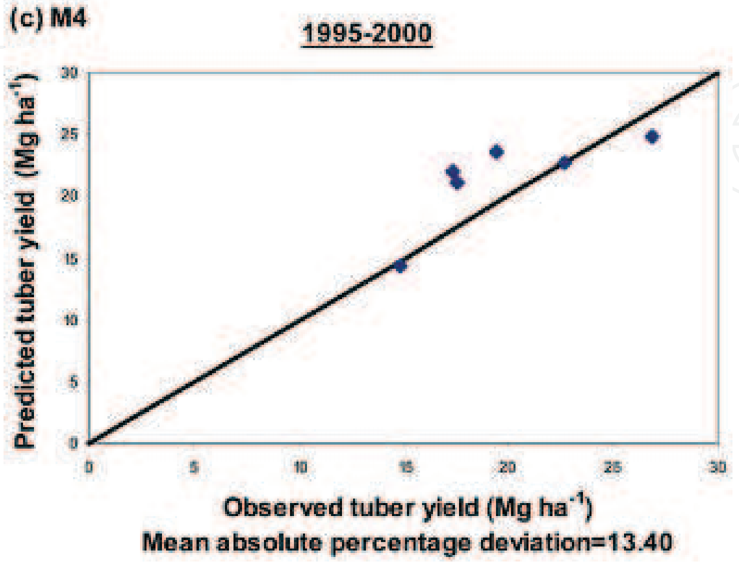


Figure 1. Observed vs. predicted tuber yield (t ha^{-1}) for the varieties: (a) Sree Visakham, (b) Sree Sahya, and (c) M4.

Parameter	**β**		
	Sree Visakham	**Sree Sahya**	**M4**
n_leaf	0.09	0.13	0.37
n_stem	0.51	0.47	0.48
d_roots	0.00	0.08	0.11
dwt_rt_MAX	0.00	0.00	0.00
dwt_rt_EMERG	0.00	0.00	0.00
n_Froots	0.00	0.00	0.00
SLA	0.20	0.19	0.18
stwt_MAX	1.23	0.47	0.48
LAREAMAX	0.34	0.33	0.97
LAREASTART	0.02	0.06	0.08
LifePOT	1.41	1.29	2.64
node_branch	0.56	0.67	0.72
st_rt_pltwt	0.35	0.29	0.34
n_S_tubers	0.57	0.00	0.01

Source: Ref. [18].

Table 2. Results of sensitivity analysis of plant parameters for the cassava varieties Sree Visakham during 6.06.1994 to 22.03.1995, Sree Sahya during 16.06.1992 to 22.03.1993 and M4 during 16.06.1996 to 22.03.1997.

8. Discussion

The GUMCAS model predicts branching based on photoperiod alone [11]. In this model, a new method is followed for predicting branching. Influence of assimilate supply on branching is widely reported. Fukai et al. [19] reported that new branches are produced when there is a good supply of carbohydrates. The assumption that branching occurs when the ratio of supply to demand of assimilates is >3 is modified and adopted in this model. Branching was found to be less under high competition for assimilates [30]. This model predicts branching based on the varietal parameter, ***node_branch***, also. Because branching is a process, which marks the beginning of reproductive phase, production of nodes is calculated as a function of P_GDD, whereby the interaction between photoperiodic effect and temperature is the basis for determining phenological development. When the number of nodes produced on the stem since the previous branching crosses ***node_branch***, the model simulates the production of another branch. The number of new branches produced from this stem is dependent on the assimilate supply. If the assimilate supply is more than that required for the stem, three branches are produced, otherwise two branches are only produced. Unlike the GUMCAS model, there is no fixed limit for the maximum number of branches. According to this model, branching is delayed by low temperature and short day conditions, because under these conditions leaf formation and dry matter production are reduced. Thus the findings of Irikura et al. [21] and Veltkamp [17] are fulfilled by this model.

The stem is an important sink and stands in strong competition to tubers for dry matter [15]. In this model, stem growth is calculated as a function of GDD. Here, the stem growth is promoted more under summer than under winter conditions. This hypothesis is supported by Manrique [20].

All factors determining LAI, which is one of the most important components of dry matter production, are carefully included in this model. To predict leaf production, the findings of Irikura et al. [21] are adopted in this model by assuming that the rate of leaf production is lowered as temperature moves from 28°C. The longer photoperiod, which results in high P_GDD, causes a large increase in leaf area, thereby substantiating the findings of Keating et al. [12]. The time to reach maximum leaf size will be longer at low temperatures [12].

The primary cause of leaf fall is shading [19]. A new algorithm to calculate shading is proposed in this model. The angle at which the leaf is held on the stem is not considered here.

Tuberization is simulated with the help of the parameter ***st_rt_pltwt*** (total plant weight at which storage root production starts), as proposed by Boerboom [30, 31]. Accumulation of plant weight is dependent on many weather parameters, which support the development of leaf area. The plant weight accumulation at low temperature becomes slow. This will result in delayed tuberization [12, 15].

Source–sink relationships are given due importance in this model. In the first phase of the model, source and sink capacity are calculated based on weather parameters and dry matter production is calculated using the existing source, i.e., the source potential of the previous day. So, dry matter production becomes more realistic. In the second phase, dry matter produced is allocated to the sink already calculated. If the dry matter produced is not sufficient to meet the potential sink capacity, its size will be proportionally reduced. In such situations, there will be no stored dry matter in the main storage organ, i.e., tubers. Whereas, if the dry matter produced is more than the sink capacity, all the sink portions will grow to their potential capacity and if some dry matter remains it will be stored in the storage organs.

Potential dry matter production on each day is calculated by this model based on the prevailing weather conditions. This is further modified by the stress experienced by the crop. This model calculates water, nitrogen and potassium stresses only. Each stress is calculated separately and the reduction from the potential yield is calculated. More elaborate algorithms for finding out stresses may improve the accuracy of the model predictions. Algorithms to calculate stresses due to shortage of P, other micronutrients, pests and diseases, etc., are not included in this model. Extensive research on impact of various stresses on the growth of cassava will definitely help to improve the accuracy of model predictions. This model helps in giving advice to farmers to reduce stresses and to realize the potential yield. The precise time and quantity of application of water, N and K help the farmers to reduce deficits and obtain maximum yield from the crop. Before giving a comprehensive advisory, extensive validation of the model is required and the economics also should be worked out.

9. Conclusion

SIMCAS, growth simulation model of cassava is composed of various submodels/routines for predicting phenology, productivity and assimilate partitioning. These models were built mainly using data reported in literature, as well as data collected by conducting field experiments. Water, potassium and nitrogen are important stress factors included in the model. The predicted values while compared with field observations shows a good agreement between predicted and observed tuber yield even though the stem and leaf weight predictions are deviating from the observed values. This model is based on sufficiently studied physiological processes and extensive validations under field conditions are necessary before its field application. Improvements in the estimation of drought, nitrogen and potassium stresses are required to give more accurate predictions. By considering the detailed dynamics of water, nitrogen and potassium in soil and plant, the estimation of stress due to their shortage will be improved. However, SIMCAS can be considered as a good tool for advising the farmers about the potential yield of cassava at a given locality and to develop strategies for maximizing the yield by managing irrigation and N and K fertilizations.

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References

[1] Rauff KO, Bello R. A review of crop growth simulation models as tools for agricultural materiology. Agricultural Sciences. 2015;**6**:1098-1105

[2] Durado Neto D, Teruel DA, Reichardt K, Nielsoen DR, Frizzone JA, Bacchi OOS. Principles of crop modeling and simulation: 1. Uses of mathematical models in agricultural science. Science Agriculture Piracicaba. 1998;**55**:46-50

[3] USSDA 2007

[4] Penning de Vries FWT, Jansen DM, ten Berge HFN, Bakema A. Simulation of Ecophysiological Processes of Growth in Several Annual Crops. Wageningen (The Netherlands): IRRI Los Bonos and Pudoc; 1989

[5] Migleitta F, Bindi M. Crop growth simulation model for research, farm management and agrometeorology. EARSeL Advances in Remote Sensing. 1993;**2**(2):148-157

[6] Cock JH. Cassava. In: Goldsworthy PR, Fisher NM, editors. The Physiology of Tropical Field Crops. New York: Wiley-Interscience; 1984

[7] Lebot V. Tropical Root and Tuber Crops. Cassava, Sweet Potato, Yams and Aroids; 2008. www.cabi.org

[8] Sarawat V, Ratanasriwong S, Puangprakon K, Sringam P, Jintrawet A. MunThaiDSS: A decision support system for cassava production. In: Zazueta F, Ninomiya S, Chitradon R, editors. Proceedings of the Joint Conference of the 4th International Conference of the Asian Federation of Information Technology in Agriculture and the 2nd World Congress on Computers in Agriculture and Natural Resources; August 9–12. Bangkok, Thailand; 2004. pp. 136-139

[9] Cock JH, Franklin D, Sandoval G, Juri P. The ideal cassava plant for maximum yield. Crop Science. 1979;**19**:271-279

[10] Fukai S, Hammer GL. A simulation model of the growth of cassava crop and its use to estimate cassava productivity in Northern Australia. Agricultural Systems. 1987;**23**:237-257

[11] Matthews RB, Hunt LA. GUMCAS: A model describing the growth of cassava (*Manihot esculenta* L. Crantz). Field Crops Research. 1994;**36**:69-84

[12] Keating BA, Evanson JP, Fukai S. Environmental effects on the growth and development of cassava (*Manihot esculenta* Crantz). I. Crop development. Field Crops Research. 1982;**5**: 271-281

[13] Gray VM. A comparison of two approaches for modeling cassava (*Manihot esculenta* Crantz) crop growth. Annals of Botany. 2000;**85**:77-90

[14] Keating BA, Evanson JP. Effect of soil temperature on sprouting and sprout elongation of stem cuttings of cassava (*Manihot esculenta* Crantz). Field Crops Research. 1979;**2**:241-251

[15] Ekanayake IJ. Physiology of cassava. In: Ekanayake IJ, Osiru DSO, Porto MCM, editors. IITA Research Guide. Ibadan (Nigeria): IITA; 1998. 55 p

[16] Aresta RB, Fukai S. Effects of solar radiation on growth of cassava (*Manihot esculenta* L. Crantz). II. Fibrous root length. Field Crops Research. 1984;**9**:361-371

[17] Veltkamp HJ. Physiological Causes of Yield Variation in Cassava (*Manihot esculenta* L. Crantz). Agricultural University Wageningen papers. Wageningen (The Netherlands): Agricultural University; 1986

[18] Santhosh Mithra VS, Sreekumar J, Ravindran CS. Computer simulation of cassava growth: A tool for realizing the potential yield. Archives of Agronomy and Soil Science. 2013;**59**(4): 603-623. DOI: 10.1080/03650340.2011.653681

[19] Fukai S, Alcoy AB, Llamelo AB, Patterson RD. Effects of solar radiation on growth of cassava (*Manihot esculenta* Crantz). I. Canopy development and dry matter growth. Field Crops Research. 1984;**9**:347-360

[20] Manrique LA. Plant morphology of cassava during summer and winter. Agronomy Journal. 1990a;**82**:881-886

[21] Irikura Y, Cock JH, Kawano K. The physiological basis of genotype temperature interaction in cassava. Field Crops Research. 1979;**2**:227-239

[22] Tan SL, Cock JH. Branching habit as a yield determinant in cassava. Field Crops Research. 1979;**2**:281-289

[23] Alves AAC. Cassava botany and physiology. In: Hillocks RJ, Thresh JM, Bellotti AC, editors. Cassava: Biology, Production and Utilization. Wallingford (UK): CAB International; 2002

[24] Hunt LA, Wholey DW, Cock JH. Growth physiology of cassava (*Manihot esculenta* L. Crantz). Field Crop Abstracts. 1977;**30**:77-91

[25] Van Kraalingen DWG, Stol W, Uithol PWJ, Verbeek M. User Manual of CABO/TPE Internal Communication. Wageningen (Netherlands); 1991

[26] Johnson IR, Riha SJ, Wilks DS. Modelling daily net canopy photosynthesis and its adaptation to irradiance and atmospheric CO_2 concentration. Agricultural Systems. 1995;**50**:1-35

[27] Allen RG, Pereira LS, Raes D, Smith M. Crop Evapotranspiration – Guidelines for Computing Crop Water Requirements. FAO irrigation and drainage paper. Rome (Italy): FAO; 1998. 56 p

[28] Van Noordwijk M, Van de Geijn SC. Root, shoot and soil parameters required for process-oriented models of crop growth limited by water or nutrients. Plant and Soil. 1996;**183**:1-25

[29] Rajendran N, Nair PG, Mohankumar B. Potassium fertilization of cassava in acid laterite soils. Journal of Root Crops. 1976;**2**:35-37

[30] Tsay JS, Fukai S, Wilson GL. The response of cassava to spatial arrangement and to soybean intercrop. Field Crops Research. 1987;**16**:19-31

[31] Boerboom BWJ. A model of dry matter distribution in cassava (*Manihot esculenta* Crantz). Netherlands Journal of Agricultural Science. 1978;**26**:267-277