THE DEVELOPMENT OF A CASSAVA GROWTH MODEL IN INDIA

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ABSTRACT

The slow advancements in the research and development of cassava is aggravating poverty in many poor countries. Achieving higher yields in a shorter time can help solve this problem. Cassava simulation models are one of the tools to improve the situation. A model to simulate cassava growth is presently being developed at CTCRI. In the model the cassava plant system is simulated by considering all the attributes, as well as the relationships between these attributes. Plant attributes, like formation and falling of leaves, leaf area, leaf area index (LAI), leaf longevity, net assimilation rate (NAR), height of the stem, root development, rate of synthesis of dry matter, partitioning of dry matter into different plant parts etc., were included. Weather variables such as the minimum and maximum temperature and rainfall, are driving the model. Genetic coefficients for each variety should be computed before using the model.

The plant system functions in relation to the temperature as well as the rainfall received by the plant. The atmospheric temperature directly influences the height of the plant (HT), the rate of formation of leaves (LFMD), potential and actual leaf age (PLFAGE and LFAGE) and the average leaf area (ALA). LFAGE is used to compute the number of leaves fallen (LFLLN) and from that the total number of leaves retained by the plant (TLF) is determined. From TLF and ALA, total leaf area (TLA) can be calculated. This dry matter is partitioned into the different plant parts, and equations are developed to compute these values. The computations are continued for the entire growth period. Such simulation experiments can partially substitute for laborious field experiments and thus save resources. The same plant model can be tested for different soil and weather conditions by suitably inputting the required soil and weather parameter values in the model. The model is now in the first phase of development. Once equations for water use, soil nutrient uptake and plant protection are included, the model will be completed. The model is presently being tested under different environmental conditions.

INTRODUCTION

Cassava is the fourth most important source of food energy, and is produced and consumed mainly in the tropics (Cock, 1984). It is an important food crop in many poor countries. Achieving higher productivity of the crop in a shorter time, will contribute to the alleviation of poverty. But to develop improved cassava technologies through field experiments requires a lot of time and resources. With the help of computers the growth of cassava can be studied. A reduced number of trials can be conducted without spending the enormous amount of resources and time, which are otherwise required for field experiments. Different soil and weather conditions can be simulated very easily and the performance of the crop under these varying conditions can be studied easily and quickly. The development of a growth model is the first and most important task. All attributes of the cassava plant system and the relationships between them should be properly understood for developing a sound model (Santhosh Mithra, 2002). A good model will help to identify the various components in the growth of the crop and the interaction among them and with the environment.

The Use of Models

Seligman (1990) lists the following uses of models in research:

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- Identification of gaps in our knowledge
- Generation and testing of hypothesis, and an aid to the design of experiments
- Determination of the most influential parameters of a system (sensitivity analysis)
- Provision of a medium for better communication between researchers in different disciplines
- Bringing of researchers, experimenters and producers together to solve common problems

To increase the efficiency of research, modeling should become a part of it. Knowledge gained should be able to refine the models, and the models should serve as a tool for identifying critical gaps and the potentialities.

Cassava Growth Models Developed Outside India

Several cassava growth models are already developed outside India. These models can be classified into two groups:

1. Those in which dry matter is partitioned according to a fixed pattern
2. "Spill-over" models, in which leaf or stem growth is calculated independently and is assumed to have "first call" on newly produced assimilate, while storage roots receive any that is remaining (Matthews and Hunt, 1994)

Fixed pattern models	**Spill-over models**
1. Boerboom(1978)	1. Cock *et al.* (1979)
2. Connor *et al.* (1981)	2. Fukai and Hammer (1987)
3. Gutierrez *et al.* (1988)	3. GUMCAS by Mathews and Hunt (1994)
4. Gijzen *et al.* (1990)	

The GUMCAS model provides the basis for the CROPSIM-Cassava model, which is included in the DSSAT set of crop models. An improvement is made in this model over the existing models by including an additional component called "Vapor Pressure Deficit."

Cassava Growth Models Developed In India

Proper understanding of the cassava growth system and the physiological processes involved in the growth of cassava are important while developing such models. The structure of the model differs because of differences in the growth systems considered. The entities and the interactions between the entities differ in each of these systems and thus the model structure also differs. Three cassava growth models, which were developed in India are discussed below

Model 1

A cassava growth model was developed for some specific varieties, i.e. Sree Sahya, Sree Visakham and M-4, to understand the growth pattern at different ages of the crop (Santhosh Mithra *et al.*, 1999). The growth of cassava was described with the following components:
1) Age (AG), 2) Height (HT), 3) Leaves formed till date (LFMD), 4) Leaves fallen till date (LFLLN), 5) Total number of leaves (TL), 6) LBN, 7) Average leaf size (ALS), 8) Total leaf area (TLA), 9) Net assimilation rate (NAR), 10) Crop growth rate (CGR), 11) Total dry

matter (TDM), 12) Dry matter in shoot (DMSHT), 13) Dry matter in root (DMRT), 14) Harvest index (HI), and 15) Leaf area index (LAI)

Regression equations were fitted for predicting HT, LFMD, LFLLN and HI as a function of AG, and ALS was fitted as a function of LBN, where LBN is the product of length and breadth of the middle lobe and the number of lobes of any randomly selected three leaves of the plant. All these equations gave very good fit and the R^2 values are shown in **Table1.**

Table 1. Correlation coefficients of the regression between various growth parameters of cassava. Data are the average values of three varieties.

Sl. No	Dependent variable	Independent variable	R^2
1.	HT = height	AG = age	0.950
2.	LFMD = leaves formed till date	AG = age	0.935
3.	LFLLN = leaves fallen till date	AG = age	0.922
4.	HI = harvest index	AG = age	0.984
5.	ALS = average leaf size	LBN = length x breath x no. lobes	0.990

This model helps in understanding the pattern of growth of stems and leaves of the crop. The effect of weather or soil parameters on the growth of the crop is not included in this model. There is no scope for calibrating this model to be used under different environments. So this model does not help in making predictions about cassava under different growing conditions.

Model 2

This model was developed using data collected from CTCRI during 1981 to 1984 (Santhosh Mithra *et al.,* 2001). Weather parameters like maximum and minimum temperature and rainfall were used for modeling. Among the biometric parameters, the number of leaves and nodes, and height and girth of the stem were collected. Three leaves were randomly selected from each plant and the length and breadth of the middle lobe and the number of lobes of each of those leaves were recorded. The biometric observations were taken at monthly intervals from three varieties, i.e. H-1687, H-2304 and M-4. Weather data were collected daily. The relationship between different physiological processes and parameters were taken into consideration while developing the model (Ramanujam, 1991).

The cassava plant growth system was developed with the following components:

a) Rate of formation of leaves–dLFMD/ dTU
b) Rate of falling of leaves–dLFELL/ dTU
c) Total number of leaves formed till “d” days after planting (DAP) –$LFMD_d$
d) Total number of leaves fallen till “d” days after planting (DAP) –$LFELL_d$
e) Total number of leaves on “d” days after planting (DAP) –TLF_d
f) Total leaf area on “d” days after planting (DAP) –TLA_d
g) Leaf area index on “d” days after planting (DAP) –LAI_d
h) Optimum leaf area index–LAI_{opt}
i) Effective leaf area index on “d” days after planting (DAP) –$ELAI_d$
j) Net assimilation rate on “d” days after planting (DAP) –NAR_d
k) Total dry matter on “d” days after planting (DAP) –TDM_d

l) Dry matter apportioned to stem on "d" days after planting (DAP) –$DMST_d$
m) Dry matter apportioned to leaves on "d" days after planting (DAP) –$DMLF_d$
n) Dry matter apportioned to roots on "d" days after planting (DAP) –$DMRT_d$
o) Matter in dry leaves on "d" days after planting (DAP) –$DMDLF_d$
p) Branching.

The three varieties were found to differ in their ability to utilize the temperature. A maximum value of mean temperature (T_{opt}) which can be effectively utilized by the crop was identified and this value depends on the average yield of the variety under that environment. T_{opt} is also dependent on the total rainfall received by the crop. If the mean temperature (t) goes beyond T_{opt}, each unit increase was found to reduce the temperature utilizing ability of the crop (TU).

$$TU_d = \sqrt{(AGE.\, T_{opt} - \sqrt{(\sum t - AGE.\, T_{opt})^2}\,)^2}$$

TU_d = Temperature utilizing ability on "d" DAP.

The height of the plant on "d" DAP (HT_d), rate of formation of leaves (dLFMD/ dTU) and rate of falling of leaves (dLFELL/ dTU) were computed as functions of TU_d

$HT_d = f(TU_d)$

$dLFMD/ dTU = f(TU_d)$.

The number of leaves formed between "d-1" and "d" DAP (dLFMD) and the number of leaves formed till "d" DAP ($LFMD_d$) was obtained as follows:

$dLFMD = dLFMD/ dTU\ .\ (TU_d - TU_{d-1})$.

$LFMD_d = LFMD_{d-1} + dLFMD$.

Under field conditions $LFMD_d$ was found to have a lot of variability ($LFSDV_d$) even under the same climatic condition. This is found to be a function of $LFMD_d$

$LFSDV_d = f (LFMD_{d-1}/ LFMD_d)$

$LFMD_d$ was modified using the variability $LFSDV_d$. This is done by generating pseudo-random numbers in normal distribution (Gordon, 1992) with mean $LFMD_d$ and standard deviation $LFSDV_d$. The average of this random value and the computed $LFMD_d$ is the final value of $LFMD_d$.

$dLFELL/ dTU = f(TU_d)$

The number of leaves fallen between "d-1" and "d" DAP (dLFELL) and the number of leaves fallen till "d" DAP ($LFELL_d$) was obtained from:

$dLFELL = dLFELL/ dTU\ .\ (TU_d - TU_{d-1})$.

$LFELL_d = LFELL_{d-1} + dLFELL$.

Under field conditions $LFELL_d$ was found to have a lot of variability ($LFLSDV_d$) even under the same climatic conditions. This is found to be a function of $LFELL_d$

$LFLSDV_d = f (LFELLd_{-1} / LFELL_d)$

$LFELL_d$ was modified using the variability $LFLSDV_d$. This is done by generating pseudo-random numbers in normal distribution with mean $LFELL_d$ and standard deviation $LFLSDV_d$. The average of this random value and the computed $LFELL_d$ is the final value of $LFELL_d$.

From $LFMD_d$ and $LFELL_d$, TLF_d was computed as follows:

$TLF_d = LFMD_d - LFELL_d$

Average leaf area (ALA) was computed as a function of the average yield of the variety (Y)

ALA = f (Y)

Total leaf area on "d" DAP (TLA_d) was computed from ALA and TLF_d as follows:

$$TLA_d = TLF_d . ALA$$

From the TLA_d (in cm^2), the leaf area index on day "d" (LAI_d) was calculated by dividing it by the space occupied by each plant.

The value of optimum leaf area index (LAI_{opt}) beyond which the increase in leaf area won't make any increase in the economic yield was computed as follows:

$$LAI_{opt} = I_{v1} . e^{Iv2.LFMD62/62.} .$$

$$I_{v1} = 1.17. Y - 15.5$$

$$I_{v2} = -0.0768 .Y + 0.63317$$

Where $LFMD_{62}$ = Number of leaves formed in 62 days.

If the age of the crop is less than 62 days LAI_{opt} is assumed to be equal to LAI_d.

LAI of the crop, which is optimum for the growth and development of the crop ie. effective leaf area index ($ELAI_d$) can be computed using LAI_{opt}

$$ELAI_d = \sqrt{(LAI_{opt} - \sqrt{(LAI_{opt} - LAI_d)^2})^2}$$

$ELAI_d$ determines the net assimilation rate (NAR_d) in $gms/cm^2/day$ on "d" DAP.

$$NAR_d = \frac{(A_1 . ELAI_d + A_2 . ELAI_d^{\ 2} + Ac)^2}{(LAI_d . 100)^2}$$

Dry matter production and partitioning

Total dry matter produced by the plant each day ($dTDM_d$), is obtained by multiplying NAR_d with TLA_d

$$dTDM_d = NAR_d . TLA_d$$

$$TDM_d = TDM_{d-1} + dTDM_d .$$

TDM_d = Total dry matter in the plant on "d" DAP

The dry matter produced is partitioned into different plant parts. First part is distributed to leaves and then to stem. Whatever is remaining is stored in roots.

Dry matter partitioned into leaves on "d" DAP ($dDMLF_d$) is obtained as follows:

$$dDMLF_d = dTDM_d . (DMLF_{d-1} / TDM_{d-1}) . (TLF_d / TLF_{d-1})$$

$$DMLF_d = DMLF_{d-1} + dDMLF_d .$$

where $DMLF_d$ = Dry matter in leaves on "d" DAP .

Dry matter partitioned into stem on "d" DAP ($dDMST_d$) is obtained as follows

$$dDMST_d = dTDM_d . (DMST_{d-1} / TDM_{d-1}) . (HT_d / HT_{d-1})$$

$$DMST_d = DMST_{d-1} + dDMST_d .$$

where $DMST_d$ = Dry matter in stem on "d" DAP.

The remaining dry matter is stored in the roots

$$DMRT_d = TDM_d - (DMST_d + DMLF_d)$$

$DMRT_d$ = Dry matter stored in the roots on "d" DAP.

Matter is stored in dry leaves on "d" DAP ($DMDLF_d$) as follows:

$$dDMDLF_d = C_d . e^{dx} . dTDM_d$$

where C_d and d are coefficients.

$$x = DMLF_d / TDM_d$$

$$DMDLF_d = dDMDLF_{d-1} + dDMDLF_d$$

Some of the results of simulations done using this model are given in the **Tables 2-10.**

Table 2. Average values of four simulation runs for the variety H-1687.

Age (DAP)	LFMD	LFELL	TLF	HT(cm)
35	37.63	7.71	29.92	33.45
74	86.21	23.44	62.71	68.03
97	116.15	37.52	78.63	87.06
156	203.58	94.17	109.42	137.20
190	258.83	140.75	118.08	166.26
228	320.84	202.11	118.72	197.30
265	377.34	265.90	111.44	224.47
323	462.58	375.48	87.10	263.82

LFMD = number of leaves formed up to a certain age
LFELL = number of leaves dropped up to a certain age
TIF = number of leaves at a certain age
HT = plant height in cm

Table 3. Average observed values for the variety H-1687.

Age (DAP)	LFMD	LFELL	TLF	HT(cm)
35	14.30	0.00	14.30	13.55
74	61.60	5.00	56.60	71.45
97	75.50	18.80	56.70	97.82
156	133.20	55.30	77.90	168.45
190	168.70	92.10	76.60	198.27
228	200.12	139.12	61.00	219.56
265	231.86	163.00	68.86	281.78
323	319.25	169.38	149.88	367.56

Table 4. Average values of four simulation runs for the variety H-2304.

Age (DAP)	LFMD	LFELL	TLF	HT(cm)
35	46.78	9.77	37.02	37.50
74	100.42	32.86	67.57	73.49
97	131.24	52.62	78.62	93.00
156	214.25	128.03	86.22	143.04
190	263.06	186.90	76.16	171.28
228	315.81	262.12	53.62	201.08
265	363.12	339.80	23.32	227.28
323	434.54	433.54	1.00	266.04

Table 5. Average observed values for the variety H-2304.

Age (DAP)	LFMD	LFELL	TLF	HT(cm)
35	20.25	0.00	20.25	12.56
74	69.80	2.10	67.70	54.30
97	94.00	15.20	78.80	99.20
156	181.10	59.20	121.90	190.40
190	205.60	117.20	88.40	202.00
228	254.60	202.90	51.70	221.80
265	319.50	212.30	107.20	243.80
323	416.22	223.78	192.44	270.11

Table 6. Average values of four simulation runs for the variety M-4.

Age (DAP)	LFMD	LFELL	TLF	HT(cm)
35	33.28	8.19	25.09	39.18
74	84.17	29.75	54.42	74.99
97	118.58	51.34	67.24	95.27
156	216.71	139.16	77.56	145.09
190	280.44	214.74	65.70	173.66
228	358.74	325.71	33.04	206.19
265	440.96	439.96	1.00	238.09
323	542.80	541.80	1.00	275.21

Table 7. Average observed values for the variety M-4.

Age (DAP)	LFMD	LFELL	TLF	HT(cm)
35	20.20	0.00	20.20	18.00
74	85.80	10.70	75.10	105.40
97	109.00	27.30	81.70	148.90
156	198.90	85.30	113.60	241.00
190	219.40	142.80	76.60	259.40
228	268.20	213.00	55.20	299.50
265	326.40	238.10	88.30	361.70
323	462.00	250.90	211.10	449.00

Table 8. Predicted distribution of dry matter (gm) in different plant parts at the time of harvest of the three varities by the simulation model.

Variety	DMLF(gm)	DMST(gm)	DMRT(gm)
H-1687	330.71	968.57	793.49
H-2304	281.81	103.39	1,208.14
M-4	125.68	240.75	978.67

DMLF = dry matter in leaves
DMST = dry matter in stems
DMRT = dry matter in roots

Table 9. Distribution of dry matter (gm) observed in different plant parts at the time of harvest in the three varieties.

Variety	DMLF(gm)	DMST(gm)	DMRT(gm)
H-1687	112.13	371.04	733.91
H-2304	201.23	525.76	1,122.92
M-4	213.67	754.29	1,005.48

Table 10. Simulated values of the fresh root weight (gm/plant) yield at time of harvest, and the corresponding values observed in the field.

Variety	Simulated	Observed
H-1687	2,602	2,406
H-2304	3,138	2,917
M-3	2,497	2,565

Coefficients used in these models represent the influence of both the varieties and the environment. So, these are to be computed for each variety and locality. Initial calibration is an essential step before using this model. The model gives fairly accurate predictions, but there is always scope for improvement. This model is helpful mainly for simulating in the computer the various cassava growth parameters.

Model 3

Including the effect of environment in the coefficients makes computer simulation more environment-specific. To develop a growth model, which is more general, the environmental effect should be removed from MODEL 2. The cassava plant system was redesigned with the following components:

a) Total number of leaves formed - LFMD
b) Total number of leaves fallen - LFLLN
c) Total number of leaves - TLF
d) Total leaf area - TLA
e) Leaf Area Index - LAI

f) Net Assimilation Rate - NAR
g) Total dry matter - TDM
h) Dry matter apportioned to stem - DMST
i) Dry matter apportioned to leaves - DMLF
j) Dry matter apportioned to roots - DMRT
k) Matter in dry leaves - DMDLF
l) Branching
m) Potential leaf age - PLFAGE
n) Leaf age - LFAGE

New variables were derived as functions of rainfall and temperature and its effects on the growth of the crop are being investigated. The coefficients, which are more general in all the environments, will give a model which is more general in nature. For using such models, computation of genetic coefficients alone will be sufficient before using such models.

The system starts with the computation of temperature during the growth of the crop and it depends on the rainfall received during the same period.

HT, LFMD, PLFAGE and ALA are the functions of total temperature during the growth of the crop.

LFAGE is calculated from PLFAGE and total temperature during the growth of the crop.

LFAGE is used to compute LFLLN

TLF is calculated as follows:

TLF = LFMD - LFLLN

From TLF and ALA, TLA is calculated as follows:

TLA = TLF * ALA

From TLA, LAI is calculated as follows

LAI= TLA/Spacing

NAR is calculated as a function of LAI

TDM is calculated as follows:

TDM = TLA * NAR

This dry matter is partitioned into the different plant parts and equations are developed to compute these partitioned dry matter values. The computations are continued for the entire growth period.

This model is now in the first stage of development. In subsequent stages, the effect of water, nutrients and pests and diseases will be included to make improvements. The ultimate aim of developing this model is to develop a perfect system for simulating the growth of cassava using a computer.

CONCLUSION

The development of cassava growth models is very important for making more rapid progress in research and development of this crop. Like any other biological system the cassava growth system is very complicated (Santhosh Mithra, 2002). A good understanding of the processes involved is very important for the correct development of the model. So, efforts should be made for the modeling process and the research on this crop to progress simultaneously. Models, which are not specific to any particular cultivar or environment, are very essential for reaping the full advantages of computer simulation,

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