American Journal of Plant Sciences, 2019, 10, 976-986
http://www.scirp.org/journal/ajps
ISSN Online: 2158-2750
ISSN Print: 2158-2742

Simulation of Growth and Leaf Area Index of Quality Protein Maize Varieties in the Southwestern Savannah Region of the DR-Congo

Jean Pierre Kabongo Tshiabukole[1,2], Roger Kizungu Vumilia[3], Gertrude Pongi Khonde[1], Jean Claude Lukombo Lukeba[1,2], Amand Mbuya Kankolongo[1,2], Antoine Mumba Djamba[2], Kabwe K. C. Nkongolo[4*]

[1]Programme National Maïs, INERA, Mvuazi, RD-Congo
[2]Université Pédagogique Nationale, Kinshasa, RD-Congo
[3]Direction Scientifique, Biométrie et Expérimentation, INERA DG & Université de Kinshasa, Kinshasa, RD-Congo
[4]Département des Sciences Biologiques, Université Laurentienne, Sudbury, Canada
Email: *knkongolo@laurentian.ca

How to cite this paper: Tshiabukole, J.P.K., Vumilia, R.K., Khonde, G.P., Lukeba, J.C.L., Kankolongo, A.M., Djamba, A.M. and Nkongolo, K.K.C. (2019) Simulation of Growth and Leaf Area Index of Quality Protein Maize Varieties in the Southwestern Savannah Region of the DR-Congo. *American Journal of Plant Sciences*, **10**, 976-986.
https://doi.org/10.4236/ajps.2019.106070

Received: May 8, 2019
Accepted: June 16, 2019
Published: June 19, 2019

Abstract

Logistic and exponential approaches have been used to simulate plant growth and leaf area index (LAI) in different growing conditions. The objective of the present study was to develop and evaluate an approach to simulate maize LAI that expresses key physiological and phonological processes using a minimum entry requirement for Quality Protein maize (QPM) varieties grown in the southwestern region of the DR-Congo. Data for the development and testing of the model were collected manually in experimental plots using a non-destructive method. Simulation results revealed measurable variations between crop seasons (long season A and short season B) and between the two varieties (Mudishi-1 and Mudishi-3) for height, number of visible leaves, and LAI. For both seasons, Mudishi-3, a short stature variety was associated with expected stable yield based on simulation data. In general, the model simulated reliably all the parameters including the LAI. The LAI value for mudishi-1 was higher than that of Mudishi-3. There were significant differences among the model parameters (K, Ti, a, b, Tf) and between the two varieties. In all crop conditions studied and for the two varieties, the senescence rate (a) was higher, while the growth rate (b) was lower compared to the estimates based on the STICS model.

Keywords

Modeling, Simulation, Climate Change, Leaf Area Index, Quality Protein Maize, INERA RD-Congo

1. Introduction

Assessing the impact of future climate change on the agricultural production system is imperative for the development of different adaptation measures to mitigate its possible negative effect. In developed countries, researchers have been able to assess the impact of different changes in meteorological parameters on crop growth and production under controlled environment [1] [2]. Because of lack of resources and efficient tools in developing countries, an alternative system for assessing climatic phenomena on crops is to use crop simulation models. These models have been an effective and extensive tool in plants and climate impact studies [3] [4] [5] [6].

Green leaf area has been simulated in many studies using different approaches such as discontinuous functions, or regression analysis [7]. In some models (e.g. CERES, GOSSYM, STICS), the leaf area is calculated from the partitioned biomass on the leaves, using the concept of the specific leaf area. The leaf area remains relatively stable at densities below 5 plant/m^2, and then decreases steadily with increasing density [8]. While the plant height increases when plant density is within 3 to 5 plants/m^2, it remains stable for lower densities [8] under normal irrigation conditions.

It has been demonstrated that the leaf area index (LAI) depends on the species, stage of development, site conditions, season and cultural practices. It is a dynamic parameter that varies from day to day and it is well studied in forests conditions [9]. Beadle [10] reports foliar indices between 2 to 4 for annual crops. These measurements can range from 0.4 to 41. He attributed these differences to measurement methods. Thus, for a mono-specific stand, the morphological variables of the model (LAI, heights) characterize the cover as a whole [1] [11] [12] [13].

The objective of this study was to develop and evaluate an approach to simulate maize leaf area index that expresses key physiological and phenological processes using a minimum entry requirement for quality protein maize grown in the field of savannah in the southwestern region of DR-Congo.

2. Materials and Method

Two QPM varieties (Mudishi-1 and Mudishi-3) provided by the National Institute for Agronomic Research and Studies (INERA) were grown in the field during two growing seasons (long season A and short season B) in 2013 and 2014. They were selected based on their agro-ecological adaptation and their socio-economic importance in savannah regions in the DR-Congo. The first sowing was completed in mid-October 2013 and the second in late April 2014. The date of second sowing was chosen to match plant maturity and the dry period. Climatic data corresponding to this experimental period are presented in **Figure 1**.

The trial was conducted following a complete randomized block design with three replications. The experimental units measured 0.8 m × 5 m corresponding

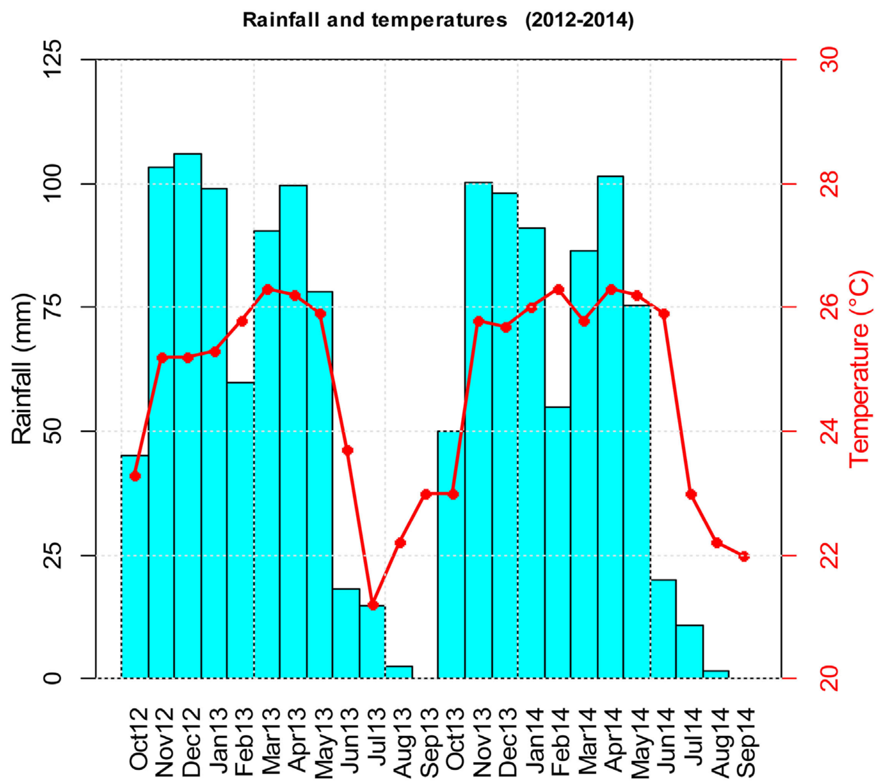

Figure 1. Monthly mean rainfalls and temperature during field trials.

to a density of 4 plants per m^2. During the two seasons, the fields were fertilized with NPK 17-17-17 mineral fertilizer at 250 kg/ha applied at seedling stage. Urea (46%) was applied at 120 kg/ha in a fractional split, half at 15 and the second half at 45 days after sowing, respectively.

Data collections were performed weekly on previously selected plants based on their phenotypic appearance. For all seasons, emergence was defined when coleoptiles of at least 50% of the plants were visible.

2.1. Measurements of Parameters

Plant phenological parameters were based on the appearance of visible leaves, which were noted from the bottom to the top. A leaf was noted as visible when its apical end points out of the horn. Leaves can be numbered from bottom to top, or from top to bottom [14]. The visible length (Lv) and the maximum width (Lm) were measured. The leaf area of an individual leaf (LA) was calculated using the Montgomery formula [15] [16]:

$$LA = Lv * Lm * k \quad (1)$$

With, $k = 0.75$ for ligated leaves, and 0.5 for non-ligated leaves. Lv is the visible length and Lm, the maximum width. The total leaf area (LAt) was estimated by summation of the individual leaf surfaces. The cover of each plant was simulated to a single leaf, the length and width of which is equivalent to the sum of the lengths and widths of the individual leaves.

The maximum plant height was measured from the collar to the last ligule. The simulation of the height and the number of visible sheets estimated the following model parameters:

Asym: parameter giving the asymptotic response as time passes to infinity. He has the same units as the answer.

- T50: parameter giving the time at which the response reaches 50% of Asym. It has the same units as the explanatory variable (time).
- Scal: scale parameter. When the time is T50 + scal, the answer is about 75% of Asym. This parameter has the same units as the variable time.

The leaf area index (LAI) was calculated by multiplying LAt by the number of plants per m^2. It should be noted that maize leaf area can be measured by two methods: the manual method or using an optical planimeter. The difference in measurements using the two methods is significant [17] [18]. The manual method was adopted in this study to minimize costs.

In the absence of water stress, leaf development is a simple function of temperature. The physiological time scale is based on the notion of sum of degree days. The thermal time was calculated according to the formula proposed by Bennouna *et al.* [15]:

$$T = \frac{T_{\max} + T_{\min}}{2} - T_b \tag{2}$$

where, $T_{\max}$ and $T_{\min}$ are respectively the maximum and minimum daily temperature of the air, and Tb the basic temperature of the culture, below which there is no growth. Its value for maize is 10˚C [15]; while for the CERES model this value is 8˚C.

The dynamics of foliar growth in maize were studied using Baret's semi-mechanistic model [13] [14] [18], whose equation is as follows:

$$LAI = K * \left[\frac{1}{1 + \mathrm{e}^{-b(T - T_i)}} - \mathrm{e}^{-a(T - T_f)} \right] \tag{3}$$

This equation is described in two parts, growth and senescence. The growth period is defined by a logistic equation with the parameter b being the growth rate with respect to T_i (cumulative thermal time at the point of inflection). Senescence is determined by an exponential equation with the parameter a as the ratio of the growth rate and T_f (thermal time expressed in cumulative temperatures where all the leaves are senescent). Parameter K describes the maximum amplitude of the leaf area index [13].

2.2. Statistical Analyses

The getInitial and SSlogis function of the R package, procedure for estimating Asym, T50 and Scal parameters were used to simulate the height of the plant and the number of visible leaves. The nls function (Y ~ SSlogis (X, Asym, T50, scal) of the R package was used as a procedure for estimating the parameters and the significance level of the simulation. Nonlinear regression was performed for the leaf area index (LAI) using the nls function of the R package, procedure for the parameterization of the model (a, b, K, Ti, Tf). The calculation of the standard error and the level of significance of the parameters were determined at P = 0.05 (*), 0.01 (**) and 0.001 (***) based on the Student's test. The different models were evaluated on the basis of observed data and theoretical predictions.

3. Results

3.1. Simulation of Maize Plant Growth

3.1.1. Plant Heights

The plant heights for each season are described in Figure 2. The measurements were recorded every 7 days after sowing until the maximum height was reached. During the high season, the model estimated the maximum height (Asym) at 207.09 cm and 202.77 cm for Mudishi-1 and Mudishi-3, respectively. Half of the height (T50) was estimated at 42.86 and 42.88 days after sowing for Mudishi-1 and Mudishi-3, respectively (Table 1).

During the short season, the model estimated the maximum height (Asym) at 173.9 cm and 154.88 cm for Mudishi-1 and Mudishi-3, respectively. The half-height (T50) estimates were 38.08 days (Mudishi-1) and 47.42 days (Mudishi-3) after sowing.

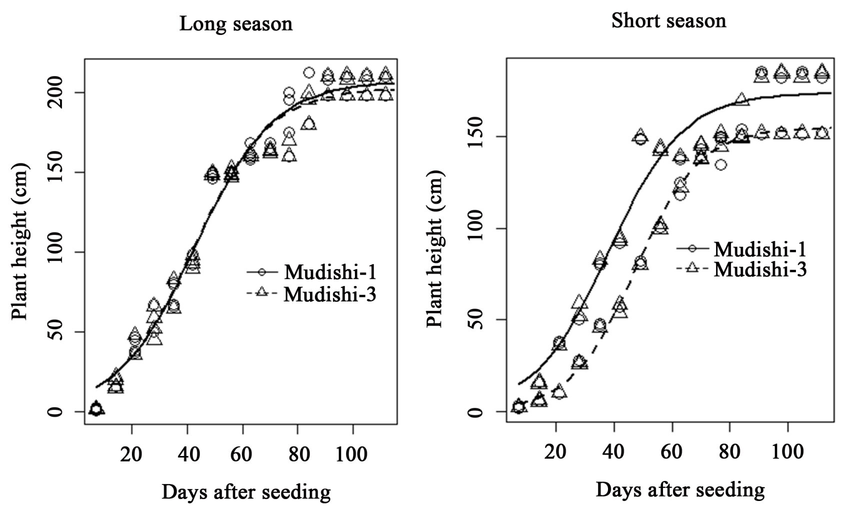

Figure 2. Evolution of plant height of two maize varieties (Mudishi-1 and Mudishi-3).

Table 1. Estimation of model parameters for two varieties of maize during two seasons for plant height.

Variety	Season	Parameters			Yld (kg/ha)
		Asym (cm)	T50 (Days)	Scal	
Mudishi1	Long	207.09***	42.86***	14.26***	2528
	Short	173.9***	38.08***	12.9***	1512
Mudishi3	Long	202.77***	42.88***	13.9***	2278
	Short	154,88***	47.42***	11.18***	1546

Signif. codes: 0 "***" 0.001 "**" 0.01 "*" 0.05 "." 0.1 " " 1, Rld: Grain yield.

3.1.2. Number of Visible Leaves

Figure 3 shows changes in the number of visible leaves during the two seasons. The simulation data show that during the long season, the number of visible leaves is at its maximum (Asym) at 12.48 and 13.23 leaves for Mudishi-1 and Mudishi-3, respectively. Since leaf expansion is a function of the daily air temperature, the simulation of this parameter shows that half of the number of visible leaves is reached at 318.18˚C and 377.06˚C after emergence, for Mudishi-1 and Mudishi-3, respectively.

Observations during the short season were similar to those of the long season but with adverse trends. The maximum number of visible leaves (Asym) was 13.70 and 12.90 after emergence, for Mudishi-1 and Mudishi-3, respectively. Half the number of leaves was estimated at 357.4 (Mudishi-1) and 352.52˚C (Mudishi-3) after emergence (Table 2).

In both cases, the appearance of visible leaves was a non-symmetrical sigmoid (Figure 3). The first 6 leaves appear at 460˚C after emergence for all varieties. Mudishi-3 variety grew faster compared to Mudishi-1 and reached the maximum number of leaves at 860˚C J, while Mudishi-1 evolved slowly at a more or less regular rate, and reached the maximum number of leaves at 1000˚C J.

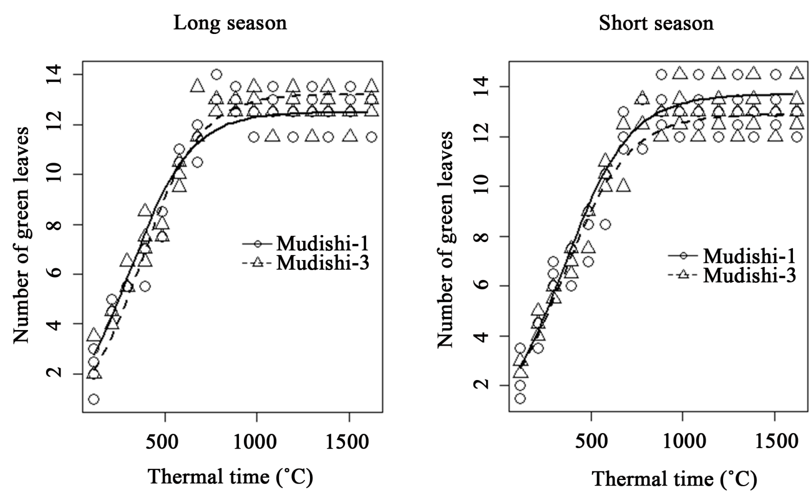

Figure 3. Evolution of the number of visible leaves of two maize varieties (Mudishi-1 and Mudishi-3).

Table 2. Estimation of model parameters for two maize varieties in two seasons for the number of visible leaves.

Variety	Season	Parameters			Yld (kg/ha)
		Asym	T50 (˚C)	Scal	
Mudishi1	Long	12.48***	318.18***	162.43***	2528
	Short	13.70***	357.4***	177.3***	1512
Mudishi3	Long	13.21***	377.06***	160.7***	2278
	Short	12.90***	352.52***	177.88***	1546

Signif. codes: 0 "***" 0.001 "**" 0.01 "*" 0.05 "." 0.1 " " 1; Yld: Grain yield.

3.2. Simulation of Leaf Area Index

Estimations of the different parameters based on the STICS model are described in Table 3. Maize has a general response of developmental rate to temperature, the genetic variation of is observed for maturity [13]. The model is well adapted and the leaf area index is a good simulation of both varieties. Figure 4 shows the evolution of observation points and simulation curves of the leaf area index during the long (A) and short (B) seasons for both varieties.

The maximum leaf area index (K) was estimated at 30.8 and 25.4 for Mudishi-1 and Mudishi-3, respectively. During the long season (A), the two varieties each yielded 2528 and 2278 kg/ha, respectively. The model simulated the parameters a, b, Ti and Tf for both varieties. For the vegetative cycle, the simulated thermal times were 1630˚C and 1605˚C J for Mudishi-1 and Mudishi-3, respectively. These parameters were also well simulated for the short season (B).The maximum amplitudes of the leaf indices were estimated at 28.1 and 27.5˚C for both varieties with yields of 1546 and 1512 kg/ha for Mudishi-1 and Mudishi-3, respectively. For all models, simulations were significantly high at $p < 0.01$ and $p < 0.001$ for all parameters during both seasons.

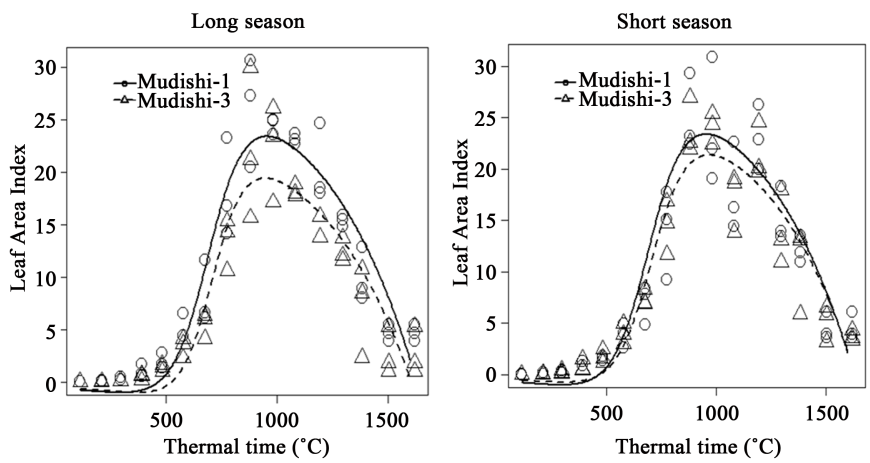

Figure 4. Simulation of the leaf area index for the two maize varieties (Mudishi-1 and Mudishi-3) relative to the thermal weather.

Table 3. Estimation of model parameters for both corn varieties (Mudishi-1 and Mudishi-3) during the long (a) and short (b) seasons.

Variety	Season STICS	Parameters					Yld (kg/ha)
		K	Ti	b	a	Tf	
		4.27	674	0.0012	0.0074	1657	
Mudishi1	Long	30.8***	692.9***	0.0023***	0.012***	1630***	2528
	Short	28.1***	718.6***	0.0026**	0.012**	1640***	1512
Mudishi3	Long	25.4***	711.2***	0.0024***	0.013**	1605***	2278
	Short	27.5***	707.9***	0.012***	0.0025***	1635***	1546

Sig. codes: 0 "***" 0.001 "**" 0.01 "*" 0.05 "." 0.1 " " 1; Yld: Grain Yield.

4. Discussion

The objective of this study was to develop and evaluate an approach to simulate LAI that expresses key physiological and phenological processes using a minimum entry requirement. A simulation of the non-source leaf area was chosen because the source limitation was minimized by maize management under optimal and semi-optimal conditions. An important goal of this effort was to develop a practical application model, with less complexity and few specific cultivar parameters.

There were measurable variations in both seasons for the simulated growth of maize plants. In fact, significant variations in size, number of leaves and yield were observed. The theoretical heights for the long season (A) were closer to the values observed for all varieties tested (207.09 cm for the Mudishi-1 variety and 202.77 cm for the Mudishi-3). During this season, the plants grew faster and half of the maximum height was reached on average 42.8 days after sowing for both varieties.

During the short season (B), Mudishi-3, with short plants, was associated with higher expected performance based on simulation data. This is in accordance with Johnson *et al.* [19] who reported that a reduction in plant height associated with increased performance. However, other authors [20] [21] have shown that the leaf surfaces of maize plants under drought conditions were smaller than those of well-watered plants. It is known that a slight reduction in the water potential in the rhizosphere immediately decreases the growth of maize leaves [22] [23] [24].

The leaf area index is a factor that plays an important role in crop production for both quantitative and qualitative traits. It was noted that K, Ti, b, a, and Tf values varied with simulation model, maize variety, and field trial location used in the study. In all cases, the model underestimated LAI based on observed values. The CERES-Maize and STICS models can also be used to evaluate LAI in some studies. Despite the underestimation of leaf area index, dry matter production can be significantly overestimated due to errors in choice of varieties and inputs.

In the present study, the LAI values for Mudishi-1 and Mudishi-3 were larger than those observed by Lukombo *et al.* [13] for improved natural varieties and by Lufuluabo *et al.* [14] for unimproved normal varieties in experimental plots in rural areas of Gandajika. This can be explained by the fact that LAI is low for a significant part of the cycle because of low seeding rates or other stressors based on multiple observations in tropical conditions [25].

The results of this study also show that during the long season, the growth rate (b) remained lower, while that of senescence (a) was high for both varieties compared to STICS estimates. The thermal time required to complete Mudishi-1 cycle is estimated at 1630˚C while that of Mudishi-3 at 1605˚C. The values are also higher than those estimated by Lufuluabo *et al.* [18] and lower than or equal to those of Lukombo *et al.* [13]. In southern Africa, the thermal time required for maize plant growth and development was estimated at 1500˚C and 1600˚C for early maturing cultivars; 1600˚C J and 1700˚C J for mature cultivars and averaged 1800˚C J for late-maturing cultivars [26].

Current trends in crop modeling are to adapt existing models to local conditions. In the present study, equations to predict both leaf area and leaf sensitivity for protein-grade maize varieties grown in a DR-Congo savannah region were tested and adapted. In fact, Affholder *et al.* [25] discussed the utility and relevance of ad hoc modeling in agronomy. They highlighted the two main problems of crop modeling: defining the structure of the model according to the issue to be addressed (conceptualizing the model) and how to minimize software development efforts (global computerization). Based on the literature discussed by these authors, the approach of integrating crop models and databases is an effective alternative for scientists who wish to have the greatest understanding of their crop models.

5. Conclusion

In the present study, the growth and development of the maize plants varied from season to season. Mudishi-1 variety tends to simulate a higher leaf area index than Mudishi-3, which seems to stabilize its development and production in all seasons. Differences in parameters such as maximum leaf area index (k), growth rate (b) and senescence rate (a) are explained by varietal differences, based on drought tolerance. Significant differences between simulated and observed leaf area index can be attributed to stressors that were not considered in the equations. Based on the results of this study and other reports, maize producers should use drought tolerant QPM varieties adapted to local growing conditions.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

[1] Leakey Andrew, A.D.B., Uribelarrea, M., Ainsworth, E., Naidu, S.L., Rogers, A., Ort, D.R. and Long, S.P. (2006) Photosynthesis, Productivity, and Yield of Maize Are Not Affected by Open-Air Elevation of CO_2 Concentration in the Absence of Drought. *Plant Physiology*, **140**, 779-790. https://doi.org/10.1104/pp.105.073957

[2] Leakey, A.D.B., Bernacchi, C.J., Dohleman, F.G., Ort, D.R. and Long, S.P. (2004) Will Photosynthesis of Maize (*Zea mays*) in the US Corn Belt Increase in Future [CO_2] Rich Atmospheres? An Analysis of Diurnal Races of CO_2 Uptake under Free-Air Concentration Enrichment (FACE). *Global Change Biology*, **10**, 951-962. https://doi.org/10.1111/j.1529-8817.2003.00767.x

[3] 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. and Ritchie, J.T. (2003) The DSSAT Cropping System Model. *European Journal of Agronomy*, **18**, 235-265. https://doi.org/10.1016/S1161-0301(02)00107-7

[4] Carbon, G.J., Kiechle, W., Locke, C., Mean, L., McDaniel, L. and Downton, M. (2003) Response of Soybean and Sorghum to Spatial Variations in the Southern United States. *Climatic Change*, **60**, 73-98. https://doi.org/10.1007/978-94-017-1984-1_4

[5] Easterling, W.E., Chhetri, N. and Niu, X. (2003) Improving the Realism of Modeling Agronomic Adaptation to Climate Change. *Climatic Change*, **60**, 149-173. https://doi.org/10.1007/978-94-017-1984-1_7

[6] Timsina, J. and Humphreys, E. (2006) Applications of CERES-Rice and CERES-Wheat Models in Research, Policy, and Climate Change Studies in Asia: A Review. *International Journal of Agricultural Research*, **1**, 202-225. https://doi.org/10.3923/ijar.2006.202.225

[7] Baker, H., Horrocks, R. and Goering, C. (1975) Use of the Gompertz Function for Predicting Corn Leaf Area. *Transactions of the ASAE*, **18**, 323-326. https://doi.org/10.13031/2013.36580

[8] Kasperbauer, M.J. and Karlen, D.L. (1994) Plant Spacing and Reflected in Phytochrome-Regulated Photosynthesis Allocation in Corn Seedlings. *Crop Science*, **31**, 1564-1569. https://doi.org/10.2135/cropsci1994.0011183X003400060027x

[9] Tuner, D.P., Acker, S.A., Means, J.E. and Garman, S.L. (2000) Assessing Alternative Allometric Algorithms for Estimating the Leaf Area of Douglas-Fir Trees and Stands. *Forest Ecology and Management*, **126**, 61-76. https://doi.org/10.1016/S0378-1127(99)00083-3

[10] Beadle, C.L. (1993) Growth Analysis. In: Hall, D.O., Scurlock, J.M.O., Bolhar-Nordenkampf, H.R., Leegood, R.C. and Long, S.P., Eds., *Photosynthesis and Production in a Changing Environment*: *A Field and Laboratory Manual*, Chapman & Hall, London, 36-46.

[11] Bouman, B.A., Van Keulen, M. and Rabbinge, H.H. (1998) The School of the Wit, Crop Growth Simulation Model: A Pedigree and Historical Overview. *Agricultural Systems*, **52**, 171-198. https://doi.org/10.1016/0308-521X(96)00011-X

[12] Brisson, N.B., Mary, D., Ropoche, D., Jeuffroy, M.H., Ruget, F., Nicoullaud, B., Gate, P., Devienne-Barret, F., Antonioletti, R., Durr, C., Richard, G., Beaudoin, N., Recous, S., Tayot, X., Plenet, D., Cellier, P., Machet, J.M., Meynard, J.M. and Delecolle, R. (1998) STICS: A Generic Model for the Simulation of Crop and Their Water and Nitrogen Balance. I, Theory and Parametrization Applied to Wheat and Corn. *Agronomy*, **18**, 311-346. https://doi.org/10.1051/agro:19980501

[13] Lukombo, L.J.C., Kizungu, V.R., Nkongolo, K.C.K., Lufuluabo, M.M. and Tsumbu, M. (2013) Growth and Leaf Area Simulation Index in Maize (*Zea mays* L.) under Small-Scale Farm Conditions in a Sub-Saharan African Region. *American Journal of Plant Sciences*, **4**, 575-583. https://doi.org/10.4236/ajps.2013.43075

[14] Lufuluabo, M., Kizungu, R.V. and Nkongolo, K.K. (2011) Corn Leaf Development and Plant Growth: Adaptation of STICS. Simulation Model to Tropical Conditions in DR Congo. *Agronomie Africaine*, **23**, 91-102.

[15] Bennouna, B., Lahrouni, A. and Khabba, S. (2005) Maize Growth Parameters in Marrakech Haouz (Morocco). *Cahiers Agricultures*, **14**, 437-446.

[16] Elings, A. (2000) Estimate of Leaf Area in Tropical Maize. *Agronomy Journal*, **92**, 436-444. https://doi.org/10.2134/agronj2000.923436x

[17] Francis, C.A., Ruget, J.N. and Palmer, A.F. (1969) A Rapid Method for Plant Leaf Area Estimate in Maize (*Zea mays*). *Crop Science*, **9**, 537-539. https://doi.org/10.2135/cropsci1969.0011183X000900050005x

[18] Koetz, B., Baret, F., Poilve, H. and Hill, J. (2005) The Use of Coupled Dynamic

Structure and Radiative Transfer Models to Estimate Biophysical Canopy Characteristics. *Remote Sensing of Environment*, **95**, 115-124. https://doi.org/10.1016/j.rse.2004.11.017

[19] Johnson, E.C., Fischer, K.S., Edmeades, G.O. and Palmer, A.F.E. (1986) Recurrent Selection for Reduced Plant Height in Lowland Tropical Maize. *Crop Science*, **26**, 253-260. https://doi.org/10.2135/cropsci1986.0011183X002600020008x

[20] Sarah, H. and Tardieu, F. (1997) Control of Leaf Expansion Rate of Drought Maize Plants under Fluctuating Evaporative Demand. *Plant Physiology*, **114**, 893-900. https://doi.org/10.1104/pp.114.3.893

[21] Cakir, R. (2004) Effect of Water Stress at Different Development Stages on Vegetative and Reproductive Growth of Corn. *Field Crops Research*, **89**, 1-16. https://doi.org/10.1016/j.fcr.2004.01.005

[22] Boyer, S. (1970) Leaf Enlargement and Metabolic Rates in Corn, Soybean, and Sunflower at Various Leaf Water Potentials. *Plant Physiology*, **46**, 233-235. https://doi.org/10.1104/pp.46.2.233

[23] Acevedo, E., Fereres, E., Hsiao, T. and Henderson, D. (1979) Diurnal Growth Trends, Water Potential and Osmotic Adjustment of Maize and Sorghum Leaves in the Field. *Plant Physiology*, **64**, 476-480. https://doi.org/10.1104/pp.64.3.476

[24] Acevedo, E., Hsiao, T. and Henderson, D. (1971) Immediate and Subsequent Growth Responses of Maize Leaves to Changes in Water Status. *Plant Physiology*, **48**, 631-635. https://doi.org/10.1104/pp.48.5.631

[25] Affholder, F., Scopel, E., Madeira Neto, J. and Capillon, A. (2003) Diagnosis of the Productivity Gap Using a Crop Model. Methodology and Case Study of Small-Scale Maize Production in Central Brazil. *Agronomie*, **23**, 305-325. https://doi.org/10.1051/agro:2003004

[26] Ristanovic, D. (2001) Maïs (*Zea mays* L.). In: Raemaekers, R.H., Ed., *Crop Production in Tropical Africa*, Ministry of Foreign Affairs, External Trade and International Cooperation, Brussels, Directorate General for International Co-Operation (DGIC), 23-45.