ea engenharia agrícola

Journal of the Brazilian Association of Agricultural Engineering

ISSN: 1809-4430 (on-line)

SIMANIHOT: A PROCESS-BASED MODEL FOR SIMULATING GROWTH, DEVELOPMENT AND PRODUCTIVITY OF CASSAVA

Doi:http://dx.doi.org/10.1590/1809-4430-Eng.Agric.v37n3p471-483/2017

LUANA F. TIRONI[1], NEREU A. STRECK[2*], PAULO I. GUBIANI[1], RÔMULO P. BENEDETTI[1], CHARLES P. DE O. DE FREITAS[1]

[2*] Corresponding author. Universidade Federal de Santa Maria - UFSM/ Santa Maria - RS, Brasil.
E-mail: nstreck2@yahoo.com.br

ABSTRACT: The objective of this study was to propose a model, named Simanihot, for simulating growth, development and yield of tuberous roots in cassava, with a choice of two soil water balance models. The model works on a day time step and is calibrated for five cassava cultivars (Fepagro – RS 14, Estrangeira, Cascuda, São José e Paraguaia), with different branching habits and different purpose of use (pasture, food and industry). The model has a graphical interface, where the user can choose one out of two soil water balance models, depending upon the number of known soil variables and details the user wants to know about soil water content.

KEYWORDS: *Manihot esculenta*, modeling, software, soil water balance.

INTRODUCTION

Cassava (*Manihot esculenta* Crantz L) is a subsistence crop in several developing tropical countries, being usually grown on small farms in Brazil. Therefore, the studies on such plant species may contribute to improving the living conditions of low income populations.

Process-based dynamic models are modern tools for simulation of growth, development, and productivity of several farming crops; they can be used for academic, scientific and extension studies and for decision-making purposes. Such models allow us to understand how plants grow and develop, how photoassimilates are translocated from the sources to the sinks within a plant, how biotic and abiotic stresses affect crop yield, and also assisting in management practices such as fertilizer application, control of pests, diseases and weeds (KIM et al., 2012; NASSIF et al., 2012, SINGH et al., 2016).

Crop models should be calibrated and tested for the local conditions of the cultivated region, so that the genetic coefficients values could be suitable for describing plant physiological and ecophysiological responses. GUMCAS is a cassava model, developed by MATTHEWS & HUNT (1994), which underwent modifications for conditions without water stress, as found in the subtropical region of Rio Grande do Sul (Brazil), and was calibrated for the cultivar Fepagro - RS13 (GABRIEL et al., 2014). This cultivar is used as forage and has a tricotomic sympodial growth habit, bringing forth up to three sympodial branches during a single growing season (SAMBORANHA et al., 2013).

Cassava morphological structure may vary with genotype, being either monopodial or sympodial (branched), having two, three, or four stems that are known as sympodial branching (TIRONI et al., 2015). Cassava genotypes also differ regarding the purpose of use (forage, human food, industry). In addition, as the modified GUMCAS model validation was carried without water restrictions (GABRIEL et al. 2014), its use is also limited in field conditions since drought episodes may impair plant growth (LAGO et al., 2011; PINHEIRO et al., 2014) and, consequently, yield of tuberous roots (MATTHEWS & HUNT, 1994).

This study aimed to propose a simulation model of growth, development, and productivity for tuberous roots of cassava using two soil water balance models.

[1] UFSM/ Santa Maria - RS, Brasil.
Received in: 3-9-2016
Accepted in: 2-15-2017

MATERIAL AND METHODS

The simulation model for cassava cropping proposed in this study, named "Simanihot" ("Si" for Simulator, and "manihot" for cassava's scientific name "*Manihot esculenta* Crantz L."), is originated from the GUMCAS model proposed by MATTHEWS & HUNT (1994) and modified by GABRIEL et al. (2014). The main changes were a third developmental clock simulating the beginning of tuberization, a nonlinear model for leaf appearance rate, and a sensitivity coefficient that affects leaf senescence at a great proportion at minimum air temperatures equal to or lower than 5 ºC.

Two soil water balance methods were introduced into the Simanihot model. One uses the Thornthwaite and Mather approach, which is simpler and requires fewer input parameters related to soil conditions. Another was the Ritchie's model, which, in turn, is more complex and considers most of the water processes and dynamics at different soil layers, besides requiring a larger number of parameters related to soil physical conditions.

For the daily calculation of the water balance with the Thornthwaite and Mather method, the maximum crop evapotranspiration (ETc) was calculated as: ETc = ETo x Kc; where ETo is the reference evapotranspiration and Kc is the crop coefficient. The variation in Kc during crop developmental cycle was described by a daily developmental response function (Dd) influenced by temperature and photoperiod. We considered as initial, maximum, and final the Kc values of 0.3, 1.1, and 0.55, respectively. Kc maximum covered the period between 65 and 100 Dd. From initial to maximum, and from maximum to final Kc, the response function was defined by linear interpolation.

In the Ritchie's soil water balance, the number curve method proposed by the Soil Conservation Service represented the infiltration and runoff sub-model. For each soil, a value depending on the physic-hydrological conditions was assigned to the curve number 2 (CN2). The maximum daily absorption of water by the roots in a given layer (RWUMX) was assumed to be 0.03 cm^3 per root cm. The amount of new roots formed daily (RLNEW), used in estimating root length density, was calculated as follows: RLNEW=(TRF(i-1)*0.5)+(TRT(i-1)*(1.5*exp(a*(DesRep-IAA)))); in which, TRF is the growth rate of fibrous roots, TRT is the rate for tuberous roots, DesRep is the sum of daily reproductive development (Dd), and OSA is the sum of daily development between emergence and early starch accumulation.

In both models, the effective root depth (ze) was estimated through the sigmoidal growth curve, as proposed by DOURADO-NETO et al. (1999). In this curve, the number of days was replaced by development time (SomaRv, Dd). Initial depth (ze_{in}) was 8 cm (depth at which maniocs were buried in the soil), yet the maximum depth (zemax) was 35 cm at 70 Dd (SomaRvfin), and the growth curve shape factor (f) was 0.9. For estimates of reference evapotranspiration (ETo), the Penman-Monteith's method was used in both water balance models.

The amount of soil water available for plants was estimated as the fraction of transpirable soil water (FTSW= (SW_{med}-$LINF_{med}$)/(DUL_{med}-$LINF_{med}$)); in which, SW_{med} is the current mean content of soil water (cm^3/cm^3), $LINF_{med}$ is the mean soil water content when plant transpiration is lower than or equal to 10% potential transpiration (cm^3/cm^3), and DUL_{med} is the mean soil water content at field capacity (cm^3/cm^3). $LINF_{med}$ was assumed as the soil water content at 650 kPa.

Under high atmospheric demand (reference evapotranspiration above or equal to 3.5 mm), the daily relative leaf growth (RLG, GABRIEL et al., 2014) was calculated as proposed by PINHEIRO et al. (2014), considering a threshold FTWS of 0.35, using the following equation: RLG= 1/(1+EXP(-12.9649*(FTWS-0.1253))). Under low atmospheric demand (reference evapotranspiration below 3.5 mm), RLG was estimated based on LAGO et al. (2011), considering a critical FTWS of 0.17, using the following equation: RLG= 1/(1+exp(-58.1033*(FTWS-0.1165))). RLG is 1 until FTWS reaching its critical value; likewise, until this moment, leaf appearance rate, leaf size, specific leaf area, and crop growth rate equations are multiplied by 1. If the threshold FTWS is achieved, crop growth starts to be affected. The next day, after water stress ceases, a compensatory effect takes place increasing the rate of leaf appearance and the size thereof (MATTHEWS & HUNT, 1994).

The cultivars used for calibration in this study were Fepagro - RS 14 (forage); Cascuda, Estrangeira, São José (human food), and Paraguaia (industry). These cultivars are the most used by farmers in Rio Grande do Sul (Brazil). Fepagro - RS14, Cascuda, and Estrangeira were calibrated with data from an experiment conducted in Santa Maria, in the 2010-2011 growing season (TIRONI et al., 2015). For São José and Paraguaia, we used data from an experiment in the same location but in the 2013-2014 growing season. Calibration was made by estimating genetic parameters through trial and error method (MATTHEWS & HUNT, 1994). This technique minimizes the mean square error between observed and estimated values. For São José and Paraguaia (2013-2014), we followed the approach proposed by GABRIEL et al. (2014), in which planting was performed on September 27, 2013 and harvests were made on April 28, 2014, for Paraguaia and May 5, 2014, for São José.

The Simanihot model evaluation was performed with independent data from six experiments, as shown in Table 1. Four of them were conducted in Santa Maria - RS (29.72º S, 53.72º W, 103 m) between the growing seasons of 2011-2012 and 2014-2015 and two experiments performed in a commercial farm in Vera Cruz - RS (29.71º S, 52.51º W, 68 m). Experiment 1 detailing can be found in TIRONI et al. (2015), while the other experiments, in Santa Maria, followed the same protocol as the one applied in 2013-2014. In Experiments 5 and 6, the commercial crop with 3,500 plants (planting holes) was divided into four quadrants. Monthly, three plants were collected randomly from each quadrant, following the same method in 2013-2014.

TABLE 1. Independent data sets used to evaluate the Simanihot model.

Experiment	Site	Growing season	Plant density (pl ha^{-1})	Planting date	Harvesting date	Cultivar
1	Santa Maria	2011/2012	15,625	27/09/2011	22/06/2012	Fepagro – RS14, Cascuda, Estrangeira
2	Santa Maria	2012/2013	15,625	06/09/2012	03/06/2013	Fepagro – RS14, Cascuda, Estrangeira
3	Santa Maria	2013/2014	15,625	27/09/2013	28/04/2014	Estrangeira
4	Santa Maria	2014/2015	15,625	24/09/2014	14/05/2015	Paraguaia, São José
5	Vera Cruz	2013/2014	12,500	10/10/2013	10/05/2014	São José
6	Vera Cruz	2014/2015	12,500	10/10/2014	16/05/2015	São José

The relevant meteorological data for the model running were taken from an automatic weather station (AWS) of Brazilian National Weather Service (INMET), in Santa Maria - RS, located about 100 m from the experiments, and from an AWS of INMET, in Rio Pardo - RS, about 18 km distant from the farm.

In the 2014-2015 growing season, soil moisture sensors were installed to measure volumetric soil water content in the experimental areas of Santa Maria and Vera Cruz (São José cultivar). The moisture measurements were made at different soil depths (5, 10, 22.5, and 40 cm), which represented three different soil layers 0-15 cm (layer 1), 15-30 cm (layer 2), and 30-50 cm (layer 3) for Santa Maria, and 0-20 cm (layer 1), 20-30 cm (layer 2), and 30-50 cm (layer 3) for Vera Cruz. A data logger stored soil moisture data every 20 minutes. In order to compare the soil water content calculated by Thornthwaite and Mather model - which provides a mean value of the layer water content - with those by Ritchie's model, a weighted average of this variable was calculated according to root depth. In Ritchie's model, CN2 in Santa Maria was 81, and in Vera Cruz was 67.

The performance of the model with the independent data (Table 1) was assessed by running the Simanihot model three times with water balance deactivated and three times activated (one round with each water balance model). Performance was evaluated using the root of the mean square error (RMSE), BIAS index, correlation coefficient (r), agreement index (dw), and model efficiency (EF) (GABRIEL et al., 2014).

Simanihot works at a one-day time step. The source code was written in FORTRAN 77 by NetBeans IDE 8.0.1 compiler and its graphical interface was written in Java (version 1.8.0_66). A copy of the software can be obtained, at no charge, at www.ufsm.br/simanihot.

RESULTS AND DISCUSSION

Table 2 contains the Simanihot genetic parameters calibrated for each cultivar. Each cultivar has a development period until emergence, OSA, and BS1, BS2, BS3, BS4. From BS1 to BS4 are represented the morphological differences among cultivars, some of them can branch up to three times (Fepagro-RS 14), while others have no branching during the growing season (Estrangeira, São José, and Paraguaia). The parameters influencing leaf size (LS_{300}, LS_{Max}, t_{TF}, tm) also vary with cultivar. For cultivars branching more than once (Fepagro - RS 14, Cascuda), LS_{Max} is lower than the calibrated for cultivars without branching (Estrangeira, São José, and Paraguaia). Each cultivar has its own LAR_{max}, which means that each genotype has a different leaf appearance rate (Table 2).

TABLE 2. Genetic parameters in the Simanihot model calibrated for the cassava cultivars Fepagro-RS 14, Cascuda, Estrangeira, São José and Paraguaia.

Parameter	Fepagro- RS 14	Cascuda	Estrangeira	São José	Paraguaia
PE	6,08	6,64	6,08	8,98	7,50
SB1	22,44	29,61	-	-	-
SB2	54,11	62,64	-	-	-
SB3	70,83	-	-	-	-
SB4	-	-	-	-	-
OSA	23,60	23,05	20,75	27,64	27,46
NMS	1	1	1	1	1
NSRS1	2,86	3,09	-	-	-
NSRS2	2,40	2,35	-	-	-
NSRS3	2,00	-	-	-	-
NSRS4	-	-	-	-	-
LS_{300}	35	25	35	35	45
LS_{Max}	290	280	370	400	350
t_{TF}	100	100	100	70	90
tm	35	35	35	35	15
SLA_0	220	220	220	220	210
CGRmax	25	23,0	30,5	31,0	30,5
P_{leaf}	170	160	110	170	110
Υ_{s1}	0,25	0,20	0,50	0,25	0,25
LARmaxMS	1,0458	0,9708	1,0419	0,9611	1,2300
LARmaxSB1	1,1066	1,1715	-	-	-
LARmaxSB2	0,7026	0,2609	-	-	-
LARmaxSB3	0,2264	-	-	-	-
HIPA	0,30	0,20	0,30	0,35	0,30
HFPA	0,65	0,65	0,65	0,85	0,76

* PE (Developmental time from planting to emergence, Dd); SB1, SB2, SB3, SB4 (Developmental time from emergence and the first simpodial branching (SB1), second simpodial branching (SB2), third simpodial branching (SB3), fourth simpodial branching (SB4) Dd); OSA (Developmental time from emergence and onset of starch accumulation, Dd); NMS (Number of the main stem); NSRS1 (Number of stems in the BS1); NSRS2 (Number of stems in the BS2); NSRS3 (Number of stems in the BS3); NSRS4 (Number of stems in the BS4); LS_{300} (Leaf size at 300 days after emergence (DAE), cm²); LSmax (Maximum leaf size, cm²); t_{TF} (Date at which max leaf size occurs DAE); tm (Form coefficient in the leaf size equation); SLA_0 (Specific leaf área for the one cultivar at a temperature of the 24ºC and without water stress, cm²/g); CGRmax (Maximum crop growth rate, g/m² dia); Pleaf (Maximum leaf age, dias); Υ_{s1} (Coefficient of senescence sensitivity to shading when Tmin> 5,0 ºC); LARmaxMS, LARmaxSB1, LARmaxSB2, LARmaxSB3 (Maximum leaf appearance rate for the MS, SB1, SB2 and SB3), HIPA (Initial stem/shoot ratio); HFPA (Final stem/shoot ratio), Dd (Development day).

When running the model with independent data (Table 1), no differences were observed regarding growth, development, and yield variables simulated both with the water balance activated or not, indicating that soil moisture was not a limiting factor for the crop during growing season and in all experiments. Figures 1 and 5 show Simanihot simulation for each cultivar in one growing season. The other simulations with statistics are shown in Table 3.

For Fepagro-RS 14 (Figure 1), the RMSE of stem dry mass (SDM) values was 188.03 g m^{-2}, corresponding to 1.88 ton ha^{-1}; RMSE for root dry mass (RDM) was 273.86 g m^{-2}, i.e. 2.74 ton ha^{-1}. LAI had an RMSE of 1.11; while dw, EF, and r were above 0.9, and BIAS index reached 0.08; therefore, the observed values were overestimated. As a forage cultivar, it is compound of large-sized plants with great shoot-yielding variability, reflecting in high standard deviation LAIs. Thus, in this process, the observed values had a great variability what brought about LAI overestimation. Leaf number presented an RMSE of 2.52 leaves, with dw, EF, and r at a maximum value (1.00), and BIAS index of 0.02, indicating good performance of the Simanihot model. The number of stems simulated by the model, in general, followed the same trend of the observed ones (Figure 1h).

TABLE 3. Statistics of the evaluation of the performance of the Simanihot model for cassava cultivars in different growing seasons in Santa Maria and Vera Cruz, RS.

Site/Cultivar/ growing season	Statistic	Stem * (g m^{-2})	Leaves* (g m^{-2})	Roots* (g m^{-2})	Total* (g m^{-2})	LAI*	NL* (leaves pl^{-1})
Santa Maria							
Fepagro – RS 14							
2012/2013	RMSE	10.93	29.80	68.15	46.55	0.37	6.31
	dw	0.99	0.93	0.69	0.98	0.98	0.98
	EF	1.00	0.93	0.83	0.99	0.99	0.99
	BIAS	0.03	0.31	-0.64	-0.12	0.17	0.14
	r	0.99	0.97	0.79	0.99	0.99	0.98
Cascuda							
2012/2013	RMSE	16.43	21.98	77.04	50.12	0.53	8.11
	dw	0.97	0.96	0.55	0.97	0.94	0.96
	EF	0.97	0.95	0.76	0.98	0.97	0.98
	BIAS	0.30	0.27	-0.79	-0.20	0.34	0.24
	r	1.00	0.99	0.92	1.00	0.98	0.99
Estrangeira							
2012/2013	RMSE	32.84	29.35	86.93	100.62	0.64	13.12
	dw	0.96	0.85	0.99	0.99	0.84	0.97
	EF	0.99	0.96	1.00	1.00	0.95	0.99
	BIAS	-0.05	0.26	-0.01	-0.02	0.32	0.18
	r	0.93	0.80	0.98	0.98	0.82	0.99
Estrangeira							
2013/2014	RMSE	58.39	25.33	89.96	166.15	0.69	10.60
	dw	0.91	0.95	0.99	0.98	0.88	0.97
	EF	0.95	0.97	0.99	0.98	0.97	1.00
	BIAS	-0.30	-0.19	-0.15	-0.19	0.04	0.15
	r	0.95	0.99	0.99	0.99	0.78	0.99
São José							
2014/2015	RMSE	86.56	26.38	195.57	161.23	0.42	5.58
	dw	0.94	0.93	0.94	0.98	0.97	1.00
	EF	0.97	0.96	0.94	0.99	0.99	1.00
	BIAS	-0.08	0.15	0.45	0.18	0.00	0.00
	r	0.90	0.90	1.00	0.99	0.94	1.00
Vera Cruz							
São José							

2014/2015	RMSE	34.07	49.52	246.30	316.47	0.93	-
	dw	0.98	0.72	0.88	0.90	0.78	-
	EF	0.99	0.64	0.86	0.90	0.82	-
	BIAS	0.14	0.82	0.64	0.50	0.42	-
	r	0.98	0.82	1.00	0.99	0.71	-

* Stem (stem dry matter; Leaves (leaves dry matter); Roots (roots dry matter), Total (total dry matter); LAI (leaf area index); NL (number of leaves per plant).

The simulation for Cascuda, in 2011-2012, resulted in SDM values slightly smaller (Figure 2a) if compared to those simulated with an RMSE of 87.69 g m^{-2}, and RDM of 131.32 g m^{-2} (Figure 2c), in which the simulated value was within the standard deviation of the observed values. LAI (Figure 2f) presented an RMSE of 0.49, EF of 1.00, dw, and r of 0.99, and BIAS index of 0.11, with simulated values overestimating the observed values. The number of leaves (NL) (Figure 2g) had an RMSE of 4.65 leaves, with dw, EF, and r at its maximum (1.00), and BIAS index of -0.03. It was because at the end of the growing season the simulated values were slightly below those observed ones.

For Estrangeira, in the 2011-2012 growing season, SDM (Figure 3a) showed good results by Simanihot simulation, with an RMSE of 23.09 g m^{-2}; and RDM (Figure 3c) was of 172.56 g m^{-2}, with simulated values above that observed but within the upper standard deviation. LAI (Figure 3f) presented an RMSE of 0.47; EF, dw, and r were near or above 0.9 while BIAS index was of 0.05, with simulated values slightly overestimating the observed ones. NL (Figure 3g) RMSE was 3.27 leaves; dw, EF, and r reached the maximum (1.00), and BIAS index was -0.01 (the closer to zero the better the model).

In Vera Cruz, the simulations of São José cultivar (Figure 4) for SDM, LDM, and RDM followed the field trends, with RMSEs of 114.42 g m^{2}, 44.48 g $m\text{-}^{2}$, and 128.03 g $m\text{-}^{2}$ respectively. Likewise, LAI followed the same field trends, with an RMSE of 0.89. Still, there was a marked decrease in LDM and LAI observed values in the last collection (Figure 4b, 4f), what might have been due to an early leaf senescence caused by fungal diseases, which is not been considered in the model.

For Paraguaia cultivar, in 2014-2015 (Figure 5), RMSE for SDM, LDM, RDM, and TDM were 60.40, 37.18, 82.12, and 92.06 g m^{-2}, respectively, with a slight LDM overestimation (BIAS = 0.31). LAI reached an RMSE of 0.61, with simulated values within the standard deviation of the observed values. Yet NL had a BIAS index of 0.22, indicating simulation overestimates, with an RMSE of 16.61 leaves $plant^{-1}$.

Figure 6 (a) and 6 (c) show both the observed and simulated mean values of soil moisture content by Ritchie's and Thornthwaite & Mather's models, during 2014-2015 in Santa Maria whereas Figure 6 (b) e 6 (d) present the observed and simulated values in Vera Cruz. For Santa Maria, comparisons of observed and simulated values by the mentioned models from the beginning of the crop cycle has RMSEs of 0.019 cm^3/cm^3 for Ritchie's and of 0.023 cm^3/cm^3 for Thornthwaite & Mather's; while for Vera Cruz, these values were 0.033 cm^3/cm^3 for Ritchie model and 0.028 cm^3/cm^3 for Thornthwaite & Mather model. Simulated soil moisture had more variations along crop cycle when simulated with the Thornthwaite & Mather model. For this model, soil water contents decreased faster than did those simulated by the Ritchie model, as well as those observed ones. As soil water storage (SWS) depends on its availability (AWC), daily values of rainfall, maximum crop evapotranspiration (ETc), and current water content make up the SWS converted to a volume basis (divided by depth - ze), and added to the AWC lower limit (at permanent wilting point). Thus, lower rainfall values and high ETc demands can lead to a decreased SWS and, consequently, smaller water contents in the soil. As a result, the values simulated by the Thornthwaite & Mather model show greater variability along the crop developmental cycle.

In Vera Cruz, the soil has about 83% sand within the first layers. At the beginning of the growing season, when once evaporation is the main component of evapotranspiration, the Ritchie model was unable to simulate the major variability in soil water content occurring in this period, however, providing better responses from the 100 DAP (days after planting). Differently, the Thornthwaite & Mather's model could well represent the mean soil water content in this period. Overall, both models deliver good results for water content in the soil, albeit with advantages and limitations. Thus, the choice depends on the number of available soil variables and on how many layers will be assessed, either a single layer (Thornthwaite & Mather's model) or all layers explored by the roots throughout the crop developmental cycle (Ritchie's model).

Our results show that Simanihot can be used in numerical studies on cassava crop grown in Rio Grande do Sul. However, its use in other areas of Brazil still requires testing. Nevertheless, for being based on processes derived from the GUMCAS model (MATTHEWS & HUNT, 1994), which is well known for cassava in the DSSAT platform, Simanihot has great potential of being used outside the environment of calibration.

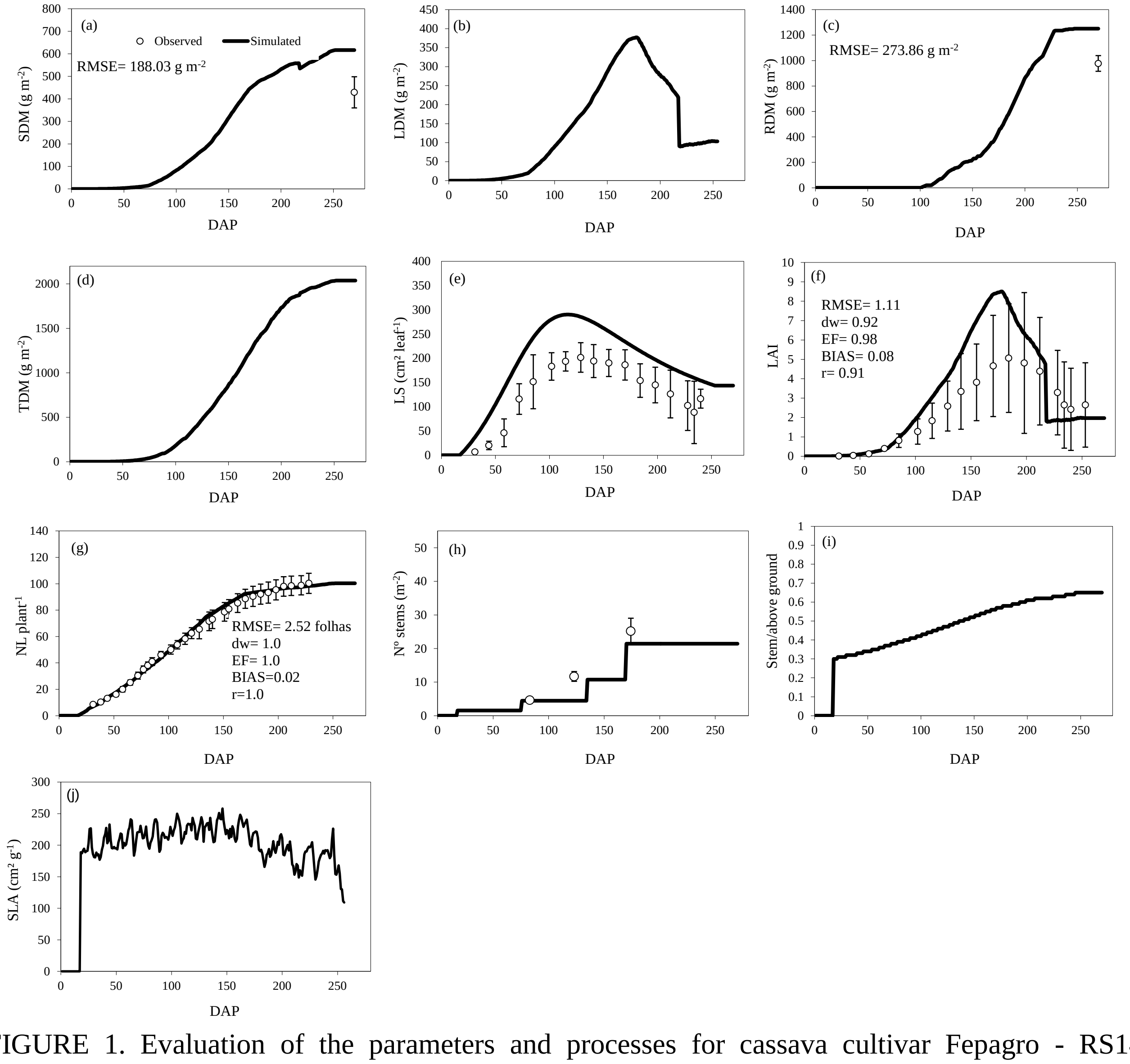

FIGURE 1. Evaluation of the parameters and processes for cassava cultivar Fepagro - RS14 simulated with Simanihot, with independent data in the 2011-2012 growing season in Santa Maria, RS. Observed data are the open circles with standard deviation error bars. Simulated data with Simanihot are the lines. Each panel is a process or parameter: stem dry matter (a), leaves dry matter (b), tuber + fiber roots dry matter (c), total dry matter (leaves+stem+roots) (d), final leaf size (e), leaf area index (f), accumulated leaf number on a stem (g), number of stems (h), stem/above ground ratio (i), and specific leaf area (j). DAP=days after planting, RMSE=root mean square error, dw=index of agreement, EF-model efficiency, BIAS=bias index, r=correlation coefficient.

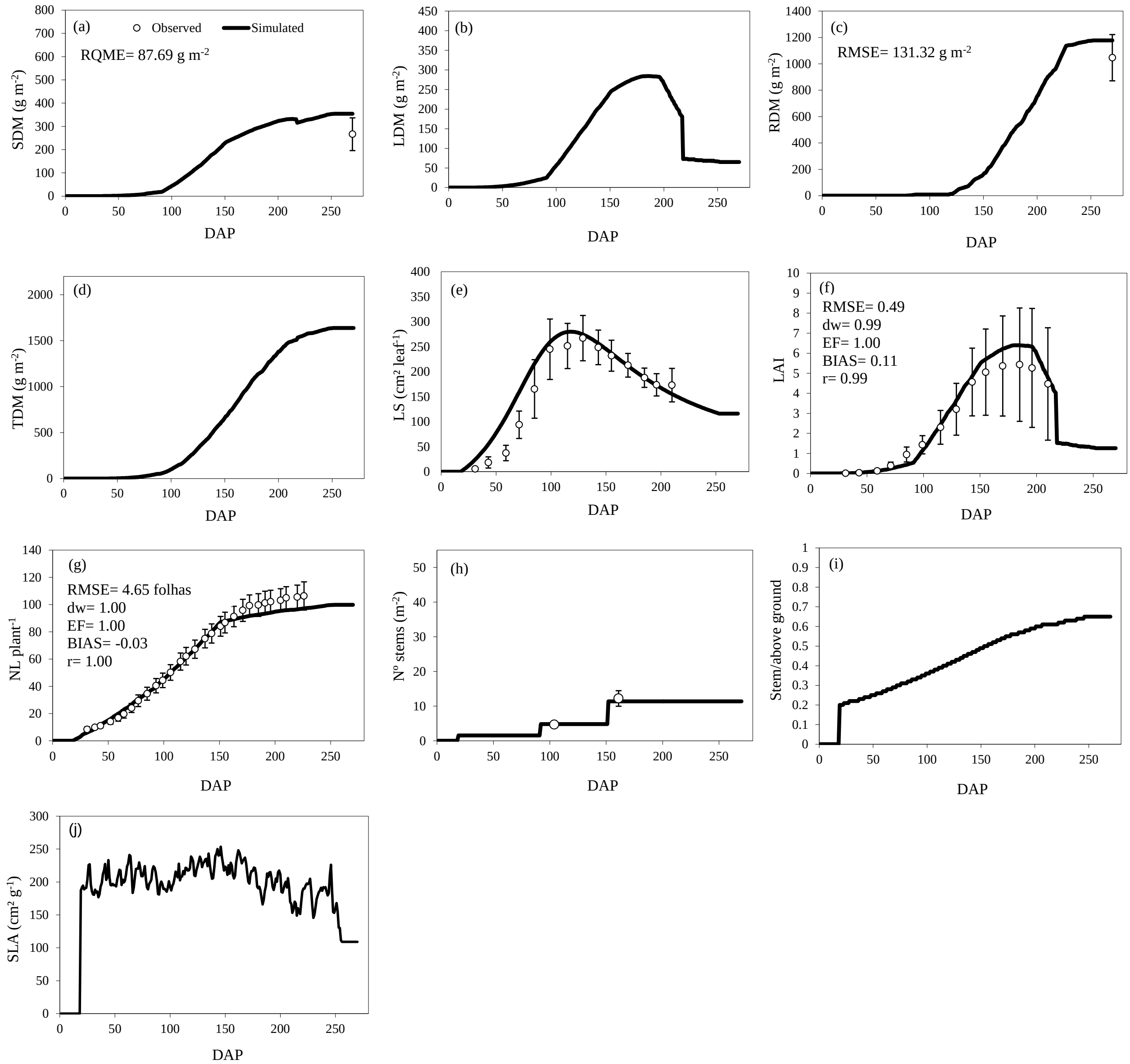

FIGURE 2. Evaluation of the parameters and processes for cassava cultivar Cascuda simulated with Simanihot, with independent data in the 2011-2012 growing season in Santa Maria, RS. Observed data are the open circles with standard deviation error bars. Simulated data with Simanihot are the lines. Each panel is a process or parameter: stem dry matter (a), leaves dry matter (b), tuber + fiber roots dry matter (c), total dry matter (leaves+stem+roots) (d), final leaf size (e), leaf area index (f), accumulated leaf number on a stem (g), number of stems (h), stem/above ground ratio (i), and specific leaf area (j). DAP=days after planting, RMSE=root mean square error, dw=index of agreement, EF-model efficiency, BIAS=bias index, r=correlation coefficient.

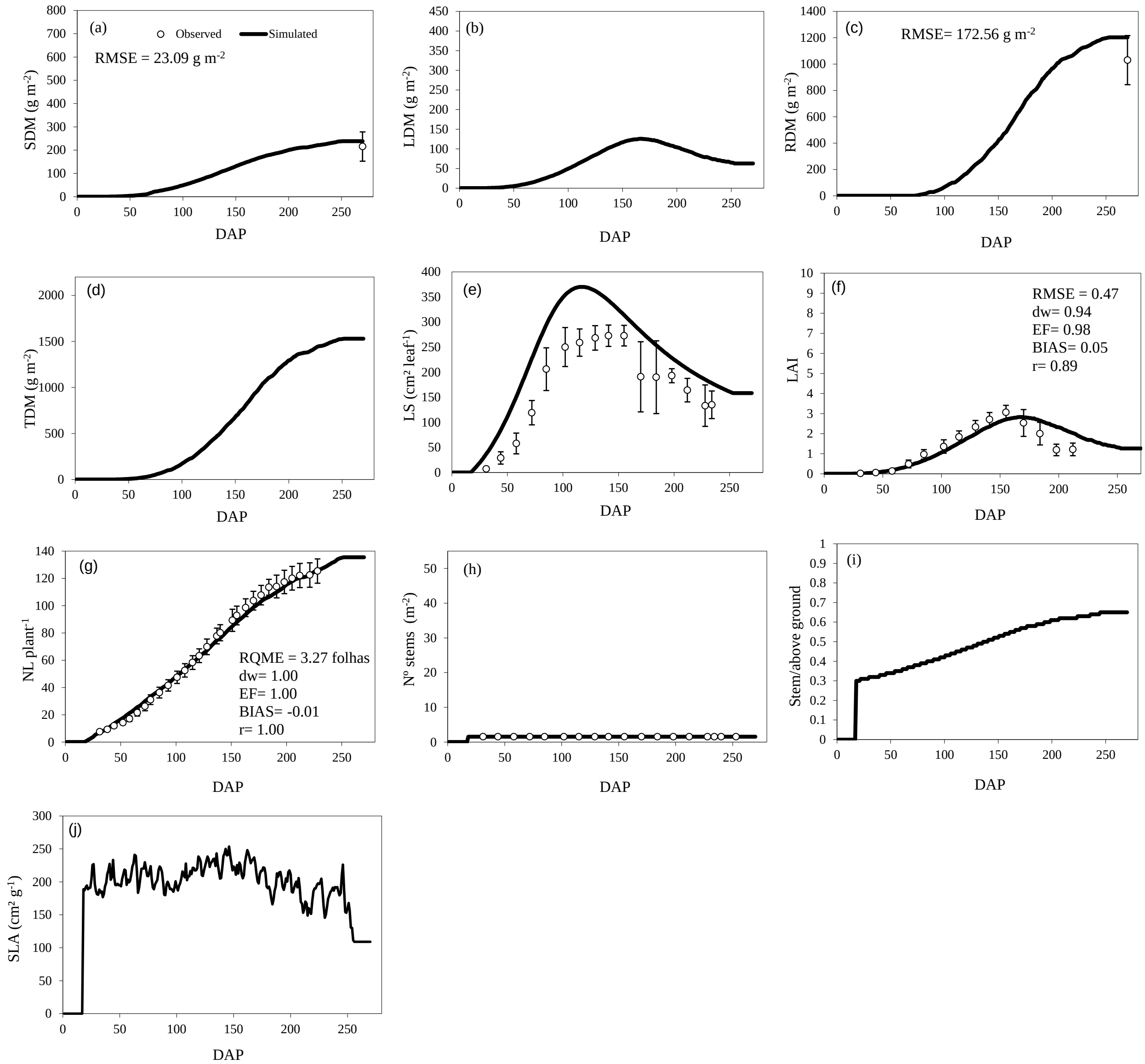

FIGURE 3. Evaluation of the parameters and processes for cassava cultivar Estrangeira simulated with Simanihot, with independent data in the 2011-2012 growing season in Santa Maria, RS. Observed data are the open circles with standard deviation error bars. Simulated data with Simanihot are the lines. Each panel is a process or parameter: stem dry matter (a), leaves dry matter (b), tuber + fiber roots dry matter (c), total dry matter (leaves+stem+roots) (d), final leaf size (e), leaf area index (f), accumulated leaf number on a stem (g), number of stems (h), stem/above ground ratio (i), and specific leaf area (j). DAP=days after planting, RMSE=root mean square error, dw=index of agreement, EF-model efficiency, BIAS=bias index, r=correlation coefficient.

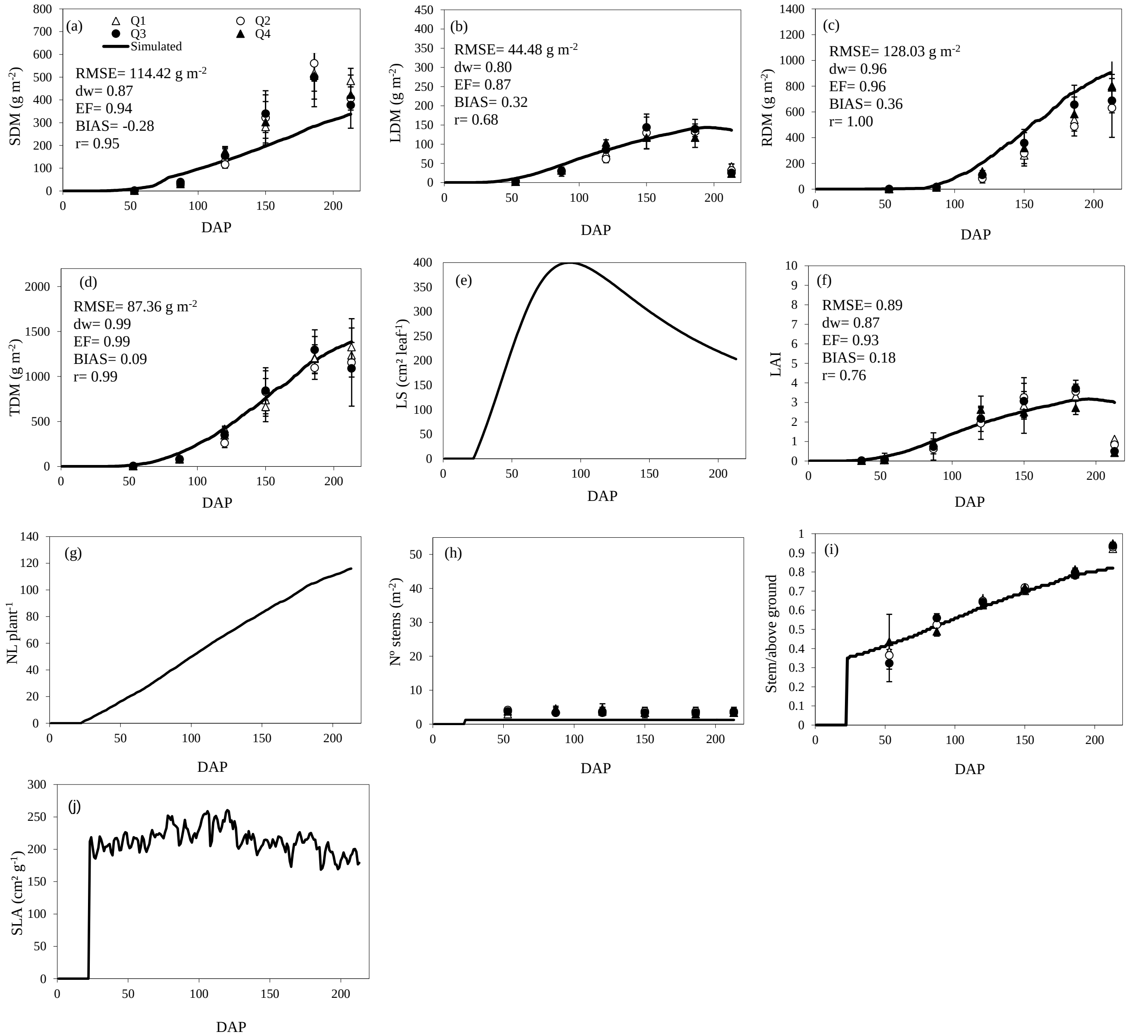

FIGURE 4. Evaluation of the parameters and processes for cassava cultivar São José simulated with Simanihot, with independent data in the 2013-2014 growing season in a commercial farm in Vera Cruz, RS. Observed data of each quadrant of the farm (Q1, Q2, Q3 and Q4) are represented by one circles and triangles (Q1, Q2) and solid circles and triangles (Q3, Q4) with standard deviation error bars. Simulated data with Simanihot are the lines. Each panel is a process or parameter: stem dry matter (a), leaves dry matter (b), tuber + fiber roots dry matter (c), total dry matter (leaves+stem+roots) (d), final leaf size (e), leaf area index (f), accumulated leaf number on a stem (g), number of stems (h), stem/above ground ratio (i), and specific leaf area (j). DAP=days after planting, RMSE=root mean square error, dw=index of agreement, EF-model efficiency, BIAS=bias index, r=correlation coefficient.

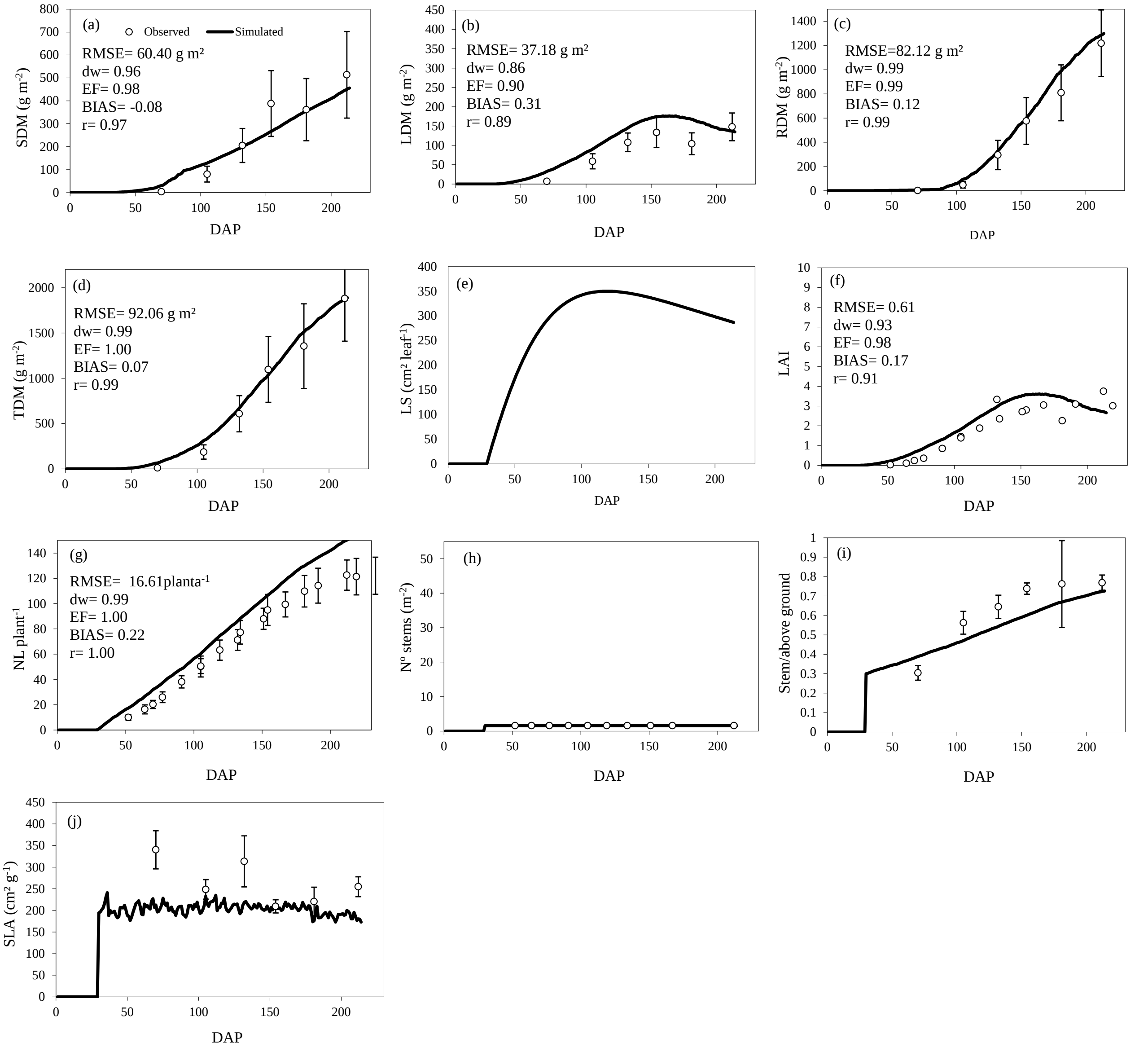

FIGURE 5. Evaluation of the parameters and processes for cassava cultivar Paraguaia simulated with Simanihot, with independent data in the 2014-2015 growing season in Santa Maria, RS. Observed data are the open circles with standard deviation error bars. Simulated data with Simanihot are the lines. Each panel is a process or parameter: stem dry matter (a), leaves dry matter (b), tuber + fiber roots dry matter (c), total dry matter (leaves+stem+roots) dry matter (d), final leaf size (e), leaf area index (f), accumulated leaf number on a stem (g), number of stems (h), stem/above ground ratio (i), and specific leaf area (j). DAP=days after planting, RMSE=root mean square error, dw=index of agreement, EF-model efficiency, BIAS=bias index, r=correlation coefficient.

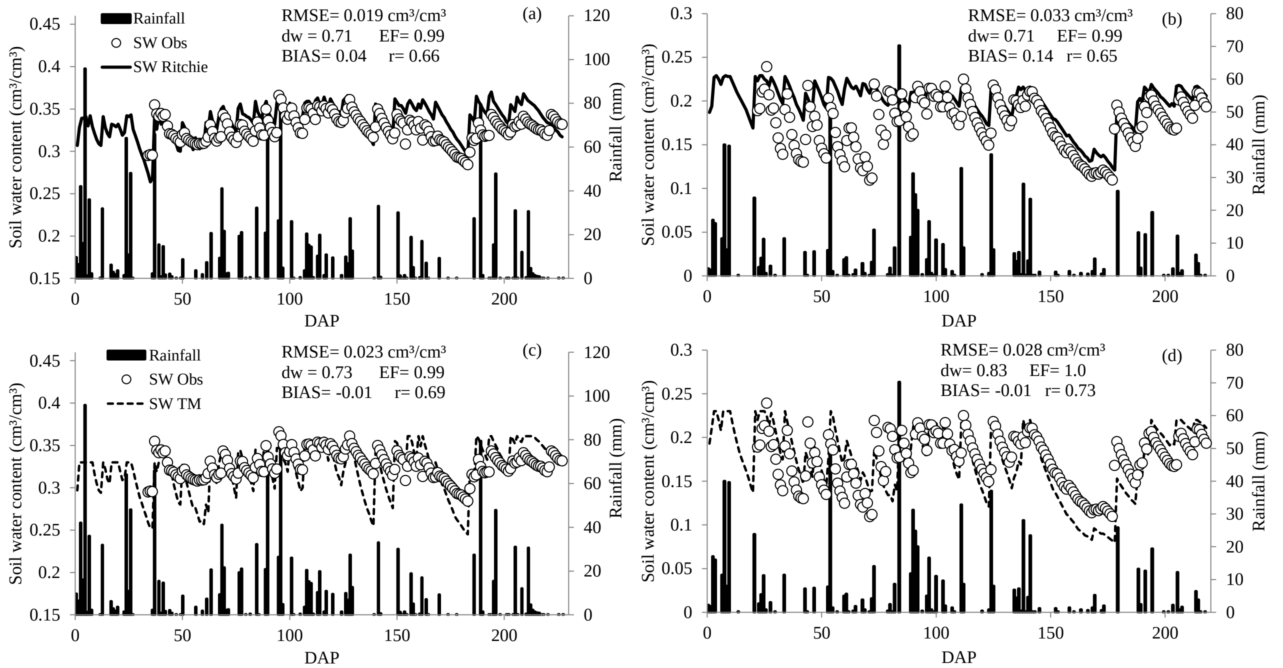

FIGURE 6. Soil water content observed (open circles) and simulated with the Ritchie model (solid line) and with the Thornthwaite and Mather model (dashed line) in the experiment with cassava in Santa Maria (a,c) and in a commercial farm in Vera Cruz (b,d), and rainfall during the crop growing season (from planting to harvest) as a function of Days After Planting (DAP) during the 2014-2015 growing season. RMSE=root mean square error, dw=index of agreement, EF-model efficiency, BIAS=bias index, r=correlation coefficient.

CONCLUSIONS

Simanihot model has good performance in simulations of cassava growth, development, and yield. The model runs at a one-day time step, being calibrated for five cassava cultivars (Fepagro - RS 14, Estrangeira, Cascuda, São José, and Paraguaia), which have different branching habits and usages (forage, table, and industry). Also, this model has a graphical interface that allows users to select one of two soil water balance models. Both evaluated models of water balance well represent the actual water content in the soil. Finally, the soil model choice will depend on the number of known soil variables and the desired detailing.

REFERENCES

DOURADO-NETO, D. et al. Balance hídrico ciclico y secuencial : estimación de almacenamiento de agua en el suelo. **Scientia Agricola**, Piracicaba, v. 56, n. 3, p. 537-546, 1999. Disponível em: <http://www.scielo.br/scielo.php?script=sci_arttext&pid=S0103-90161999000300005>. Acesso em: 11 fev. 2016.

GABRIEL, L. F.; STRECK, N. A.; ROBERTI, D. R.; CHIELLE, Z. G.; UHLMANN, L. O.; SILVA, M. R. da.; SILVA, S. D. da. Simulating cassava growth and yield under potential conditions in Southern Brazil. **Agronomy Journal**, Madison, v. 106, n. 4, p. 1119-1137, 2014. Disponível em: <https://dl.sciencesocieties.org/publications/aj/abstracts/106/4/1119?access=0&view=pdf>. Acesso em: 11 fev. 2016.

KIM, S.; YANG, Y.; TIMLIN, D.J.; FLEISHER, D.H.; DATHE, A.; REDDY, V.R.; STAVER, K. Modeling temperature responses of leaf growth, development, and biomass in maize with MAIZSIM. **Agronomy Journal**, Madison, v. 104, p. 1523-1537, 2012. Disponível em: < https://dl.sciencesocieties.org/publications/aj/abstracts/104/6/1523?access=0&view=pdf>. Acesso em: 11 fev. 2016.

LAGO, I.; STRECK, N.A.; BISOGNIN, D.A.; SOUZA, A.T.de.; SILVA, M.R.da. Transpiração e crescimento foliar de plantas de mandioca em resposta ao deficit hídrico no solo. **Pesquisa Agropecuária Brasileira**, Brasília, DF, v. 46, p. 1415-1423, 2011. Disponível em: < www.scielo.br/pdf/pab/v46n11/v46n11a01.pdf>. Acesso em: 11 fev. 2016.

MATTHEWS, R.B.; HUNT, L.A. GUMCAS: A model describing the growth of cassava (*Manihot esculenta* L. Crantz). **Field Crops Research**, Amsterdam, v. 39, p. 69–84, 1994. Disponível em: < http://www.sciencedirect.com/science/article/pii/037842909490054X>. Acesso em: 11 fev. 2016.

NASSIF, D.S.P.; MARIN, F.R.; FILHO, W.J.P.; RESENDE, R.S.; PELLEGRINO, G.Q. Parametrização e avaliação do modelo DSSAT/Canegro para variedades brasileiras de cana-de-açúcar. **Pesquisa Agropecuária Brasileira**, Brasília, DF, v. 47, p. 311-318, 2012. Disponível em: <http://www.scielo.br/scielo.php?script=sci_arttext&pid=S0100-204X2012000300001>. Acesso em: 11 fev. 2016.

PINHEIRO, D.G.; STRECK, N.A.; RICHTER, G.L.; LANGNER, J.A.; WINCK, J.E.M.; UHLMANN, L.O.; ZANON, A.J. Limite crítico de água no solo para transpiração e crescimento foliar em mandioca em dois períodos com deficiência hídrica. **Revista Brasileira de Ciência do Solo**, Viçosa, MG, v. 39, p. 1740-1749, 2014. DOI: 10.1590/S0100-06832014000600009

SAMBORANHA, F.K.; STRECK, N.A.; UHLMANN, L.O.; GABRIEL, L.F. Modelagem matemática do desenvolvimento foliar em mandioca. **Revista Ciência Agronômica**, Fortaleza, v. 44, p. 815-824, 2013. Disponível em: <http://ccarevista.ufc.br/seer/index.php/ccarevista/article/view/2326>. Acesso em: 11 fev. 2016.

SINGH, S.S.; BOOTE, K.J.; ANGADI, S.V.; GROVER, K.; BEGNA, S.; AULD, D. Adapting the CROPGRO Model to Simulate Growth and Yield of Spring Safflower in Semiarid Conditions. **Agronomy Journal**, Madison, v. 108, p. 64-72, 2016. Disponível em: <https://dl.sciencesocieties.org/publications/aj/tocs/108/1>. Acesso em: 11 fev. 2016.

TIRONI, L.F.; UHLMANN, L.O.; STRECK, N.A.; SAMBORANHA, F.K.; FREITAS, C.P.O.de.; SILVA, M.R.da. Desempenho de cultivares de mandioca em ambeinte subtropical. **Bragantia**, Campinas, v. 74, p. 58-66, 2015. DOI: 10.1590/1678-4499.0352