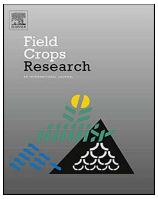
Field Crops Research 219 (2018) 256–272

Contents lists available at ScienceDirect

Field Crops Research

journal homepage: www.elsevier.com/locate/fcr



Simulating drought impact and mitigation in cassava using the LINTUL model

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ARTICLE INFO

Keywords:
Dormancy
Rain-fed
Planting date
Leaf area index
LINTUL
Simulation modelling

ABSTRACT

We adapted and used a crop simulation model based on light interception and use efficiency (LINTUL-Cassava) to improve our understanding of water-limited yields of cassava under rain-fed conditions in Southern Togo. Data collected in four different fields in two locations, Sevekpota and Djakakope, during two consecutive growing seasons from 2012 to 2014 were used. Data from Sevekpota in Year 2, when a larger amount of rainfall was received than in Year 1, were used for model parameterisation and calibration. The model was evaluated with data from Year 1 in Sevekpota and Years 1 and 2 in Djakakope. The model calibration and testing results indicated an overall good agreement between simulated and observed storage roots and total biomass dry matter. A decline in leaf area index (LAI) towards the end of the cropping season and the regrowth at the onset of the new rainy season matched fairly well with the simulated dormancy and recovery from the dormancy phase. The model also captured the decline in yield of storage roots due to leaf regrowth at the recovery from dormancy as observed in Sevekpota. Best harvest periods to minimise storage root losses can be identified on that basis. The assessment of the effect of drought as the difference between simulated potential yields, assuming water content at field capacity, and water-limited yields indicated that drought can cause 9–59% loss of yield. The largest yield loss was recorded in Sevekpota in Year 1, and was mainly due to water stress occurring between 78 and 125 days after planting. The best planting period simulated was around mid-February, which is one to two months earlier than the usual planting time in Southern Togo. Further experimental studies are required to confirm this finding and assess how this can practically fit into existing cropping systems. These findings enhance our understanding of water-limited yield of cassava and unveil possibilities of improving it in future.

1. Introduction

Drought stress can cause serious yield reductions in cassava production despite its drought tolerance. Yield losses ranging from 32 to 60% have been reported under prolonged drought as compared with irrigated cassava crops (Connor et al., 1981; Alves, 2002). Cassava is particularly sensitive to drought stress when it occurs between 1 and 5 months after planting. Prolonged water stress towards the end of the first 12-month cycle of the crop's growth period can result in cassava entering the dormancy phase (Alves, 2002). Dormancy is characterised by decreased leaf production, increased leaf shedding (to an extent that almost all leaves fall) and termination of shoot vegetative growth (Alves, 2002). Dormancy is generally broken by rainfall, but little is known about which soil moisture suction suffices to trigger the recovery from dormancy. It has been reported that the recovery from drought is characterised by a rapid production of new leaves, which temporarily occurs at the expense of carbohydrate reserves in the stem and storage roots (El-Sharkawy and Cock, 1987). The extent to which this process affects stem and storage root yields is not well understood. A better understanding of this process could guide decisions on harvest time for increased cassava yield. These knowledge gaps unveil the need for understanding drought stress impacts on yields in sub-Saharan Africa where most cassava is produced under rain-fed conditions.

Process-oriented models are used to assess water-limited yields. A process-oriented model for cassava growth is the GUMCAS model (meaning "simulate" in Tagalog, the national language of the Philippines) by Matthews and Hunt (1994). The GUMCAS model, also referred to as CROPSIM-Cassava in the framework of the Decision Support System for Agrotechnology Transfer (DSSAT) (Singh et al., 1998; Jones et al., 2003), was designed to simulate potential, water-

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https://doi.org/10.1016/j.fcr.2018.01.033
Received 19 September 2017; Received in revised form 17 January 2018; Accepted 28 January 2018

limited and nitrogen-limited growth of cassava as affected by environmental variables (temperature, solar radiation, drought stress, photoperiod, vapour pressure deficit) and crop-genetic characteristics (time to the first branching and duration of each branching phase, leaf appearance rate, maximum canopy photosynthetic rate, stem weight to node weight ratio, leaf number increase rate and increase period, maximum leaf area and duration to reach maximum, leaf life, leaf area at 300 days after sprouting, leaf area to weight ratio, stem number and shoot number). In this model, the growth of leaf, stem, storage roots and fibrous roots are modelled in great detail with many variables. However, the lack of data to assess these input parameters in West Africa could decrease the accuracy of simulation results. Moreover, the contribution of storage roots as a source of assimilates to boost the production of new leaves after cessation of a long drought stress as soon as rain resumes (Connor and Cock, 1981) is not featured in the compensatory growth simulated in GUMCAS. A reduction in storage roots dry matter and increase in leaf dry matter after the removal of long drought stress has been observed in previous studies (Howeler and Cadavid, 1983) under climatic conditions with distinct separation between wet and dry seasons as encountered in West Africa.

The Light INTerception and UtiLisation (LINTUL) model (Spitters, 1990) provides an alternative modelling approach. The first version of the model (LINTUL 1), developed for simulating potential growth, aimed to assess potato growth from daily intercepted photosynthetically active radiation (PAR) and light use efficiency under optimal growth conditions. It was thereafter extended to simulate crop growth under water-limited conditions (LINTUL 2) (Spitters and Schapendonk, 1990). The model has been adapted for crops such as maize (Farré et al., 2000), winter oilseed rape (Habekotté, 1997), rice (Shibu et al., 2010) and banana (Nyombi, 2010; Taulya, 2015). In the model, biomass growth rate is assumed to be linearly correlated with the amount of light intercepted with a constant light or radiation use efficiency following Monteith (1977). Unlike in GUMCAS, the partitioning of the dry matter among different plant organs is modelled in LINTUL using partitioning factors defined as a function of the physiological age of the crop. It has been reported that fibrous root, stem and leaf growth have priority on storage root growth in the juvenile vegetative stage of the crop, and that translocation of dry matter to storage roots increases in the reproductive stage (Alves, 2002). The LINTUL model had not earlier been adapted for cassava.

This study aims at enhancing our understanding of cassava growth and yield as affected by drought stress and planting date in rain-fed systems in West Africa. In separate field experiments in contrasting agroecological regions in Southern Togo, data were collected for LINTUL model parameterisation and testing, followed by the application of this model to assess the contribution of planting date on mitigating the impact of drought on the performance of the crop. A successful modelling of cassava growth and yield under these agroecological conditions using LINTUL model will help to improve cassava production in the region where this crop is a major staple food and is increasingly considered a commercial crop.

2. Materials and methods

2.1. Description of LINTUL-Cassava

2.1.1. Cassava development simulation

The original LINTUL2 model to simulate water-limited production was modified to incorporate the development and growth of cassava under water-limited conditions. The model assumes three development phases as in CROPSIM-Cassava: i) planting to sprounting, ii) sprounting to first branching, iii) first branching to maturity or harvest. The word ‘sprouting’ is used in this paper instead of ‘emergence’ since crop growth begins after planting the cassava stake. The functioning of the model is summarised in the relational diagram in Fig. 1, which depicts relationships between key parameters as described in the sections below. Temperature is the key environmental factor driving these phases. The duration of each phase is measured using the temperature sum (T_{sum}). The T_{sum} is the physiological variable driving plant development. It is determined as a function of the daily effective temperature (T_{eff}) after the planting date (t_{doypl}) (Eq. (1)). The T_{eff} is calculated as the difference between the daily average temperature (T_{av}) and the base temperature (T_b) (Eq. (2)).

$$T_{\mathrm{sum}} = T_{\mathrm{eff}} \times f\,(TIME,\, t_{\mathrm{doypl}}) \tag{1}$$

$$T_{\mathrm{eff}} = \mathrm{MAX}\,(0,\, T_{\mathrm{av}} - T_{\mathrm{b}}) \tag{2}$$

T_{eff}: [°C] is the daily effective temperature. T_{av}: [°C] is the actual average daily temperature approximated by $(T_{\max} + T_{\min})/2$. T_{b}: [°C] is the base temperature below which the crop no longer develops; t_{doypl} is the planting date (day of the year on which planting occurred).

a. Sprouting

The model assumes that the sprouting (SPROUT) occurs when soil profile water content (Θ) is above wilting point (Θ_{wp}) and that T_{sum} accumulation from the time of planting has reached $T_{\mathrm{sum\_sprout\_av}}$. The $T_{\mathrm{sum\_sprout\_av}}$ defines the optimal amount of T_{sum} accumulated from planting to sprouting. Sprouting normally occurs within two weeks after planting (Alves, 2002), but can occur earlier or later depending on growing conditions. We back calculated and used a default $T_{\mathrm{sum\_sprout\_av}}$ value of 180 °C under an optimum temperature of 27 °C (optimum cassava growth is achieved between 25 and 29 °C) and a T_{b} of 15 °C (Alves, 2002). The list of model parameters and their default values are presented in Table 1.

b. Simulation of first branching

Two types of branches characterise a cassava plant: the main branches emerging from the planted stem cutting and the lateral branches arising from the main branches where an apex evolves into an inflorescence. The appearance of the first lateral branch marks the start of the reproductive stage (Matthews and Hunt, 1994). This phase is temperature and photoperiod dependent, and cultivar specific. However, the current model does not include photoperiod effects, not only due to a lack of data, but also because it is reported that photoperiod may not limit storage roots production in the tropics because of the small variation in day length between 10 and 12 h (Alves, 2002). The period from sprouting to first branching, denoted as $T_{\mathrm{sum\_br1}}$ in LINTUL-Cassava, has been reported in the literature to occur between 15 and 65 developmental days (Keating, Evenson, and Fukai (1982); Veltkamp, 1985; Gutierrez et al., 1988) depending on whether the cultivar grown was branching early or late. This period corresponded to a T_{sum} range of 180–780 °Cd for an optimum temperature of 27 °C and T_{b} of 15 °C (Hillocks et al., 2002). Since the cultivar used in this study was a late branching type (TME 419 or “Gbazekoute” as local name in Togo), 780 °Cd was considered as default value for $T_{\mathrm{sum\_br1}}$ in our simulations.

c. Simulation of maturity and harvest

As a perennial shrub, cassava is an indeterminate crop. It can grow for more than a 12-month cycle and can be harvested from 8 to 24 months after planting (MAP). The current version of the model simulates only the first 12-month cycle since most farmers in Southern Togo and in other land constrained areas commonly harvest cassava before 12 MAP because the land needs to be prepared for other crops in the subsequent growing season. Thus, the simulation stops when a T_{sum} of 4320 °Cd, corresponding to 360 days under optimal temperature of 27 °C and T_{b} of 15 °C, is reached, or when a predefined end of simulation time or harvest time is attained.

2.1.2. Simulation of cassava growth processes

The model describes nine main processes: the growth of i) stem cuttings, ii) leaf area index, iii) biomass, iv) leaf, stem, fibrous root and storage roots, v) senescence, vi) dry matter partitioning, vii) dormancy; viii) biomass production upon the recovery from dormancy and ix) the increase of rooting depth. Temperature is the key environmental factor affecting the growth processes. Cassava growth is inhibited below 15 °C