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Water yam (*Dioscorea alata* L.) development as affected by photoperiod and temperature: Experiment and modeling

J. Marcos [a], A. Lacointe [b], R. Tournebize [a], R. Bonhomme [a], J. Sierra [a,*]

[a] INRA, UR135, Agropédoclimatique de la zone Caraïbe, Petit-Bourg F-97170, France
[b] INRA, UMR 547 PIAF, Clermont-Ferrand, F-63100, France, and Université Blaise Pascal, UMR 547 PIAF, Aubiere, F-63177, France

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ABSTRACT

Water yam (*Dioscorea alata* L.) is one of the most popular tuber crops in the tropics. Although it is well known that photoperiod greatly affects yam development, little information is available on the effect of temperature on different developmental phases, and there has been no attempt to model the effect of both environmental factors. The aim of this study was to assess the combined effect of photoperiod and temperature on the development of two early maturing varieties of yam with similar growth pattern. For this we used a model proposed for potatoes grown under tropical conditions. Experimental information was obtained from 15 field experiments carried out in Guadeloupe (French West Indies) covering a wide range of planting dates. Two yam phases were analyzed: from emergence (EM) to tuber initiation (TI), and from TI to harvest (HA). The EM–HA period varied from 3 to 6 months, with the longer cycles corresponding to early planting dates (e.g. April). On average, EM–TI represented one-third of the EM–HA period, and was mainly affected by photoperiod and to a lesser extent by temperature. Both factors also affected the duration of TI–HA but their effects were less noticeable. The observed mean temperature during TI–HA was near the estimated optimum and its effect was less than that of photoperiod. The variation of the phase duration was higher for EM–TI (CV 45%) than for TI–HA (8%), which was satisfactorily explained by the model. For EM–TI there was a positive interaction between both environmental factors which, together with the greater influence of climatic conditions, resulted in much variability in its duration. For TI–HA, a small influence of environmental factors, coupled with a compensatory effect between environmental factors, resulted in a relatively smaller variation in the duration of this phase. The model estimated satisfactorily the dates and the duration of each phase. The root mean square error (RMSE) was 7.4 d which corresponded to 13% and 7% of the observed mean duration of EM–TI and TI–HA, respectively. Our results showed that small changes in photoperiod and temperature, which are very usual in the tropics, have a big effect on the tested yam varieties. We also showed that the model applied in this study can be a useful tool to predict yam development for management purposes as well as for the modeling of yam growth.

1. Introduction

Yam (*Dioscorea* spp.) is the third most important tropical root crop after cassava (*Manihot esculenta* Crantz.) and sweet potato (*Ipomoea batatas* L. Lam.). This is especially true in West Africa, Central America, the Caribbean, Pacific Islands and Southeast Asia (Onyeka et al., 2006). Water yam (*Dioscorea alata* L.) is the most popular species in Central America and Caribbean countries (Bonhomme, 2006). Average yields of water yam in these countries are about 15 Mg ha^{-1} yr^{-1} fresh weight. Although yields increased in the last decade due to improvements in host–plant resistance to anthracnose, which is the most severe foliar disease of water yam, current yields are still far below their potential, which is about 70 Mg ha^{-1} yr^{-1} (Onyeka et al., 2006). Several factors influence differences in yam production in the tropics, including plant breeding and new cultivars development, pests and diseases, water and nutrient availability, weed competition, farming practices (e.g. unstaked vs. staked crops) and sett quality (Rodríguez Montero, 1997; Onyeka et al., 2006).

Modeling of yam growth can be an effective aid for the interpretation of experimental data and for the assessment of constraints affecting yam production. Several models have been proposed for tropical root and tuber crops; e.g. Singh et al. (1998) for taro (*Colocasia esculenta* L. Schott) and tanier (*Xanthosoma* spp.), Gray (2000) for cassava, and Rodríguez Montero (1997) for water yam. All these models assume that during vegetative growth leaves and stems are the dominant sinks for assimilates while the storage parts are the dominant sinks once they are initiated. Changes in

* Corresponding author. Tel.: +590 590 255949; fax: +590 590 259416.
E-mail address: jorge.sierra@antilles.inra.fr (J. Sierra).

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assimilate partitioning throughout the tuber crop cycle are controlled mainly by development, which depends on environmental variables such as temperature and photoperiod (Singh et al., 1998). Thus, the key developmental event affecting assimilate partitioning in tuber crops is tuber initiation. As in potato (*Solanum tuberosum* L.), development of water yam is strongly influenced by daylength. Daylengths greater than 12 h favor growth of vines while satisfactory tuber growth only takes place during shorter daylengths (Shiwachi et al., 2002; Vaillant et al., 2005). Other species of yam showed the same trend; e.g. *D. rotundata*, *D. opposita*, *D. bulbifera* and *D. cayenensis* (Rodríguez Montero, 1997).

While most models of tuber crops account for the effect of temperature on tuber initiation, the effect of photoperiod has not been considered in some of them; e.g. Prihar et al. (1995) for potatoes, Rodríguez Montero (1997) for water yam. Some potato development models consider a combined effect of temperature and photoperiod on tuber initiation (e.g. Griffin et al., 1993; Streck et al., 2007). In these models, the effect of each factor is described by a normalized function and the combined effect is calculated by a multiplicative approach. Furthermore, Streck et al. (2007) noted that this approach predicted potato development better than the usual procedure based on thermal time. To our knowledge, there are no yam models that account for the combined effect of temperature and photoperiod on crop development.

Assessing yam development is important to predict the effect of different planting dates on yields. In many tropical regions, where water for irrigation is not available, the planting date of yam varies from year to year according to variation in the start of the rainy season. Similarly, in several Caribbean countries, yam is planted after sugarcane (*Saccharum officinarum* L.), whose harvest date is determined by the schedule of the sugar factory (Bonhomme, 2006). Late planting dates (i.e. after July) of yam may reduce yields because early tuber initiation with short days causes a depression of the vegetative growth and the resulting poor tuber enlargement (Shiwachi et al., 2002).

The objective of this study was to assess the individual and the combined effect of photoperiod and temperature on the development of two varieties of water yam having a similar growth pattern, using the model proposed by Streck et al. (2007) for potato. The overall purpose is to develop a crop growth model that can be used to evaluate yam performance under different environmental scenarios. The data used for this study was obtained from several field experiments carried out in Guadeloupe (French West Indies) over several years.

2. Materials and methods

2.1. Model of yam development

We adapted the potato development model described by Streck et al. (2007). In their model, the response to temperature and photoperiod is simulated by dimensionless cultivar-specific factors that range from 0 to 1. To simulate the progression of the crop through the developmental phases, a rate of development (r, d^{-1}) is computed daily by multiplying the temperature ($f(T)$) and photoperiod ($f(P)$) factors by the phase-specific daily maximum rate (r_{max}, d^{-1}). Streck et al. (2007) divided the potato cycle into three phases: the vegetative phase, from emergence (EM) to tuber initiation (TI), a tuberization phase, from TI to beginning of plant senescence (BS) and a senescence phase, from BS to harvest (HA). The rate r is initialized at EM with a value of 0; TI, BS and HA are reached when the accumulated r exceeds 1, 1.8 and 2, respectively. In their model, both $f(P)$ and $f(T)$ affect r during the EM–TI phase; after TI, $f(T)$ is the only factor affecting development.

The $f(T)$ is a beta function of the mean daily temperature (T, °C), with cardinal minimum, optimum and maximum temperatures (T_{min}, T_{opt} and T_{max}, °C):

$$f(T) = 0, \quad T < T_{min} \tag{1}$$

$$f(T) = \frac{2 \times (T - T_{min})^{\alpha}(T_{opt} - T_{min})^{\alpha} - (T - T_{min})^{2\alpha}}{(T_{opt} - T_{min})^{2\alpha}}, \quad T_{min} \leq T \leq T_{max} \tag{2}$$

$$f(T) = 0, \quad T > T_{max} \tag{3}$$

$$\alpha = \frac{\ln 2}{\ln[(T_{max} - T_{min})/(T_{opt} - T_{min})]} \tag{4}$$

The $f(P)$ is a negative exponential function that equals 1 when the daily photoperiod (P, h) is less than a critical photoperiod (P_c, h). Above P_c, the response to photoperiod decreases according to the sensitivity coefficient (ω, h^{-1}):

$$f(P) = 1, \quad P \leq P_c \tag{5}$$

$$f(P) = \exp[-\omega(P - P_c)], \quad P > P_c \tag{6}$$

Further details of the model can be found in Streck et al. (2007).

To simulate potato development, Streck et al. (2007) estimated the maximum rates of each developmental phase using a predefined set of T_{min}, T_{opt}, T_{max}, P_c and ω from the literature. As such information is not available for yam, we calculated the maximum rates from measured data as described below, and used the model to estimate that set of parameters. In addition, we introduced two modifications in the use of the model from that proposed by Streck et al. (2007). One is that we divided the crop cycle only in two phases: EM–TI and TI–HA because available data was insufficient to identify the start of yam senescence properly. The other modification is that we also tested the effect of photoperiod in the TI–HA phase. Thus, in our approach $f(P)$ and $f(T)$ affected r_{max} in both phases. For the EM–TI phase:

$$r = r_{max-EM-TI} \times f(T) \times f(P) \tag{7}$$

and for the TI–HA:

$$r = r_{max-TI-HA} \times f(T) \times f(P) \tag{8}$$

Activating $f(T)$, $f(P)$ or both allowed us to evaluate the single and the combined effect, respectively.

2.2. Data set

We selected 15 data sets from field experiments done in different years with a fairly wide range of planting dates (Table 1). All the experiments were carried out in Guadeloupe (French West Indies) at the Experimental Stations of Duclos (latitude: 16°12′N, longitude: 61°39′W, 250 m a.s.l.) and Godet (latitude: 16°24′N, longitude: 61°29′W, 10 m a.s.l.) of the Institut National de la Recherche Agronomique (INRA). Mean daily temperature and mean annual rainfall are 24.8 °C and 2700 mm, respectively at Duclos, and 26.6 °C and 1200 mm, respectively at Godet. The yam varieties used in the experiments were Lupias and Belep (Table 1). Both varieties are very similar in terms of crop development and biomass production and are resistant to anthracnose (Bonhomme, 2006). All the experiments had similar crop management and did not experience any water, nutrient, pest or disease limitations. The crops were irrigated when necessary, and sufficient fertilizer was applied at planting.

Each experiment consisted of 200–350 plants that were sampled monthly (i.e. above-ground and tuber biomass) from vine emergence to harvest, with 2–3 replicates of 3–5 plants at