Dendrometers reflect physiological growth, leaf flushing cycles and water stress levels of cocoa trees

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Abstract: We aimed to understand the development of cocoa trees in the semi-arid conditions of Brazil. Dendrometers continuously measure stem diameter variations of trees, displaying the trees' direct reaction to endogenous and exogenous factors. We analysed Daily Shrinkage (DS) and Daily Net Growth (DNG) with specific regard to the plants' behaviour regarding the flushing of new leaves.

We monitored the stem diameter of 15 trees over a period of 6 months. Additionally, we scored the plants leaf flushing behaviour. We found that DNG was determined by flushing behaviour, whereas environmental stressors determined DS. The largest growth of the trunk occurs during the no-flushing stage, whereas hardly any stem growth takes place during the flushing of new leaves. Once the new flushes are mature, the growth of the stem starts again. Daily Shrinkage, on the other hand, is affected by climatic parameters, where the level of shrinkage increases with increasing evapotranspiration.

Keywords: Daily shrinkage, daily net growth, evapotranspiration, stem, trunk diameter

1 Introduction

Cocoa is traditionally grown in humid tropical conditions. However, these conditions often result in phytosanitary issues, and thus poor production levels [Bl17]. This led farmers to explore new areas for cocoa production. Currently the semi-arid regions of Brazil are receiving increasing attention from farmers who assume that the hot and dry climate in these areas could reduce such phytosanitary problems and allow the implementation of intensive cropping systems with densities up to 2000 trees/ha [AC12; Ag14]. This intensification of production systems achieved satisfying results, yet, particularly the new climatic characteristics of the region raised concerns regarding the optimal management of

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trees in this environment. Sensors can precisely monitor plant behaviour and allow understanding the plants' reaction to stressful conditions.

The dendrometer is one of these sensors that can be installed directly on the tree stems to obtain information on the development of the plant [Co14]. This variation in stem growth reflects the physiological reaction of a plant to climatic stressors, such as drought [Ga19]. Considering the plants' physiological reaction to climatic stress in the semi-arid region could therefore allow managing irrigation more precisely.

2 Material and Methods

We monitored the daily stem variation of 15 cocoa trees of the cultivar CCN51 over 6 months in Juazeiro- BA, a semi-arid region of Brazil (BR, Coord. -9.122 -40.258). This region is characterized by average temperatures around 25°C and relative humidities below 50%. Dendrometers (Megatron, Megatron Electronic GmbH & Co.KG Munich, Germany) were fixed on top of the tree bark around the stem and aligned in the north direction (Fig. 1). The Agriscope (www.agriscope.fr) online platform was used to gather data every 15 minutes and sent to the Internet via a gateway that was installed on the farm. A meteorological station collected data on air temperature, radiation, air humidity and wind speed. We calculated Evapotranspiration (ET_0) [Al98] from this meteorological data. The plants' leaf flushing behaviour was further recorded weekly via direct observation (scoring 0-3, where 0 showed no flushing, and 3 the highest level of flushing).

Fig. 1: New flushes after pruning (left) and Dendrometer fixed to the cocoa tree (right)

Data were analysed in R version 4.0.2 (R Development Core Team 2018). We determined the Daily Shrinkage (DS) by calculating the daily maximum - daily minimum stem diameter per day [Go01]. Additionally, we calculated Daily Net Growth (DNG) by calculating the daily maximum value of the current day - the daily maximum value of the previous day. Data were cleaned from noise by excluding outliers (DNG < 150). For better functioning of the model, negative growth was also omitted.

We performed generalized linear mixed effects models ("lme" method, [PB00]) from the package "nlme4" for the two target variables DNG and DS. ET_0, Flush stadium and consecutive day of year were considered as fixed effects, whereas fruit abortion nested in fruit and trees were considered as random effects. The model residues were checked graphically using the Pearson correlation. Subsequently, we applied the function "*dredge*" (package MUMin, [Ba15]) with the Bayesian Information Criterion (BIC) to obtain the best model by considering all possible combinations of explanatory variables as well as their interactions. All models are hereby compared by model weight (w_i), where the best model will be the model with the highest w_i and include those explanatory variables which best describe the data. This approach presents an alternative to frequentist p value testing.

3 Results

We found that DS was determined by ET_0 and the consecutive day of the trial ($w_i = 0.82$), whereas DNG was determined by the stage of flushing and the consecutive day of the trial ($w_i = 0.94$) (Fig 2).

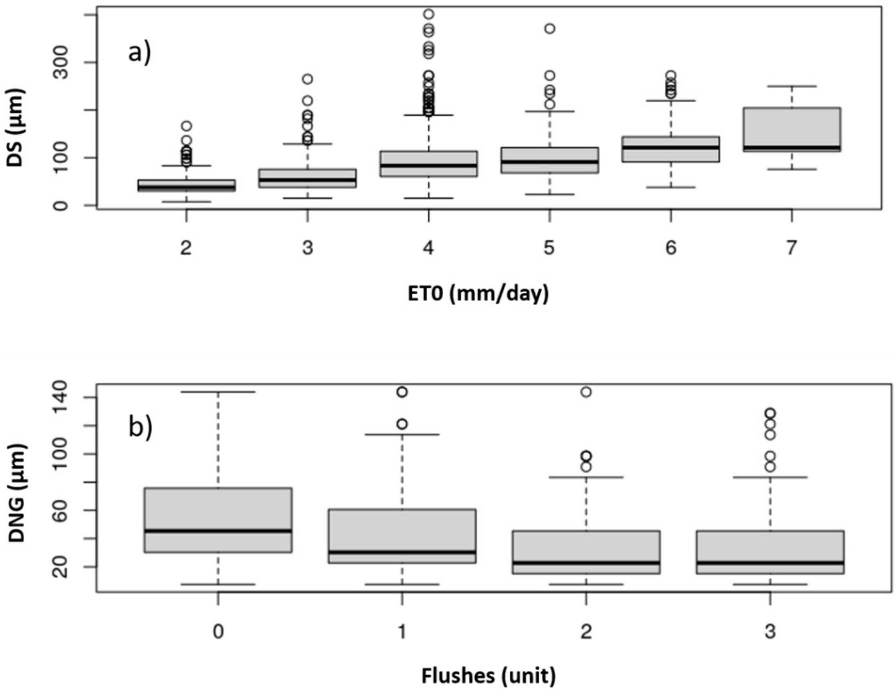

Fig. 2: Above) Daily Shrinkage (DS) increased with ET_0. Below) Daily Net Growth (DNG) is highest during the no flushing period (0: no flushing, 1: beginning of flushing, 2: more advanced stage of flushing and 3: mature leaves)

4 Discussion

4.1 Daily Shrinkage

We found that Cocoa trees reacted to rising ET_0 levels with increased shrinkage. The stem loses water during the day, which is due to the exposure to sun, wind and heat, and then expands after sunset, when the plant is recovering. The higher the exposure to environmental constraint, the stronger the tree will react. With specific regard to irrigation, we aim to use as little water as possible, without exceeding the plants' compensation potential.

4.2 Daily Net Growth

Our results confirmed the findings of Waldburger et al. [Wa19], which show that stem growth and flushing of leaves occur separately. The production of new leaves is characterized by release cycles lasting around 15 days and followed by one month of quiescence. The flushing cycle was observed by Abo-Hamed et al. (1981) [ACH81]. They portrayed the alternation in shoot elongation and quiescence periods, suggesting that flushing cycles are controlled by a regular cycle of accumulation and reduction of "*growth promoter*" and inhibitor compounds in the bud [ACH81; AV10]. During flushing of leaves, the growth of the cocoa trees' stem stagnates. As soon as the flushing of leaves has finished, the stem starts to grow again. Despite literature reporting the release of new leaves in cocoa being triggered by rain season [Ca12], this was not the case in our study. In fact, endogenous factors have a greater influence in this process [GLP71]. We hypothesise that rain season may play a minor role due to the continuous irrigation of the trees.

5 Conclusion

We found that cocoa trunk development was driven by alternating phases of new shoot elongation (flushes) and quiescence. This stop of stem growth shows that flushes have priority over stem and hence as fruits are attached to the stem, we assume to fruit growth too. Maybe better management could help to decrease important fruit abortion, which is more significant in the semi-arid climate.

DS is a good indicator of weather constraint, reacting coherently with ET_0, and could therefore be used to improve irrigation management. In a next step, we suggest to define cocoa specific thresholds that avoid excessive irrigation, but allow the plant to reach optimal production levels.

We can apply our knowledge on plant behaviour to create practical solutions for irrigation systems, if we use sensors such as dendrometers, climate sensors and soil moisture sensors. Software can combine this information, and thus allow administering precise automated irrigation and thus reduce the wastage of water.

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