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Physiographic position drives Eucalyptus productivity in Mato Grosso do Sul, Brazil

José Luiz Stape[1]
Clayton Alcarde Alvares[1,2]

[1]Unesp/FCA (jlstape@gmail.com), [2]Suzano SA (calcarde@suzano.com.br)

ABSTRACT: *The Southeastern region of Mato Grosso do Sul State, Brazil, has slight regional variations in climate (rainfall, temperature) and soils (sandy and low fertility due to sandstone geology), leading to label the region as "homogeneous" for Eucalyptus management. This study showed that this concept was wrong and identified the main driver of forest productivity in this system. Sequences of abnormal and low rainfall years, coupled with 11 years of high intensity forest inventory, has exposed the region to distinct forest survival and yields, and allowed the identification of physiography (position in the landscape) as the main controller of water availability and consequently to Eucalyptus plantations productivity. This knowledge has already been applied to better recommend clonal varieties, spacing among other prescriptions.*

Keywords: physiography, ecophysiology, wood-production environments, data science

Introduction

Eucalyptus growth driver has been deeply studied and associated with species/clones, soil type, fertilization regime, spacing, weed control, temperature, and rainfall over the years (Binkley et al, 2020; Ryan et al., 2020).

In parallel a lot of effort has been carried out to understand eucalypt root system, and at spot trials, it proved to be important to fully describe *Eucalyptus* growth in deep profile soils (Oxisols and Quartzpsaments) and its relationship with the traditional tropical monsoon climate in Brazil, Australia, and South Africa (Laclau et al., 2013; Christina et al., 2017, Pinheiro et al., 2019).

Based on that review and in broad field mortality observation we hypothesized that the water table depth and root dynamics would play a strong role in tree growth (Figure 1).

Material and methods

In this study an extensive spatial (270 km x 270 km range) and temporal scale inventory network was put together and related with a water table algorithm based on most recent geo-information data available in a 30 m x 30 m resolution for the forestry part of the Brazilian state of Mato Grosso do Sul.

Water table depth algorithms

We used the HAND terrain descriptor (Height Above Nearest Drainage, Rennó et al., 2008) as a surrogate for the water table depth (WTD) on the watershed scale. The production of the WTD map requires a digital elevation model (DEM). We used the recent digital surface model (proxy for a DEM) Copernicus (https://spacedata.copernicus.eu), with a spatial resolution of 30 m, and provided by the European Space Agency (https://spacedata.copernicus.eu).

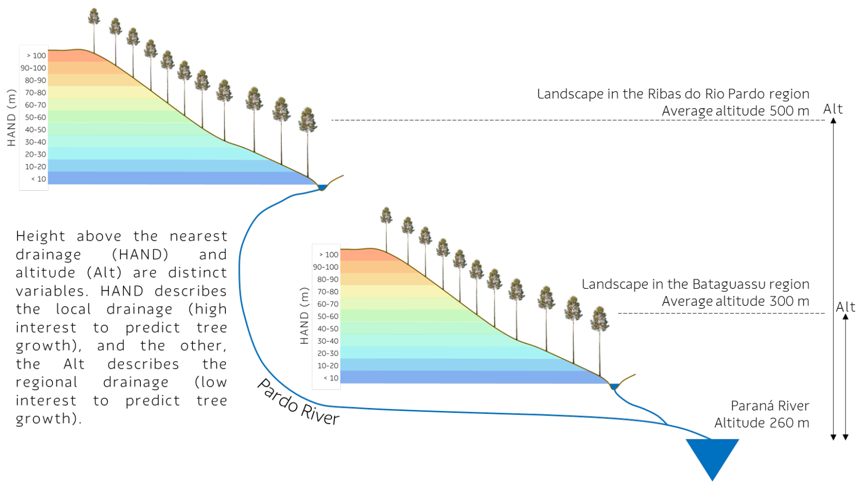

Figure 1. Surface-water features such as streams and rivers represent the intersection of the water table with land surface, and the terrain above of them is the surrogate for the water table depth (WTD).

Forest datasets

Approximately 113,000 plots of the permanent forest inventory of Suzano's commercial *Eucalyptus* plantations, spread over dozens of thousands of hectares for the last 10 years, were made available for this study. The forest dataset included planted stands from 2005 to 2018 and tree measurements from 2008 to 2021.

Remote sensing (canopy drought-induced damage)

A dataset with a couple hundred thousand orbital observations resulting from the vegetation index monitoring of the Suzano were also made available. The normalized difference vegetation index (NDVI) was calculated for each scene and its distribution within each stand was used to classify its canopy. Each stand classified with critical or very critical NDVI was surveyed in the field to identify the biotic or abiotic agents causing those NDVI anomalies. Thus, for this study we used only stands with the NDVI anomaly affected by canopy drought-induced damage.

Results and discussion

The WTD was reducing the mean annual increment (MAI) due to the chronic recurrent effect of the annual water deficit. Tallest trees and most productive sites are in the lowest positions of the landscape. The MAIs were approximately of 46, 42, 39 and 37 m^3/ha/year for WTD of 10, 50, 75, and 125 m (Figure 2). The distribution of inventory plots across the region provides spatial robustness to the MAI reductions with WTD increase. Similar trends are maintained per measurement year (Figure 2). This shows that the water deficit is always greater with an increase in WTD and occurs every year, regardless of the rainfall of the year, providing temporal robustness.

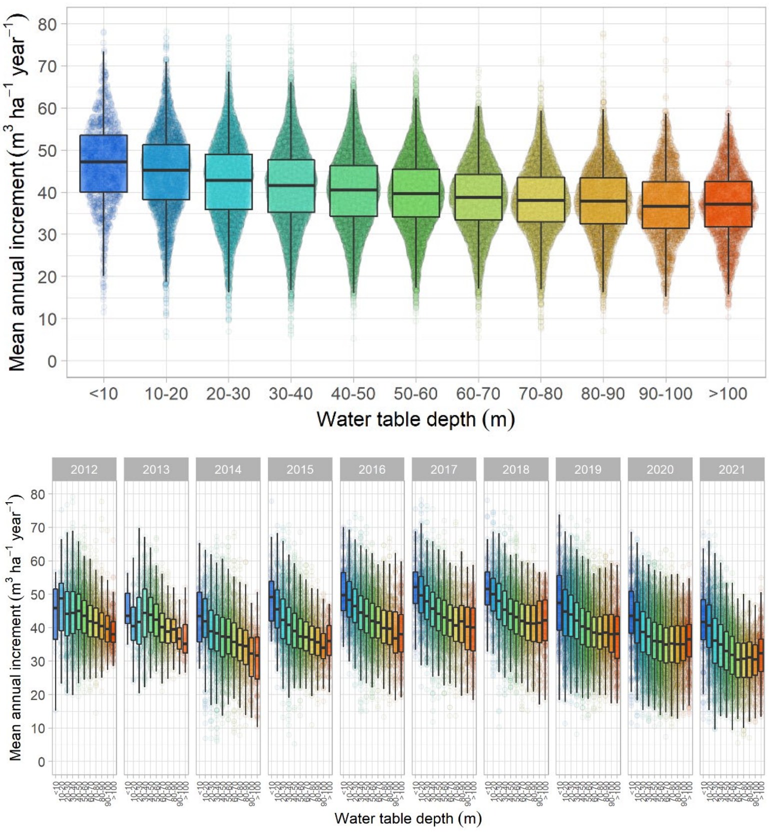

Figure 2. Effects of water table depth on the reduction of the mean annual increment of 113,000 *Eucalyptus* permanent forest inventory plots were observed for all years (top plot) and in the last 10 years for each measurement year (bottom plot).

The soil water deficit annually causes the loss of leaf area and, in extreme cases, spots of tree mortality within the stand, which become detectable as an NDVI anomaly by remote sensing. The biennium 2020-2021 was dry, proving ideal to verify that these NDVI anomalies increase in the higher sites of the landscape (Figure 3). Consistently, all clones are more productive for smaller WTD and reduce IMA in higher sites of the landscape (Figure 4). Thus, in addition to WTD being spatially and temporally robust, it is captured in all clones. As water is essential for all of them, and this was expected, however the sensitivity (inclination) seems to differ among clones.

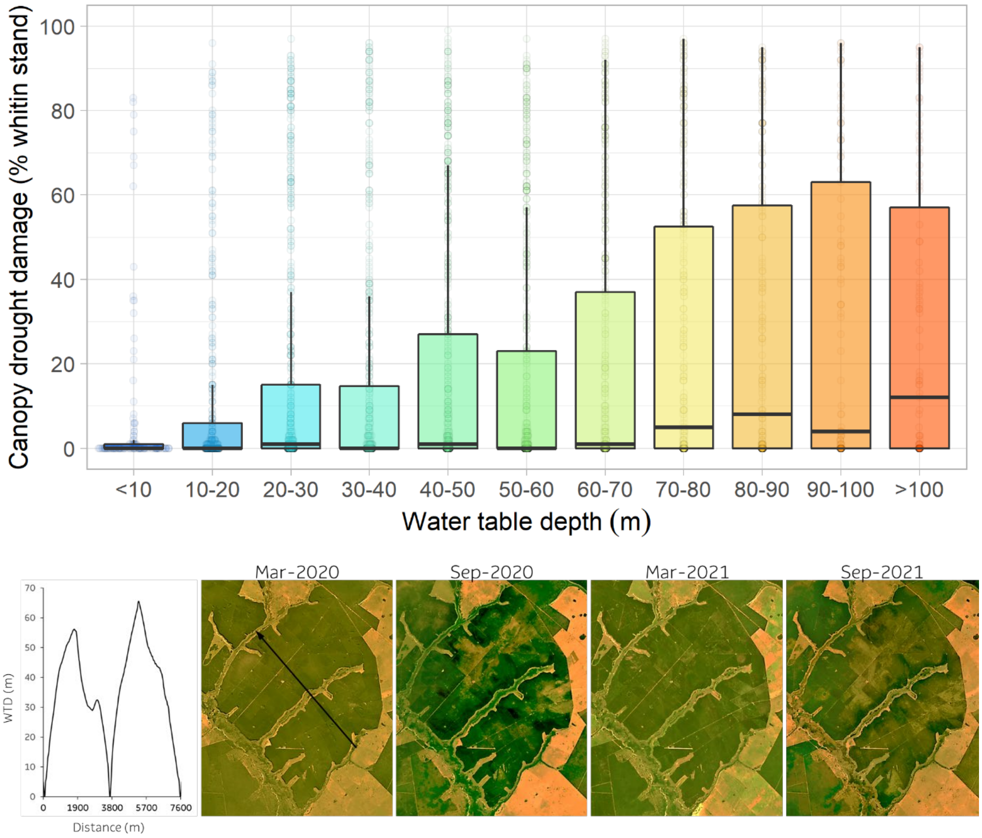

Figure 3. Stands with canopy drought-induced damage are more frequent in higher positions in the landscape (top figure). False color composite twin-images, one at end of the wet period (March) and another at end of the dry period (September) of both years show that NDVI anomalies increase in the higher sites of the landscape (bottom figure).

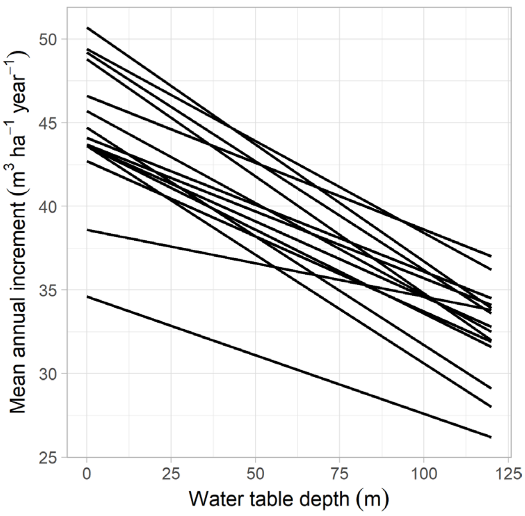

Figure 4. The 15 most frequent clones in the study area are responsive to the topographic position where they are growing. The maximum mean annual increment for all clones averaged 44.6 m^3 ha^{-1} yr^{-1}. On average, for these clones, there was a decrease of 1.0 m^3 ha^{-1} yr^{-1} in MAI for each 10 m increase in the water table depth.

Conclusions

Higher yields and lower forest formation costs depend on adequate choices of clones, management, and operation per environment, as each environment has a certain availability of water, nutrients, and degree of protection, which leads to a specific MAI.

Our study identifies physiography (position in the local relief) as the factor that controls the availability of water, and indirectly nutrients, to the Eucalyptus forests on sandstone derived landscapes in the Mato Grosso do Sul. The results obtained will allow the classification of the region into physiographic zones, which explain productivity by the effect of local drainage and water deficit, opening opportunities for clonal adequacy, management, operational activities, increasing tree survival and the MAI.

Genetic and silvicultural prescriptions as variety and spacing recommendations have already been implemented, and further ones as fertilization rates, weed control and site preparation and conservation are being considered.

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