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# GIS-based approach applied to optimizing recommendations of *Eucalyptus* genotypes

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ABSTRACT

The study of the genotype × environment interaction is a prominent issue, requiring care for recommending improved superior genotypes to certain areas. Experimentally, it is possible to infer that the puzzle of genotype recommendations relies on edaphic and climatic changes over different terrain latitudes and longitudes, and further fluctuates in microenvironments as a result of site variations. Different gene expression is activated or suppressed in accordance with environmental requirements, resulting in phenotypic plasticity of cultivars. The goal of this study was to generate an optimal recommendation of eucalyptus genotypes in a 6846.0 km$^2$ using climatic and geographical information. For this purpose, we used 24 clones unevenly distributed in 988 plots over the area, with planting ages between 2.5 and 6.5 years. The evaluated trait was production, measured in cubic meters of wood per hectare. Our study area typically has a mid-to-low altitude range (0–390 m), rainfall between 599 and 1749 mm, temperature from 22 to 25 °C, and a series of other bioclimatic variables. For statistical analysis, we used the random regression via mixed-effects models (REML/BLUP) combined with logistic growth models. Among the total number of clones, six proved to be the most suitable to maximize volumetric production in the work area. In addition, a change in the recommendation was verified for clones between 2.5 and 6.5 years of age. This study presents an alternate concept of environmental stratification, which to date has been made categorically by evaluating a number of locations. Our study proposes a way to perform quantitative stratum over an entire area, according to the environmental gradient. The optimal selection of genotypes promotes increased wood production without necessarily increasing the planting area, which is extremely desirable because land is a resource that is becoming increasingly scarce. Furthermore, eucalyptus productivity represents an important part of the costs and revenues of the forest enterprise, such that minimal improvements can significantly affect profit margins. The proposed method is easily adapted for use for other crops and domestic animal production.


## 1. Introduction

Plant breeding has been conducted through many ages, from Mendel and Fisher up to the current application of molecular markers in the selection of the most reliable genotypes (Bradshaw, 2016). Nonetheless, the study of the genotype × environment interaction (G × E) is a prominent issue with respect to improved materials recommendations (Brawner et al., 2013; Ogut et al., 2014). It is possible to infer that the decision regarding the indication of genotypes can vary because of the macro-environmental, edaphic, and climatic changes over different latitudes, longitudes, and times (Bourret et al., 2015; Gray et al., 2016) and can vary further with respect to micro-environmental changes at a particular site (Resende et al., 2016; Soares et al., 2016). Different gene expressions are activated or suppressed in accordance with the environmental requirements, resulting in phenotypic plasticity to cultivars (El-Soda et al., 2014). This phenomenon is pivotal to governing the G × E interaction. Thus, especially when dealing with traits with mid-to-low heritability, such

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as the productivity of *Eucalyptus* sp. (Castro et al., 2016), the environmental interference is even more problematic in the trait expression (Lynch and Walsh, 1998) and requires carefully detailed recommendations according to changes in the environmental profile (Ogut et al., 2014; Taïbi et al., 2015).

Certain genotypes are more stable in different environments. In most cases, these genetic materials are selected because they do not present unwanted yield surprises, being more resilient to local climate change (Eberhart and Russell, 1966; Nunes et al., 2002). Moreover, some genotypes are more adaptive, responding positively to improvements in environmental growth conditions (Brawner et al., 2014; Santos et al., 2015). The recommendation of cultivars for different environments is effective when the cultivar contains certain alleles that are compatible to the site growth response, in other words, genotypes that can maximize the conversion of the available resources to biomass or productivity (El-Soda et al., 2014).

Eucalyptus is a culture of great economic importance in Brazil. For this reason, many researchers and companies investing in research are seeking to better understand the environmental factors that increase its productivity. The country has continental proportions. It is estimated that there are currently 5.1 million hectares of eucalyptus plantations distributed throughout Brazil (ABRAF, 2014). It is known that gender responds in a very peculiar way to environmental changes. Several studies (da Silva et al., 2016; Ryan et al., 2010; Stape et al., 2004, 2010) have demonstrated productivity gains according to the availability of light, water, and nutrients in southeast and northeast Brazil. Almeida et al. (2010) and Calegario et al. (2005) mapped eucalyptus productivity according to spatial and temporal variations and recommend the practice of genetic selection to increase productivity. In this sense, Pérez-Cruzado et al. (2011) performed productivity prediction of *E. nitens* using a similar methodology to previous authors. Although the aforementioned authors address the use of different genetic material, there are no studies in the literature that examine, at a breeding level, a clonal recommendation according to continuous environmental change in the area.

Commonly environmental variables are assigned as discrete phenomena, generating groups with similar environmental features – called the stratum – such that environments are treated as categorical variable levels (Burdon, 1977). In a geographic information system (GIS), the environmental information may be represented by a *raster*, a continuous spatial variable (Li et al., 2004). Considering the environment categorically means losing the ability to diagnose smooth and gradual changes of the environment. Thus, GIS can be considered a useful tool in edaphic and climatic characterization of region, allowing the recommendation of genotypes to areas with environmental features similar to those in which certain genotypes performed well.

The number of planted clones is also something broadly discussed in the forestry sector (Ivetić et al., 2016; Roberds and Bishir, 1997). The recommendation of a few genotypes (e.g., the most stable ones) becomes attractive from an economic point of view because of a reduction of productivity losses risks and nursery costs (Rezende et al., 2014). However, to maintain genetic variability and to prevent unmanageable disease incidence problems (Castro et al., 2016), a suitable number of clones should be maintained and planted recurrently.

In animal and plant science, is quite common to use mixed-effects regression and reaction norms for studies of biological behavior and ecological interactions (Calegario et al., 2005; Nothdurft et al., 2006). This method also has several applications in breeding and $G \times E$ studies (Pérez-Rodríguez et al., 2015; Raidan et al., 2015; van de Pol, 2012). The mixed effects regression is typical for calculating regression coefficients for each random effect, such as genotypes in genetic selection studies (Resende, 2007).

In this context, the aim of this study was to propose a method to optimize genotype recommendations in accordance with environmental gradients, and thus determine the optimal number of eucalyptus clones that will maximize the productivity of the available area.

## 2. Material and methods

### 2.1. Data and work area description

We used continuous forest inventory data from forest stands of eucalyptus clones, including 988 plots, that had been measured four or five times (4197 observations in total). In addition to the variables commonly derived from inventories (such as age, height, dominant height, and volume), genotype provenance (total of 24 clones distributed unevenly throughout the work area) and geographical location (coordinates X, Y on Fig. 1) were also noted for each plot. The classical site index (i.e., based on the dominant height of the stand) was computed for validation of the proposed environmental index (based on climatic variables). Climatic information was obtained using the WorldClim dataset (Hijmans et al., 2005), which includes 19 bioclimatic variables (see Table 1). Bioclimatic variables represent annual trends, seasonality, and extreme and limiting environmental factors, such as precipitation during the driest quarter. This database is available in *raster* format, with a spatial resolution of approximately 0.9 $km^2$, and corresponds to a historical series from 1950 to 2000. These variables are derived from monthly values of temperature and precipitation. The study area consisted of 8132 pixels, distributed in 76 lines and 107 columns.

The area was delimited from a rectangular buffer extending 5 km beyond the geographic extent of the spatial feature points (the location of inventory plots), covering 19 municipalities in the northeastern Bahia state of Brazil (Fig. 1). The region is characterized by high variation in precipitation, with high rainfall near the coast (bathed by the Atlantic Ocean) that gradually decreases further inland. Similar behavior is observed for the temperature, but the decrease is more related to increasing elevation.

### 2.2. Methodology

#### 2.2.1. Step 1: Environmental Index (EI)

The first step of the methodology is to obtain variables representing the environmental gradient of the study area. In order to summarize the climatic variables, while maintaining simplicity of interpretation and developing parsimonious models, we created a single environmental indicator called the environmental index (EI). There are several statistical methods for generating indices (Johnson and Wichern, 2014; Skovsgaard and Vanclay, 2008). In this study, the index was created using the principal components analysis procedure (PCA).

The EI must represent the productive capacity of the site. In forest science, there are two basic approaches to express productive capacity through local indexes: (1) Plant-based, that is based on the development of the plant itself (usually dominant stand height at a reference age) and (2) earth-based, based on site characteristics such as topography, climate, and soils (Skovsgaard and Vanclay, 2008).

The EI used was derived only from climatic variables (earth-based type), specifically the 19 bioclimatic variables obtained from WorldClim, is represented as *raster* data, with extensions, pixel size, and alignment equal to the bioclimatic variables. The application of PCA was performed using the *prcomp* function of