IDENTIFICATION OF SUITABLE AREAS FOR IMPLEMENTATION OF EUCALYPTUS CULTIVATION IN THE ESPIRITO SANTO STATE, BRAZIL

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ABSTRACT: This study aimed to verify the aptitude of areas for the implantation of two varieties of eucalyptus in the state of Espírito Santo, Brazil. In the analysis there were used mean precipitation, mean temperature, hydric deficit and land slope data, resulting in the final aptitude mapping. The results showed that the northwestern region and part of the northern region the ones that presented less suitability for both analyzed eucalyptus varieties and that the most suitable areas for planting the two eucalyptus varieties are located in the mountainous regions, part of the southern and near the northeastern coast.

INDEX TERMS: Zoning; Multicriteria analysis; Fuzzy logic.

INTRODUCTION

The productive potential of eucalyptus plantations planted in tropical regions, especially in Brazil, is very large and with few restrictions. The country's high competitiveness in the forestry sector is based on the favorable environmental conditions and on the efficiency of the employed technology, as a result of consistent investments in research and development by companies, together with universities and other research institutions (Ribeiro et al., 2009). As a wood that can be used in the segment of cellulose, siderurgy, charcoal, firewood, plywood and wood sheets, eucalyptus has a great influence on the national economy. Characteristics such as favorable natural conditions, forestry advanced technological development and other privileged conditions (geographic location, infrastructure, transportation logistics and industrial plants diversification) favor forestry activity growth in Espírito Santo state (Valverde et al., 2005).

However, the fast expansion of eucalyptus cultivated area with its high number of varieties and its great adaptability to the most varied ecological conditions led to the need for studies that could predict its productive capacity in different environments (Bognola et al., 2009). Therefore, climatic zoning is an important tool for the delimitation of areas with climatic aptitudes for forest varieties implantation and development, since it establishes the region's thermal and hydrological indicators, besides it helps the decision making process that can bring direct benefits to the crop (Klippel et al., 2013).

The use of Geographic Information Systems (GIS) to identify areas where economically important forest plantations can be implanted is of great value, since it provides the zoning elaboration that aggregates several types of information into a single database, making it possible to differentiate between areas with greater or lesser ability.

The identification of areas suitable for planting different varieties generally uses Boolean Logic based modeling, which is easy to apply, but in practice is considered very conservative in terms of risks, since the problem's solution is obtained satisfying all criteria. In this classification binary results (0 or 1) are obtained, that is, false or true. This limitation can be solved by factor assessment and aggregation with Weighted Linear Combination (WLC) analysis. In this, the adopted weights govern the degree to which one factor can compensate the other.

In the WLC analysis the factors are not reduced to simple Boolean criteria. Instead they are standardized on a continuous suitability scale from zero, the less adequate, to 255, the most adequate. By rescaling the factors on a standard continuous scale it is possible to compare them and combine them as in the Boolean case. In this way, the rigid Boolean decision on the definition of a location as absolutely adequate, or not, for a given criterion is avoided.

According to Calijuri et al. (2002) the WLC procedure includes the spatial analysis potentiality when compared to the Boolean ones, since it allows to insert the risk variable and the inter factors compensation.

In the case of climatic classification, due to the intrinsic imprecision character, fuzzy logic can be used as an alternative methodology for this process. Fuzzy modeling, proposed by Zadeh (1965), has been widely used to characterize classes that do not have or do not set strict limits (Burrough & Mcdonnell, 1998), and is indicated to deal with ambiguities, abstractions, and ambivalences in complex mathematical models which represent common fuzzy limits in natural processes (Bonisch et al., 2004). With this, this modeling can present results which are closer to natural reality, making the learning process about forestry most suitable areas more reliable and less subject to errors.

In many cases it is also necessary to use tools for multiple goals suiting. The Multi-Objective Land Allocation module (MOLA) identifies locations based on the principle of the total area, working in areas where many objectives conflict in order to provide a better solution for all of them.

Due to the growing importance of eucalyptus cultivation, this work's objective was to determine suitable areas for *Eucalyptus grandis* and *Eucalyptus urophyla* development in Espírito Santo state using the Weighted Linear Combination (WLC) and Multi-Objective Land Allocation module (MOLA).

METHODOLOGY

Studied area and database

The studied area of the present study considered the state of Espírito Santo, located in the southwestern region of Brazil, with a 46,078 km² total area. Geographically, the state lies between the meridians 39°38' and 41°50' west longitude and between the parallels 17°52' and 21°19' south latitude. According to the Köppen classification system, the region fits into climatic zones A and C, which identify humid climates. In the state the Aw, Am, Cf and Cw climatic subtypes are also found, as well as the Cfa, Cfb, Cwa and Cwb variations (Siqueira et al., 2004).

In order to identify suitable areas for eucalyptus planting, air temperature, precipitation, water deficit and land slope data were used. The mean annual rainfall was obtained using the historical series of 79 rainfall stations belonging to the hydrometeorological network of the National Water Agency (ANA), to the National Meteorological Institute (INMET) and to the Center for Weather Forecasting and Climate Studies (CPTEC), considering a historical series of 30 years of data (1979-2008). The pluviometric stations location is shown in Figure 1.

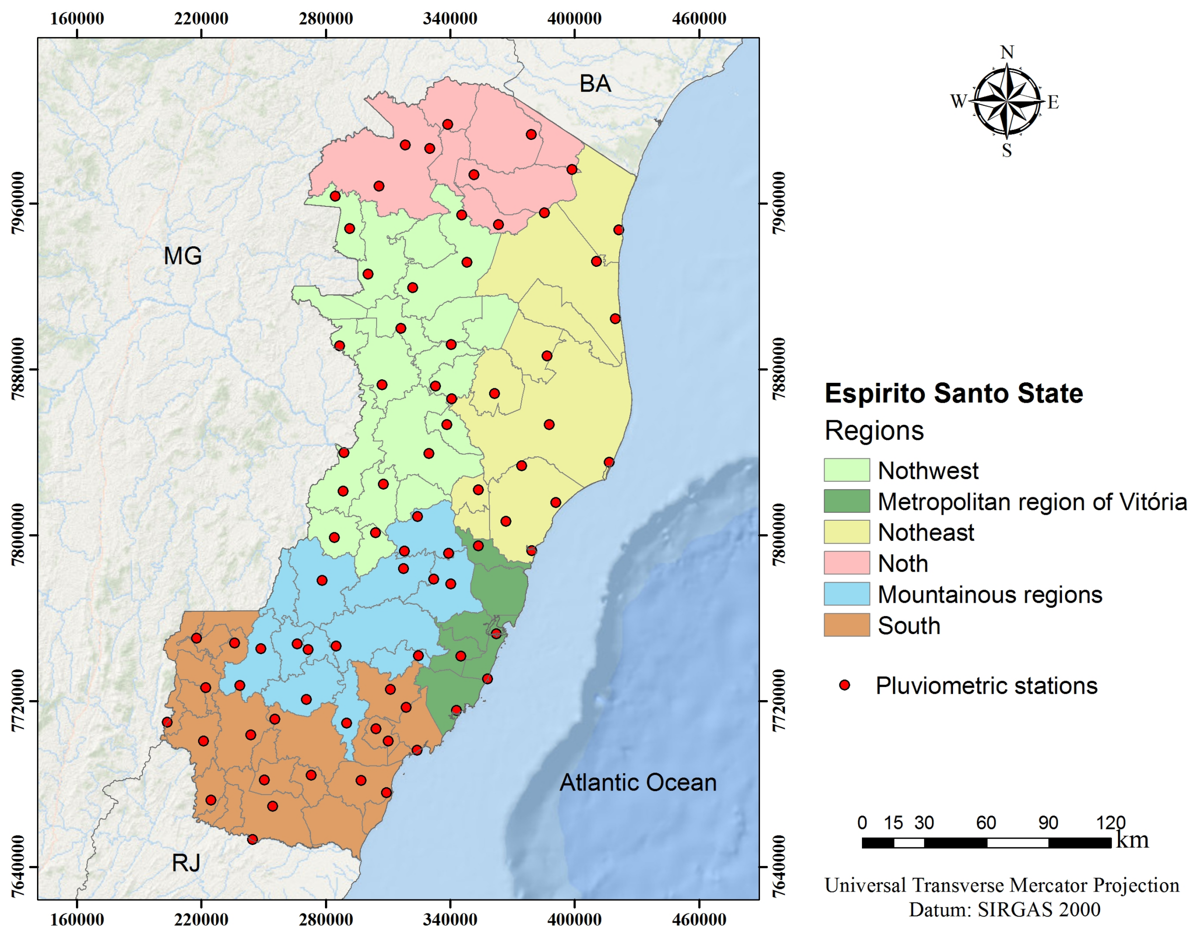

Figure 1. Map with the pluviometric stations location used in the study.

Since in ANA pluviometric stations no air temperature measurements were performed, those were obtained using the CALCLI software developed by Stock et al. (1991). The software makes temperature estimates based on geographic coordinates and distance from the coast. For this purpose, the geographic coordinates of the 79 rainfall stations were used. Based on the meteorological data for average air temperature and rainfall for all localities, the monthly climatic hydric balance was calculated using the methodology proposed by Thornthwaite and Mather (1955), described by Pereira et al. (2002). The land slope was determined by means of a digital elevation model, obtained by SRTM (Shuttle Radar Topography Mission) radar data, with a spatial resolution of 90 meters.

The interpolation of temperature, precipitation and water deficit data was performed by means of ordinary kriging. Thus, for spatial dependence analysis, the semivariance was obtained as a function of the distance separating the samples. Works such as Carvalho and Assad (2005); Castro et al. (2010); and Gomes et al. (2011) obtained satisfactory results when using ordinary kriging to study the spatial distribution of rainfall and water deficit.

With the calculation of the semivariance as a function of different distances, the experimental semivariogram was obtained. Then it was necessary to adjust a theoretical model to this experimental semivariogram. The theoretical models of semivariogram (Soares, 2006) were spherical, exponential, Gaussian and linear. With the nugget effect, the plateau and range obtained by means of the theoretical semivariogram, it was possible to obtain the spatial distribution of the variable under study by means of ordinary kriging. The theoretical model of semivariogram chosen was the one that provided in the cross-validation the highest correlation between the values observed and estimated by kriging, evaluated by the Pearson correlation coefficient tested by the t test at the 5% probability level.

To obtain the restrictions related to the study, geographic information related to the location of flooded areas, special areas (environmental protection area, biological reserves, state parks, among others), hydrography and urban boundary were used.

Evaluation by multiple criteria

The zoning consisted mainly of the identification of areas with climatic aptitude for the cultivation of *Eucalyptus grandis* and *Eucalyptus urophylla*, in which the ideal hydrothermal conditions were established for their development and consequent productivity. In this work the fuzzy concept was used to give all Espírito Santo’s locations a representative value of its suitability degree for a certain factor.

Due to the fact that several factors were used to determine suitable areas and considering that they have different weights in the decision process, a weighting of the variables was established using the Idrisi Selva software WEIGHT matrix according to each factor’s degree. Exemplification of the WEIGHT module can be found in Pinto (2010).

In order to finalize the factor aggregation process, we used the Weighted Linear Combination (WLC) method of the Idrisi Selva software in the Multi Criteria Evaluation (MCE) module, which allows for compensation between factors. The WLC analysis was done by multiplying each standardized factor by its obtained weight and adding up all the results below. In this process, the weights of the respective criteria were assigned according to their importance to the proposal. The weights of the factors adopted in the analysis were: 0.522 for annual water deficit; 0.1998 for average annual temperature; 0.1998 for annual mean rainfall; and 0.0781 for land slope, totaling 1. The last step in the WLC was to multiply the Boolean constraints.

The requirements of the eucalyptus varieties analyzed in this study regarding temperature; precipitation; and hydric deficit; and land slope factors can be seen in Table 1.

Table 1. Established requirements for two eucalyptus varieties stands implanting

Varieties	Average Annual Temperature (°C)	Average Annual Rainfall (mm)	Annual Hydric Deficit (mm)	Land slope (%)
Eucalyptus grandis	6 - 32	1000 – 1800	0 – 400	0 - 100
Eucalyptus urophyla	12 - 29	1000 – 1500	0 – 400	0 - 100

FONTE: Ribeiro et al. (2009)

For the choice of the suitability function, the relationship between the criterion and the decision set was used, and the information availability to infer the fuzzy member. In most cases, sigmoidal or linear functions are sufficient. For the temperature and precipitation factors the symmetrical sigmoidal function was used, as can be observed in Figure 2, where it is considered that the suitability increases from point "a" to "b", it maintains itself maximum from "b" to "c" and it decreases from "c" to "d". For the factors hydric deficit and land slope, we used decreasing functions, where it is considered that the suitability is maximal the closer it is to the "a" point.
Figure 2 shows the adequacy functions used in this study. Table 2 shows the limits used in the adequacy functions for each factor under analysis.

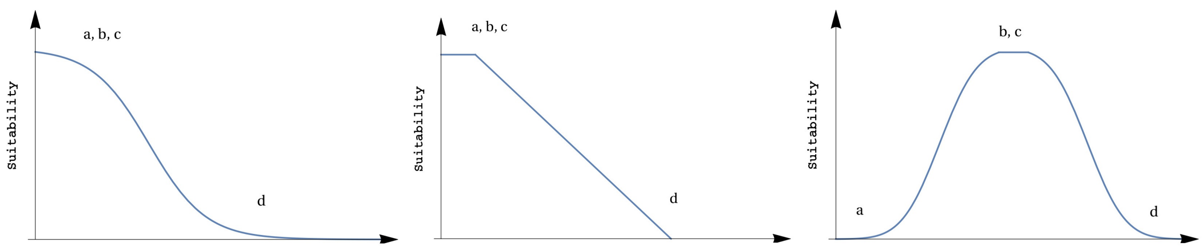

Figure 2. Sigmoidal decreasing adequacy function (a), linear decreasing (b) and sigmoidal symmetric (c).

Tabela 2. Limit of adequacy functions for each analyzed factor

Function	Factor	a	b	c	d
Sigmoidal symmetric	Temperature[1]	0	6	32	32,5
	Temperature[2]	0	12	29	29,5
	Precipitation[1]	0	1000	1800	1900
	Precipitation[2]	0	1000	1500	1600
Sigmoidal decreasing	HD[1]	0	-	-	400
	HD[2]	0	-	-	400
Linear decreasing	Land slope[1]	0	-	-	100
	Land slope [2]	0	-	-	100

1: *Eucalyptus grandis*; 2: *Eucalyptus urophylla*

Since areas can be considered suitable for both eucalyptus varieties ("conflict areas"), the Multi-Objective Land Allocation Module (MOLA) identifies locations based on the total area principle. The module works in areas where multiple objectives conflict, as to provide the best solution for all of them.

The MOLA module identifies a conciliatory solution to maximize the land suitability for each objective, considering the weights assigned to each one of them. Thus, to identify "conflicting" areas and to obtain a conciliatory solution considering the suitability for the two eucalyptus varieties development, the MOLA module was used in this study. For this analysis, it was decided to identify the most adaptable 10,000 km^2 for eucalyptus cultivation, in order to identify potential areas for these crops expansion in the state of Espírito Santo. In MOLA, the same weights were assigned to the varieties, as well as to the division of the area, with 5,000 km^2 for each variety.

RESULTS AND DISCUSSION

Figure 3 shows the spatial distribution of temperature, precipitation and hydric deficit factors used in this study.

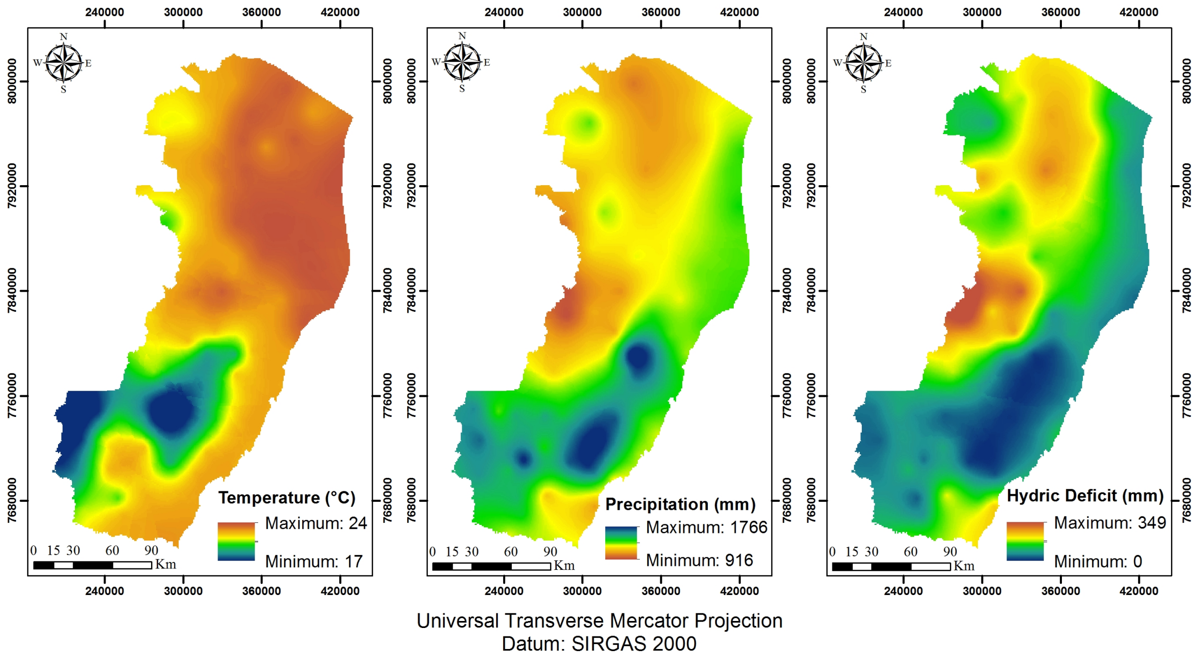

Figure 3. Precipitation, temperature and hydric deficit maps used in the study.

It can be seen from Figure 3 that there are potential areas with a climatic aptitude in Espírito Santo state for the implantation of forest stands for eucalyptus varieties, since the values of temperature, precipitation and hydric deficit, are almost entirely within the established aptitude limits. The northern and northwestern regions have the largest areas of water deficiency when compared to the other regions, with values up to 349 mm/year, due to low water availability and high evaporative demand.

From the spatial distribution of the factors and with the WLC analysis, adequacy maps were obtained for planting *Eucalyptus grandis* and *Eucalyptus urophylla* varieties in Espírito Santo state. The factors' integration process resulted in the identification of areas with high potential for eucalyptus crop implantation, varying from 0 to 255 (Figure 4). It can be seen from Figure 4 that the entire state presents areas with climatic potential for the implantation of forest stands of the studied varieties, according to the established bases for zoning.

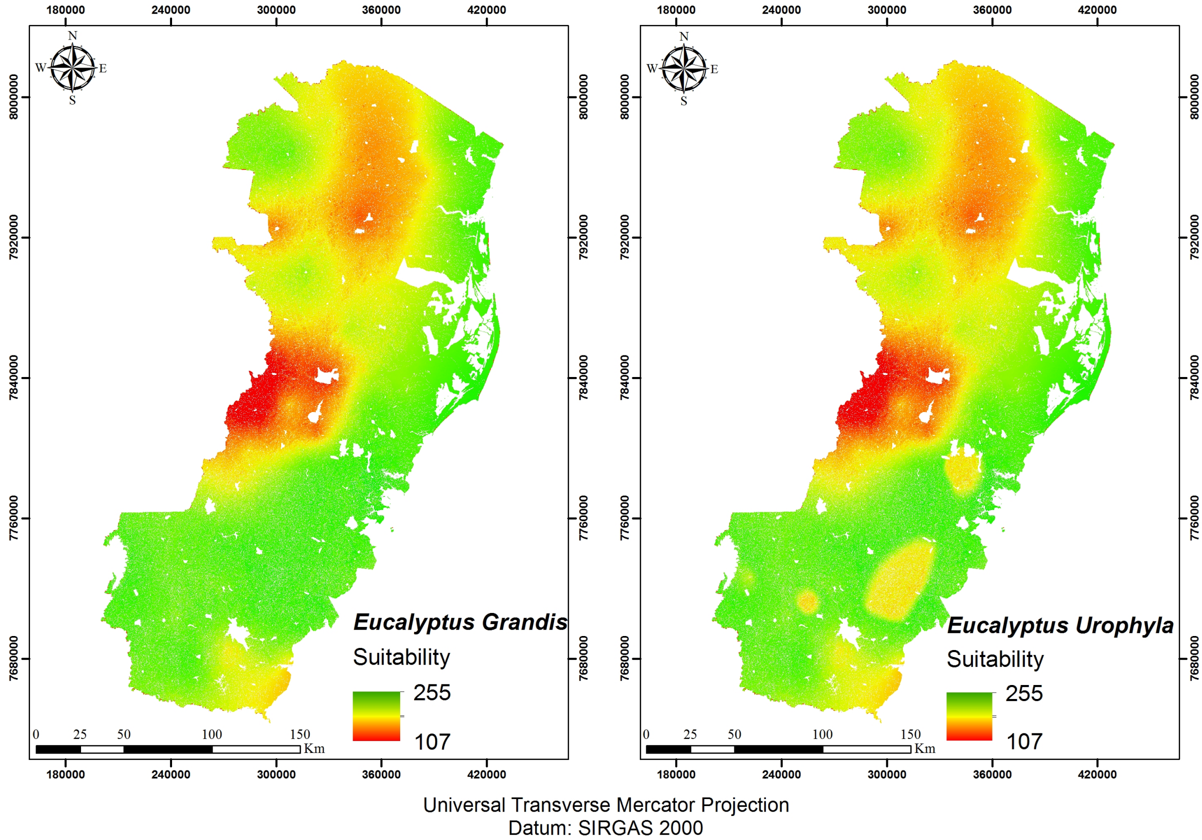

Figure 4. Suitability map for *Eucalyptus grandis* and for *Eucalyptus urophylla*.

As it can be seen, the less suitable areas have characteristics that adversely interfere in the crop growth, such as high land slope, high hydric deficit and large variations in the ranges of suitability for precipitation and temperature. However, most of Espírito Santo state has high suitability for these varieties development, being the northwestern region and part of the northern region the ones that showed less suitability for both analyzed varieties of eucalyptus. This behavior is related to the largest annual water deficit in these regions. In contrast to the variety *Eucalyptus grandis*, it is verified that the variety *Eucalyptus urophylla* presented a lower suitability in some localities of the mountain region. This behavior is due to the precipitation factor, which exceeded the upper limit of the optimum range for this variety development.

With the images of suitability, it was also possible to obtain, in the entire state of Espírito Santo, the most suitable areas for planting the analyzed varieties, as well as the area of conflict between them, that is, the area that is suitable for planting both (Figure 5 (a)). In Figure 5 (b) the results can be observed after the varieties conflict resolution, by MOLA tool.

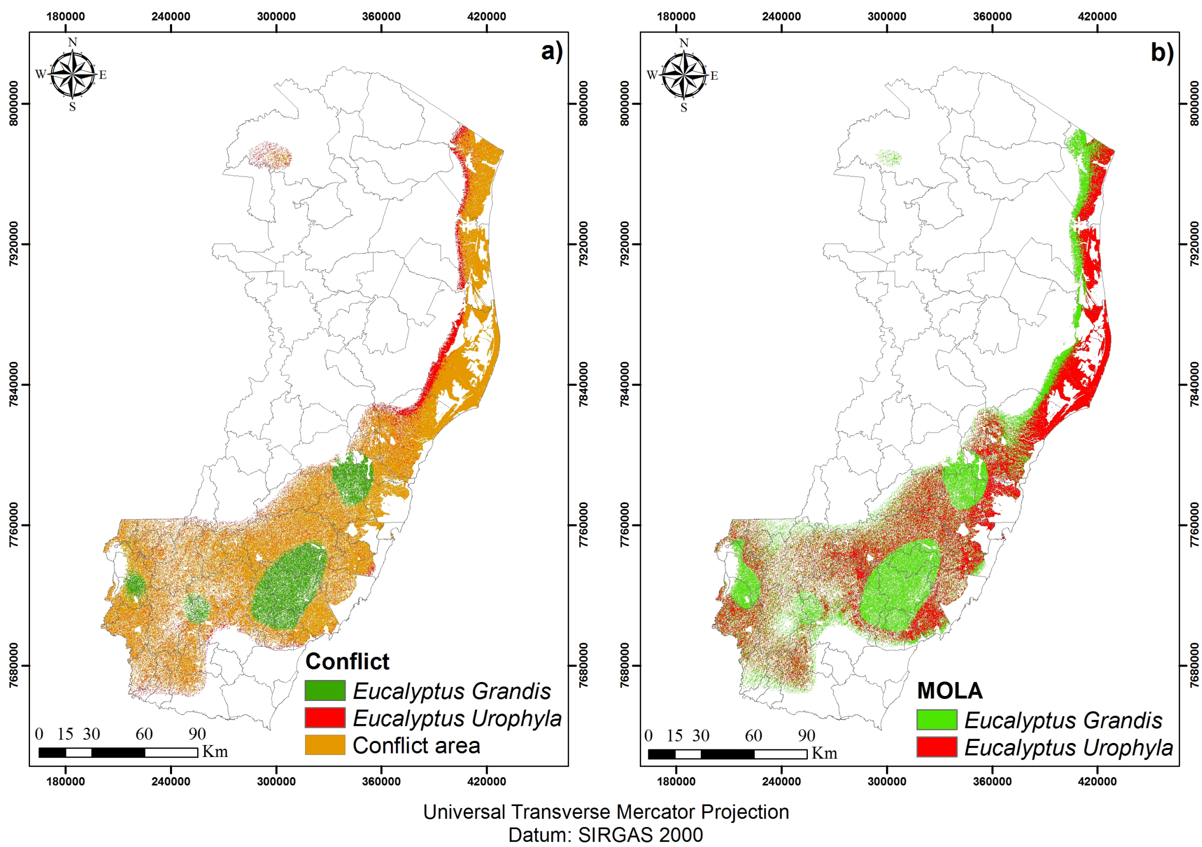

Figure 5. Conflict and aptitude map between different eucalyptus varieties (a) and adequacy map obtained with MOLA tool (b).

By means of Figure 5 it is possible to state that, preferably, areas of the mountainous region of the state and near the northeast region coast are the most suitable for the eucalyptus development, considering the 10,000 km^2 of area most suitable for cultivation. For this the two varieties were allocated in areas of 5,000 km^2 each, having equal weights for each variety. It is observed in this figure that areas near the northeastern coast of the state that were presenting conflict (Figure 5 (b)) are more suitable for the development *of Eucalyptus urophylla*.

CONCLUSIONS

The state of Espírito Santo presented high climatic aptitude for *Eucalyptus grandis* and *Eucalyptus urophyla*. The Weighted Linear Combination (WLC) allowed to identify areas suitability in the state of Espírito Santo, for cultivating both studied varieties, being the northwestern region and part of the north region the ones that presented the smallest adaptability value. The MOLA tool allowed solving the conflict of suitability between the two eucalyptus. The most suitable areas for planting the two eucalyptus in Espírito Santo are located in the mountainous regions, part of the southern and near the northeastern shore, considering for 10,000 km^2 more suitable for eucalyptus cultivation.

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