



Agroclimatic zoning for jatropha crop (*Jatropha curcas* L.) in the State of Goiás

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ABSTRACT. *Jatropha* stands out in the Brazilian agribusiness scenario as one of the most promising nuts for biodiesel production, although there are few studies on this culture's introduction, management and cultivation techniques. Through the characterization of the state of Goiás' climate based on climate, rainfall and evapotranspiration maps, this work aimed to define areas suitable for the cultivation of *Jatropha* by designing an agroclimatic zoning system. Rainfall climatic data from 114 stations and air temperature data related to 34 stations were used. The zoning did not show any area that was considered unsuitable for the cultivation of *Jatropha* in the state, with much of the territory having full culture capability and some marginal regions characterized by water deficit or thermal deficiency. Throughout the state of Goiás, 64.6% of its territory is fit for the cultivation of *Jatropha*, whereas 35.4% has some marginal conditions for culture development. Of the total of areas defined as marginal to the cultivation of pinion, 28.8% are considered marginal due to water deficits and 6.6% are considered marginal due to thermal deficiency.

Keywords: agrometeorology, climate modeling, agricultural potential.

Zoneamento agroclimático para a cultura do pinhão manso (*Jatropha curcas* L.) no Estado de Goiás

RESUMO. O pinhão manso destaca-se no cenário do agronegócio brasileiro como uma das mais promissoras para a produção de biodiesel, muito embora sejam poucos os estudos voltados para a implantação, manejo e técnicas de cultivo dessa cultura. Por meio da caracterização do clima do estado de Goiás através da geração de mapas de temperatura, precipitação e evapotranspiração, objetivou-se neste trabalho, definir áreas aptas no estado para o cultivo do pinhão manso por meio de realização de um zoneamento agroclimático. Para isso foram utilizados dados climáticos de precipitação pluviométrica de 114 estações e dados climáticos de temperatura do ar referentes à 34 estações. O zoneamento não evidenciou nenhuma área que seja considerada inapta ao cultivo do pinhão no estado, estando grande parte do território sujeito à aptidão plena da cultura, com algumas regiões marginais, ora por deficiência hídrica, ora por deficiência térmica. Do total do estado de Goiás, 64,6% do território goiano é apto ao cultivo do pinhão manso, enquanto que 35,4% apresenta alguma condição de marginalidade para o desenvolvimento da cultura. Deste total de áreas definidas como marginais ao cultivo do pinhão, 28,8% é tida como marginal por deficiência hídrica, e 6,6% é tida como marginal por deficiência térmica.

Palavras-chave: agrometeorologia, modelagem climática, aptidão agrícola.

Introduction

Agriculture has been practiced by mankind for thousands of years and is essential for its survival. When unplanned, agricultural production may suffer severe disturbances, resulting in yield shortcomings and even in the total loss of the crop. Thus, for proper planning, the climate and soil conditions of different arable regions must be considered.

The climate of Brazil's center-west region is characterized by a well-defined dry season, which extends from May to September, as in almost the entire region of the Brazilian Cerrado. In this

region, agricultural activity is concentrated in the rainy season, when 80-90% of total annual rainfall (approximately 1,500 mm) is concentrated. Although this total is considered sufficient for many crops, water deficit is a limiting factor for agriculture in this region due to poor rain distribution, intense evapotranspiration, low retention capacity and high rate of water infiltration in these types of soils (Alvares, Stape, Sentelhas & Gonçalves, 2013).

In recent years, agricultural production has evolved, and this activity, in addition to producing food, is also responsible for most of the energy generation. Biofuels are important alternatives to

incorporate into the national energy matrix to reduce the consumption of fossil fuels, such as regular diesel, and the environmental damage caused by them.

Jatropha (*Jatropha curcas* L.) is a promising plant for biodiesel production because its seeds are rich in excellent quality oil that exceeds even the Colza oil quality that currently used for biodiesel production in Europe. In addition, the by-products generated in the production phase have the potential to be used in chemical, pharmaceutical, steel and animal feed industries. However, there is little technical information, such as agroclimatic zoning, available on the cultivation of this crop. This technical information suggests an aptitude for cultivation in a certain region.

Silva and Assad (2003) reported that the optimization of any agricultural practice involves the definition of periods and areas where climate impact, particularly caused by water shortages, constitutes a limiting factor in production. The use of geographic information system (GIS) tools is increasingly common for spatial data distribution, processing, analyzing and modeling: it is currently being applied in various areas (Câmara, Casanova, Hermely, Magalhães & Medeiros, 1996). The use of GIS for the development of agroclimatic zoning has proved to be a fundamental tool because it can be used for various procedures, from basic data collection and generation of geo-referenced information to define areas suitable for the cultivation of certain crops (Câmara et al., 1996).

From the hypothesis that *Jatropha* has high socio-economic potential to be exploited in the state of Goiás, studies providing definition of the suitable and unsuitable areas for *Jatropha* cultivation based on climatic variables are of utmost importance. Thus, the aim of this study was to identify climatically suitable, unsuitable and marginal areas for growing *Jatropha* in the state of Goiás.

Material and methods

Climate variable studies were conducted in the state of Goiás, located in the Midwestern region of Brazil, between the parallels 12°30' and 19°30' S and the meridians 46°00' and 53°00' W, with an extension of approximately 345,965 square kilometers of land. The climate is tropical semi-humid and is characterized by two seasons, a rainy (October to April) and a dry (May to September) season, with average air temperatures ranging from 18–32°C.

The rainfall historical series used to define suitability classes were compiled by the Office of Geology and Mining (SGM-GO) and were made available by the SGEI (State System of Statistics and

Geographic Information of Goiás). For rainfall, data from 114 stations located in different regions of the state were used, of which 98 stations have historical series records with more than twenty years and 16 stations have time series with less than twenty years.

Air temperature was also used to define the suitable and unsuitable regions. Air temperature data were obtained from the SIMEHGO station network (Meteorology and Hydrology System of the State of Goiás) and INMET (National Institute of Meteorology). In regions lacking data, temperatures were estimated according to latitude, longitude and altitude using multiple linear regression equations (Bardin, Júnior & Moraes, 2010). Therefore, the average air temperature data observed in 34 stations were used, among which 26 stations had a data record with 20 years or more, and 8 stations had records for between 15 and 20 years. Altitude values were taken from the digital elevation model of the state, obtained from SRTM (Shuttle Radar Topography Mission) radar data.

Figure 1a and b show the spatial distribution of weather stations in the state of Goiás.

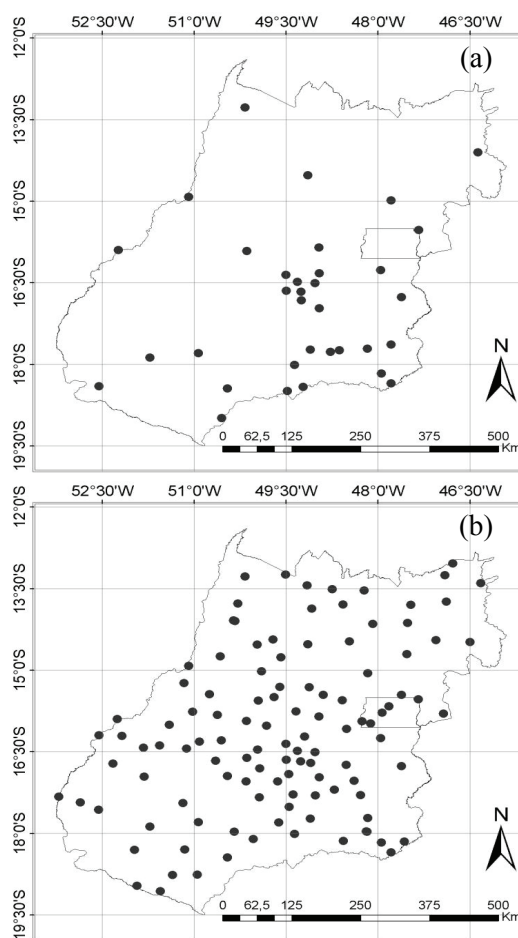


Figure 1. Spatial distribution of weather stations with air temperature (a) and rain (b) records.

The water balance (WB) was made with an electronic spreadsheet based on the methodology proposed by Rolim, Sentelhas, and Barbieri (1998), who used the Thornthwaite and Mather (1955) method. A 100 mm water storage capacity was considered. This was calculated for the stations with available weather data, and subsequently the spatial interpolation was made using the ordinary kriging method (Mello, Lima, Silva, Mello, & Oliveira, 2003) and a spherical semivariogram model as the function to estimate the values for the entire state. The map of the annual water deficit and surplus was then drawn.

Climate suitability class degrees for *Jatropha* were defined based on the methodology proposed by Yamada and Sentelhas (2014) as suitable, marginal and unsuitable, based on temperature, water deficit and water surplus agroclimatic parameters. Table 1 shows the temperature values and water deficit and surplus recommended for *Jatropha*.

Table 1. Climate suitability classes for the *Jatropha* crop as a function of the average annual temperature, annual water deficit and annual water surplus.

Classification	Annual Average temperature
Suitable	23 ≤ to ≤ 27°C
Marginal due to thermal disability	15 ≤ to ≤ 22.9°C
Marginal due to high temperatures	27.1 ≤ to ≤ 28°C
Unsuitable due to risk of frost	< 15°C
Unsuitable due to excessive temperatures	> 28°C
Annual DEF	
Suitable	≤ 360 mm
Marginal	361 ≤ to ≤ 720 mm
Unsuitable	> 720 mm
Annual WS	
Suitable	≤ 1,200 mm
Marginal	1,201 ≤ to ≤ 2,400 mm
Unsuitable	> 2,400 mm

Results and discussion

Although Goiás has a high total rainfall (approx. 1,400 mm per year), the Cerrado region, which is part of Goiás, is characterized irregular and low homogeneous rainfall during the year, presenting only two well-defined seasons: dry, from May to September, with a monthly average lower than 30 mm; and rainy, from October to April, with a monthly average of approximately 250 mm.

This irregularity of rainfall has a significant impact on agricultural activity in the state because the region goes through a long period of drought, during which it becomes virtually impossible to cultivate certain plant species without the use of irrigation. Drumond et al. (2010) and Horschutz, Teixeira, Alves, Silva and Silva (2012) found a positive relation between the use of irrigation and the growth and development of *Jatropha* plants in the region of Petrolina, Pernambuco State.

Data interpolation is the last stage of geostatistical analysis. The analysis of the spatial dependence of the two studied attributes through the semivariogram diagnosis revealed anisotropy behavior for both attributes.

The two semivariograms (for water deficit – DEF and surplus – SUR) were tested, and statistical errors for interpolation were obtained by cross-validation analysis, as shown in Table 2.

Table 2. Cross-validation errors for both attributes studied.

Error	Attributes	
	DEF	SUR
Mean	1.31	0.46
Root-Mean-Square	36.58	38.05
Mean Standardized	0.0317	0.0136
Root-Mean-Square Standardized	1.17	1.062
Average Standard Error	33.75	36.94

Table 3 shows the results of the estimated model parameters adjusted to DEF and SUR for the whole state, by the ordinary least squares (OLS) method. By obtaining the adjustment parameters from the OLS method and the spherical model, the DEF and SUR values can be interpolated without bias and with minimum variance by kriging, using the following parameters.

Table 3. Parameters estimated for each attribute through the adjusting methods.

Attribute	Nugget	Range	Sill
DEF	498.43	2.459	2,810.64
SUR	0	1.026	9,942.33

Figure 2a and b show the experimental semivariogram for each attribute tested.

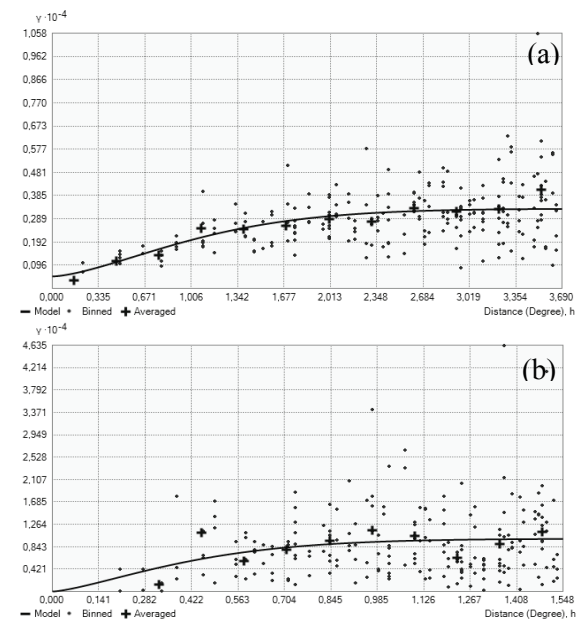


Figure 2. Semivariogram model for a) annual water deficit and b) water surplus.

Figures 3a and 2b show the water deficit (DEF) and surplus (SUR) maps accumulated for the state of Goiás resulting from the water balance.

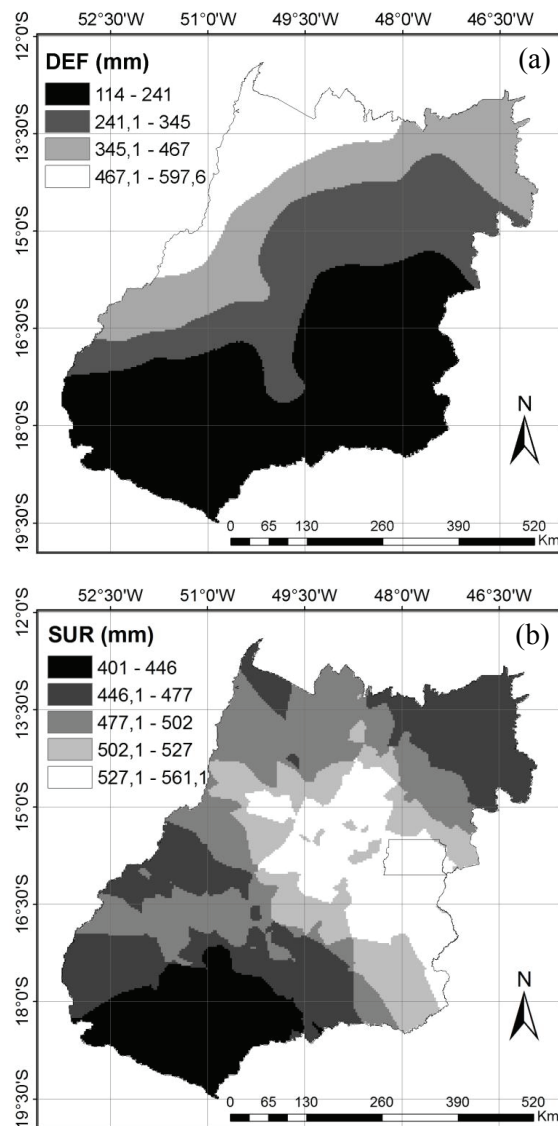


Figure 3. a) Annual water deficit and b) water surplus for the state of Goiás.

Goiás' northwest had the highest water deficit values observed (400 to 597 mm), whereas the center-south region had the lowest values, and consequently the highest water surplus values. According to Yamada and Sentelhas (2014), water deficit increases with decreasing latitude due to higher temperatures and scarce rains during the dry season (winter). In the southern region of the state, water deficits less than an annual 200 mm and water surpluses less than 400 mm per year were recorded. Finally, in the center-south region of Goiás, where the highest annual rainfalls are recorded, a water deficit higher than 500 mm was recorded.

Figure 4a and b show the agroclimatic suitability maps of *Jatropha* for the variables water deficit and surplus.

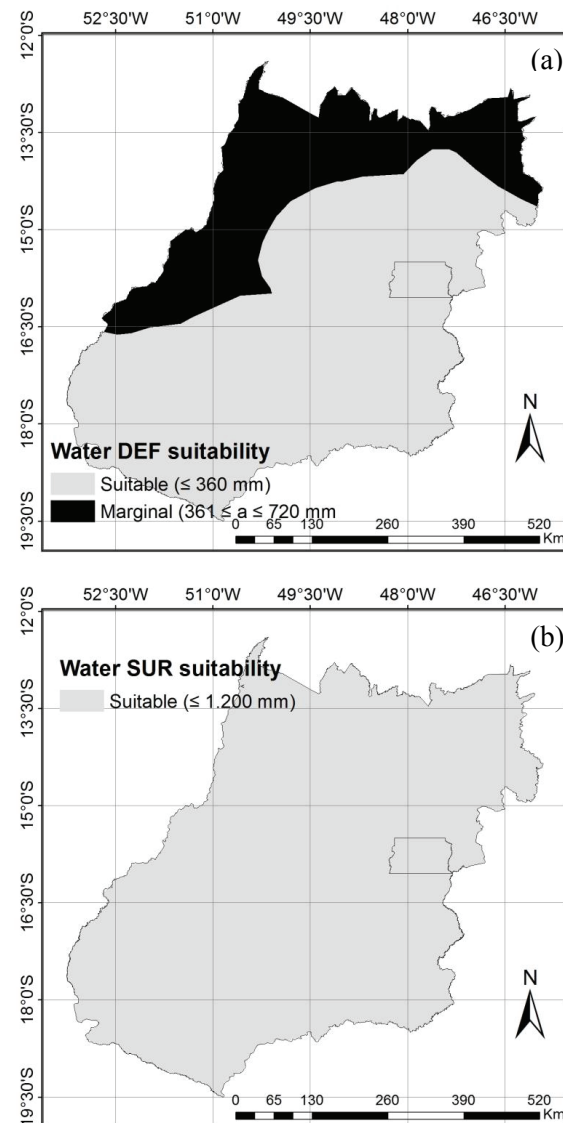


Figure 4. Climate suitability based on the values of annual a) water deficit and b) water surplus.

The state of Goiás has, almost in its entirety, suitable conditions for the cultivation of *Jatropha*, except in the northwest, which has marginal conditions regarding the variable water deficit.

The planting of *Jatropha* should occur at the beginning of the rainy season, which for the entire state, starts in November. This recommendation does not consider adverse weather conditions, such as the occurrence of mild summers, for example. This fact would ensure the good development of young cultures in the field, without the need for irrigation at this early stage. On the contrary, the

implementation of a crop of *Jatropha* from May to October would be conditioned to the use of irrigation to ensure the survival of seedlings in the field, considering the water requirements of the seeds and saplings of *Jatropha*. According to Krishnamurthy, Zaman-Allah, Marimuthu, Wani and Rao (2012), *Jatropha*, as most cultures, does not tolerate drought at this phenological stage, requiring supplying the plant with water to ensure its survival.

The state's highest air temperatures occur in the northwest and the lowest in the center-south region. The northwest region has an average annual temperature of 26.1°C, whereas the central-south region has an average temperature of approximately 22°C.

Based on the analysis of the average monthly air temperature, most of the territory of the state of Goiás is suitable for the cultivation of *Jatropha* (Figure 5) because it lies in a favorable range for the development of the culture, except in June and July, when the average temperatures are considered marginal due to thermal deficiency for the full development of the pinion.

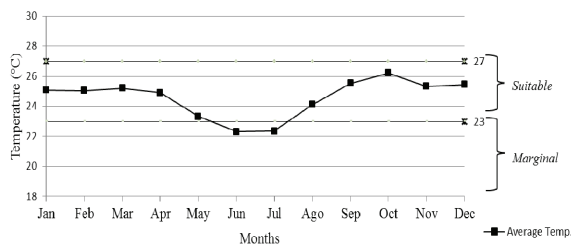


Figure 5. Monthly variation of average air temperature in the state of Goiás and the limits of thermal suitability.

However, there are no literature records of *Jatropha* plants that went into senescence due to exposure to air temperatures above 28°C, considering that these temperatures are recorded on only a few days of the year and for a few hours of the day. It is believed that the plant is able to withstand such conditions without damage to its phenology or final oil yield.

As for the germination of *Jatropha* seeds, tracing an analogy with papaya, a species that belongs to the same family as *Jatropha* (Euphorbiaceae) and has seeds with high oil content and whose center of origin is a tropical region, it has been recommended that the temperature for the germination of seeds is between 20 and 30°C (Singh et al., 2013). This temperature range is also recommended for the germination of most tropical and subtropical tree species cultivated in Brazil. A similar result was observed by Martins, Machado, and Cavasini

(2008), who, analyzing the influence of temperature and substrate on *Jatropha* seed germination, set the ideal temperature range for the germination of pinions between 20 to 30°C. Therefore, no air temperature and soil-related problems should occur during *Jatropha* seed germination in the growing areas during warmer months.

Figure 6 shows a view of the areas with respect to agroclimatic suitability for *Jatropha* crops in different parts of the state based on the annual average air temperature.

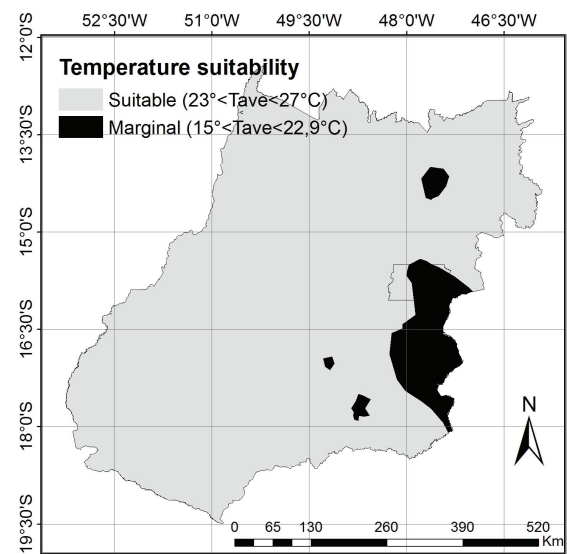


Figure 6. Climate suitability based on extreme values of the annual average temperature.

Higher average temperatures are not a limiting factor for the cultivation of *Jatropha* in the state because most of the area is suitable for cultivation, which is limited only in the southeastern region of the state, which has a marginal suitability due to thermal deficiency.

Based on the results, the average temperature recorded in the state of Goiás is suitable for the cultivation of *Jatropha* because even regions considered as marginal due to thermal deficiency do not have temperatures low enough to cause plant death.

Agroclimatic zoning showed that *Jatropha* could be grown in most of the state of Goiás, even in marginal regions, such as Goiás' northwest, which was marginal due to the annual water deficit, and the southeast, which proved to be marginal due to thermal deficiency. The spatial distribution of suitability classes is shown in Figure 7.

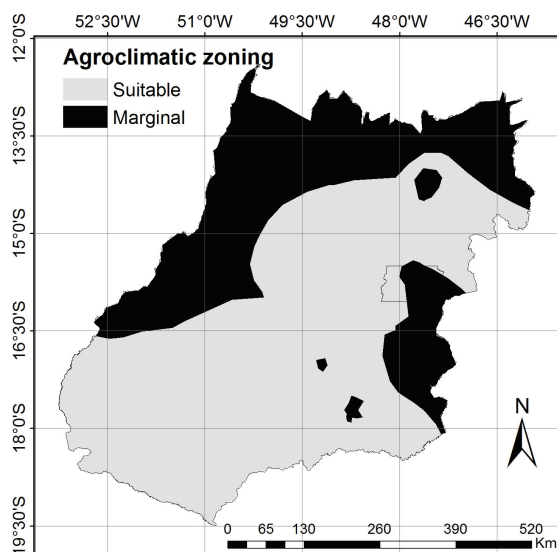


Figure 7. Agroclimatic zoning of *Jatropha* for the state of Goiás.

Table 4 shows the values of agroclimatic suitability classes for *Jatropha* in the state of Goiás.

Table 4. Values of the agroclimatic suitability classes for *Jatropha* in the state of Goiás.

Classification	Area (km ²)	Area (%)
Suitable	223,510.74	64.60
Marginal	122,461.03	35.40
Total	345,971.76	100
Marginal due to water deficit	99,634.82	28.80
Marginal due to thermal disability	22,826.21	6.60

As also reported by Yamada and Sentelhas (2014), no unsuitable areas for *Jatropha* were found within the state. The areas classified as suitable extended from Goiás northeast to Goiás southwest, and corresponded to approximately 64.60% (223,510.74 km²) of Goiás' territory. In these regions, the rainfall and the average air temperature ideal for crop growth.

The other regions, such as Goiás northwest and southeast, were marginal suitability areas because they did not satisfy all necessary conditions for the full development of the crop, either due to excess or deficient water or thermal deficiency. Thermal deficiency limited *Jatropha* cultivation in the southwest region. The average air temperature was between 15°C and 22.9°C, which is considered unsuitable for *Jatropha*, and corresponded to 6.60% of the territory. In the northwest region, water deficiency was responsible for the marginality condition, covering 28.80% of the state. The regions considered as marginal for growing *Jatropha* corresponded to approximately 35.40% (122,461.03 km²) of Goiás' territory. No unsuitable regions for *Jatropha* cultivation in the state were observed.

Although *Jatropha* can grow in very dry tropic areas, without a great water supply (Andrade, Caramori, Caviglione, Oliveira, & Ribeiro, 2007), its cultivation, when subjected to an irrigation system, tends to present an increase in yield, as shown by Andrade et al. (2007). They noted that when growing *Jatropha* in fields under hill irrigation in the northern area of Minas Gerais, the plants produced an average of 2,500 kg of seeds ha⁻¹ at 18 months, whereas plants with the same age grown under rainfall conditions in the Felixlândia Region (central Minas Gerais), produced only 500 kg of seeds ha⁻¹.

The management adopted in the growing fields directly influences the development, which indicates that, even in an areas considered climatically suitable for the cultivation of *Jatropha*, factors such as soil and fertility conditions may restrict plant development. Therefore, regions considered as high climate risk regions due to water deficiency may, under certain circumstances, be 100% suitable for cultivation, provided that irrigation is used. According to Chaves, Cunha, Barros Júnior, Lacerda, and Dantas Júnior (2009), *Jatropha* requires good soil fertility to achieve high seed yields, unlike what was previously believed. The plant survives in low fertility fields, obtaining water from summer rainfalls. However, with proper soil fertility, the plant will produce more than with poor soil and climate conditions. Therefore, the correction of acidity and soil fertility are decisive factors for the profitability and success of this crop (Schiavo et al., 2010).

Treatments, such as pruning, can also result in beneficial effects and help in the establishment and development of the plant. Therefore, pruning is a fundamental management process, even in areas with full climate suitability for *Jatropha*, because it helps the crop to express the maximum productive potential. According to Peixoto (1973), this cultural treatment can be performed annually to increase the numbers of branches and crop yield.

Thus, despite 28.80% of Goiás' territory being considered as having marginal suitability for *Jatropha* due to water deficits, the use of irrigation and the adoption of good agricultural practices with proper cultivation are sufficient to ensure high yields, producing plants with high seed production, which would result in high oil content. Similarly, the regions considered as marginal due to thermal deficiency may also have high yields, considering the soil's agricultural potential. Some fertility correction is enough to make the plants highly fertile.

Jatropha can be considered as a possible oilseed to be explored in family agriculture in the state of Goiás as an additional crop to castor bean. The

National Program for Production and Use of Biodiesel (PNPB), a major government proposal implemented in 2003 that provides for the incorporation of biomass in the Brazilian energy matrix, aiming at reducing the release of greenhouse gases into the atmosphere, offers tax, financial and trade incentives for all industrial biodiesel source producers, politically and economically supporting oilseed production by small and medium farmers.

Conclusion

The total annual rainfall supply is sufficient to meet the total water demand of a *Jatropha* production cycle in the state of Goiás;

The state of Goiás has no unsuitable regions for *Jatropha* cultivation;

The cultivation of *Jatropha* is recommended for the entire state of Goiás, except in regions characterized by high annual water deficits, if irrigation techniques are used to meet the water demands of the plant.

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