Special Supplement: Bamboo

Agro-climatic zoning of bamboo as a support for crop farming in the central-north region of the Brazilian Savannah[1]

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ABSTRACT

Bamboo has a huge potential for several uses; however, there are many species with numerous climatic growth requirements. This makes it difficult to characterize the agro-climatic bamboo demands, in order to define areas suitable for its cultivation. This study aimed to quantify the bamboo agro-climatic requirements, as well as to define areas suitable for growth in the central-north region of the Brazilian Savannah. The agro-climatic requirements were defined from averages of the center of origin of the *Bambusa vulgaris* species, in southwest Asia. The climatic characterization was based on the daily mean, minimum and maximum air temperature, annual rainfall and water deficit, and consecutive months with a rainfall rate lower than 40 mm. These limits were used to define suitable, marginal and unsuitable regions. The optimal range was between 15.14 ºC and 35.33 ºC for mean air temperature, with a lower limit of 12.07 ºC and a higher limit of 38.83 ºC, respectively, for minimum and maximum air temperature. The annual minimum rainfall required was 775 mm, with a maximum annual water deficit of 1,320 mm, and a maximum of eight consecutive months with rainfall of less than 40 mm. Most of the studied region was classified as suitable (74 % of the total area), followed by marginal due to water deficit (12.9 %), unsuitable (8.9 %) and marginal due to air temperature (4.2 %).

KEYWORDS: *Bambusa vulgaris*, climatic suitability, bamboo weather requirement, crop modeling, agrometeorology.

RESUMO

Zoneamento agroclimático como subsídio para o cultivo de bambu no centro-norte do Cerrado brasileiro

O bambu possui grande potencial de uso em inúmeras finalidades; entretanto, as várias espécies apresentam diferentes demandas climáticas. Isto dificulta a caracterização das demandas agroclimáticas do bambu para definir áreas aptas ao seu cultivo. Objetivou-se quantificar as demandas agroclimáticas do bambo, bem como definir áreas aptas ao seu cultivo no centro-norte do Cerrado brasileiro. As demandas agroclimáticas foram definas a partir das médias do centro de origem da espécie *Bambusa vulgaris*, no sudoeste da Ásia. A caracterização climática baseou-se na temperatura do ar diária média, mínima e máxima, chuva e déficit hídrico anual, e meses consecutivos com chuva abaixo de 40 mm. Estes limites foram utilizados para classificar áreas aptas, marginais e inaptas. A temperatura média ótima variou entre 15,14 ºC e 35,33 ºC. Já as temperaturas mínimas e máximas foram iguais a 12,07 ºC e 38,83 ºC, respectivamente. A demanda anual mínima de chuva foi de 775 mm, com déficit hídrico anual máximo igual a 1.320 mm, e valor máximo de oito meses consecutivos com chuva menor que 40 mm. A maior parte da região estudada foi classificada como apta (74 % da área total), seguida por marginal por déficit hídrico (12,9 %), inapta (8,9 %) e marginal por temperatura do ar (4,2 %).

PALAVRAS-CHAVE: *Bambusa vulgaris*, adaptabilidade climática, exigência climática do bambu, modelagem de cultura, agrometeorologia.

INTRODUCTION

Bamboo has been used for many purposes, such as construction and reinforcing fibers, paper and textiles, food and combustion, and other bioenergy applications. It is also ornamental (Scurlock et al. 2000). In addition, bamboo forests have a large capacity for carbon sequestration and play an important role in maintaining the regional ecological environment and the global carbon balance (Zhou & Jiang 2004, Mao et al. 2016).

There are around 75-90 genera and 1,100-1,250 species of bamboo (Manhães 2008, Sanquetta et al. 2015). They occur naturally in all continents, except for Europe and Antarctica, in different climatic conditions (Scurlock et al. 2000). Bamboo forests are widely planted on hillsides and along roads in Japan, Malaysia, Brazil, Indonesia and Thailand, because

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they have extensive root systems and underground rhizomes, which avoid landslides, as well as water and soil losses (Liese 2001, Li & Kobayashi 2004, Zhou et al. 2005). The large number of bamboo species means a challenge to define adequate agro-climatic criteria for identifying areas where bamboo can be grown with a low climatic risk.

Climatic requirements may change considerably among bamboo species. *Dendrocalamus asper* is adapted to full sun and tolerates air temperatures of up to -5 ºC, while *Bambusa multiplex* tolerates growth under shadow environments and air temperature of up to -10 ºC (Tombolato et al. 2012). As for annual rainfall, there is a huge requirement range recorded, from a lower limit of 700-1,200 mm year^{-1} (Rojas-Sandoval & Acevedo-Rodriguez 2014, KFRI 2015) up to a maximum limit reaching 4,000 mm year^{-1} (Scurlock et al. 2000, KFRI 2015).

When there are uncertainties regarding crop climatic requirements, an alternative is to characterize the climatic conditions at the center of origin, defining limits for crop growth, and then to apply to the region of interest. This approach was used for jatropha (Yamada & Sentelhas 2014, Pena et al. 2016) and African mahogany (Casaroli et al. 2018), perennial plants, identifying agro-climatic requirements and delimiting suitable areas for growth in Brazil.

In Brazil, there are commercial areas of bamboo in the states of Maranhão and Pernambuco, growing the *Bambusa vulgaris* species (Manhães 2008). This species can be used for paper production and construction in the rural area (Tombolato et al. 2012). Bamboo has received many incentives to be included as an alternative in the farm system production, improving the farmers' profit due to its faster growth rates and multipurpose uses focusing on green biomass (Darabant et al. 2014).

Thus, bamboo has a high potential to be grown in the central-north region of the Brazilian Savannah, after identifying suitable areas, especially where traditional crops represent a high agro-climatic risk. Based on that, this study aimed to characterize the agro-climatic requirements of the center of origin of *Bambusa vulgaris* in southwest Asia, in order to define agro-climatic criteria for bamboo growth based on the probabilistic level of occurrence, as well as to classify the suitability of bamboo in the central-north region of the Brazilian Savannah biome, in Brazil.

MATERIAL AND METHODS

The bamboo agro-climate requirements were defined based on its center of origin, following the approach used for jatropha (Yamada & Sentelhas 2014, Pena et al. 2016) and African mahogany (Casaroli et al. 2018), in Brazil.

Bambusa vulgaris has an uncertain origin, but evidences indicate southwest Asia, mainly south China, northeast India and Myanmar (Kleinhenz & Midmore 2001, Tombolato et el. 2012). In India, bamboo is grown in the states of Arunachal Pradesh, Assam, Bihar, Madhya Pradesh, Manipur, Mizoram, Odisha, Tripura and West Bengal (KFRI 2015). The center of origin was selected including the states from India, Bangladesh and south of Nepal and Bhutan (Figure 1).

Gridded weather data were obtained from NASA POWER (2018), for the center of origin of *Bambusa vulgaris*, in a grid of 0.5 x 0.5 º (Figure 1). The weather data were obtained daily from 01 January 1981 to 31 December 2017. Data included solar radiation, mean, maximum and minimum air temperature, rainfall, relative humidity and wind speed. The water deficit was estimated following the Thornthwaite & Mather (1955) water balance approach, using 100 mm as soil water-holding capacity, and potential evapotranspiration was estimated by the Penman-Monteith method (Allen et al. 1998).

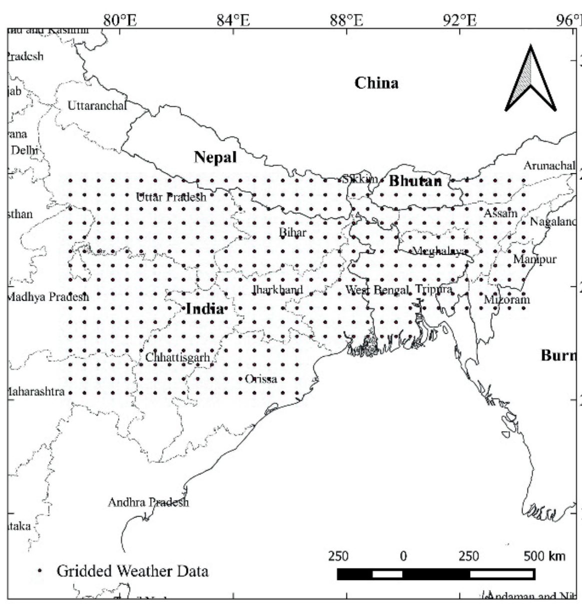

Figure 1. Location of the weather data (grid) at the center of origin of bamboo in southwest Asia.

The bamboo agro-climatic requirements were obtained based on daily minimum, mean and maximum air temperature, annual accumulated rainfalls and water deficit, and consecutive months with rainfall of less than 40 mm. The observed limits were defined for each location by eliminating 20 % of weather data extremes. For daily mean air temperature, the interval of 10-90 % was considered, and the limits for daily minimum and maximum air temperature were, respectively, 20 % and 80 %. The limit for annual accumulated rainfall was 20 %, and, for accumulated water deficit and consecutive months with rainfall of less than 40 mm, 80 %. An example using these criteria for the gridded weather data point latitude 23.75 º and longitude 85.26 º is shown in Figure 2. Then, the final limits were defined

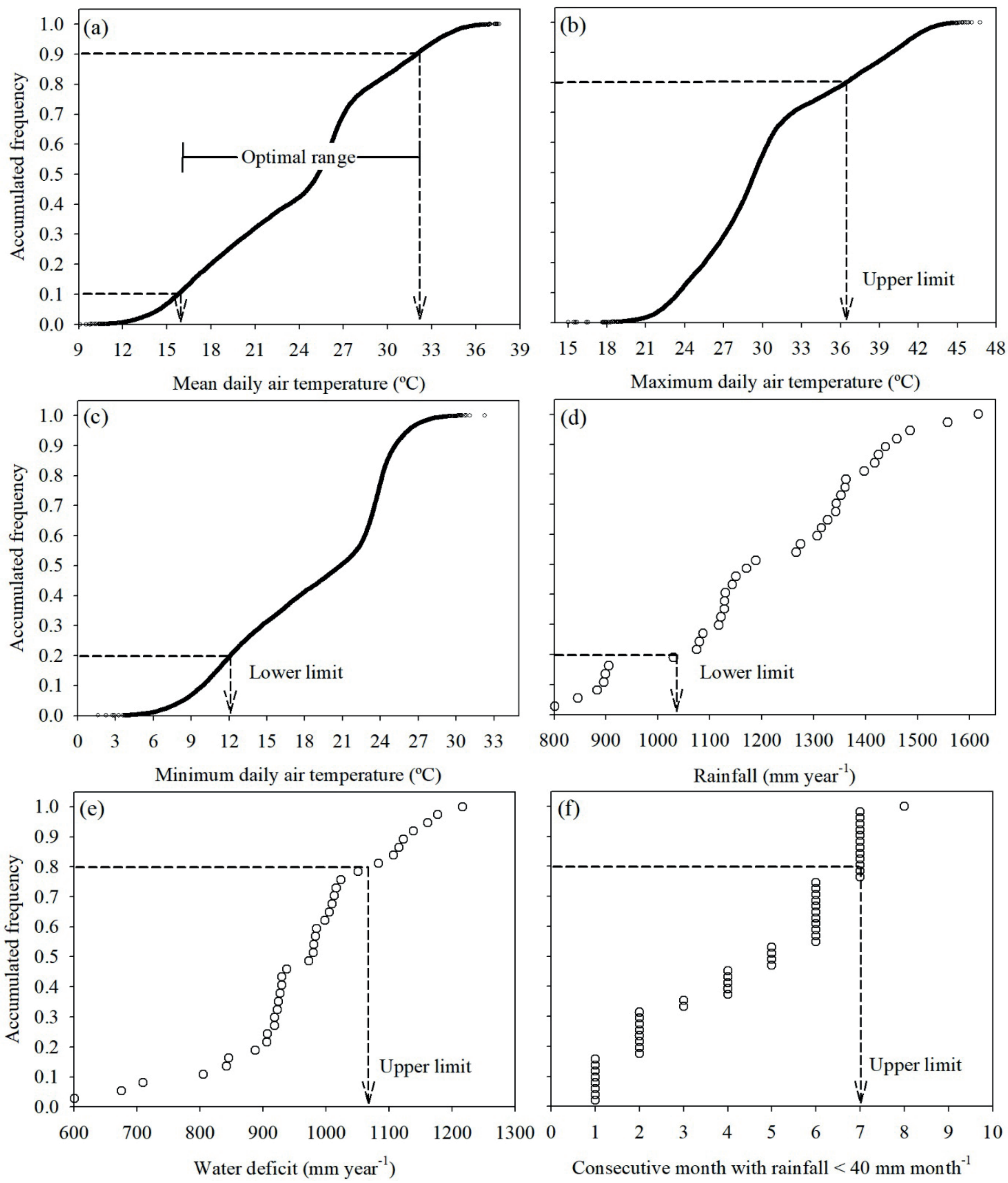

Figure 2. Agro-climatic limits for bamboo based on accumulated frequency of daily mean (a), maximum (b) and minimum (c) air temperature, annual accumulated rainfall (d) and water deficit (e), and consecutive months with rainfall of less than 40 mm (f) for the gridded weather data point latitude 23.75 º and longitude 85.26 º.

considering 70 % of locations to represent the suitable area for bamboo growth.

The study area comprised the central-north region of the Brazilian Savannah biome, including the states of Goiás, Tocantins, Maranhão, west Bahia and south Piauí (Figure 3). That region has not only different climate conditions, but also a higher potential for the inclusion of bamboo in degraded areas and areas unsuitable for grain crops. In this region, the gridded weather data were obtained daily by Xavier et al. (2015), in a grid of 1.0 x 1.0 º (Figure 3), for the period from 01 January 1980 to 31 December 2013, including the same variables aforementioned. The mean air temperature was obtained using the mean from maximum and minimum air temperatures for the gridded weather data.

The daily minimum, mean and maximum air temperatures, annual accumulated rainfalls and water deficit, and consecutive months with rainfall of less than 40 mm limits were used to define whether the weather location is suitable, marginal or unsuitable for bamboo growth. The point was suitable when all variable limits were within at least 95 % of the weather series (days or years); marginal if variable limits were within at least 80 % of the weather series; and unsuitable if one variable limit was outside 80 % of the weather series. The marginal level was divided by air temperature (minimum, mean and maximum) or limitation of available water (annual accumulated rainfalls and water deficit, and consecutive months with rainfall of less than 40 mm).

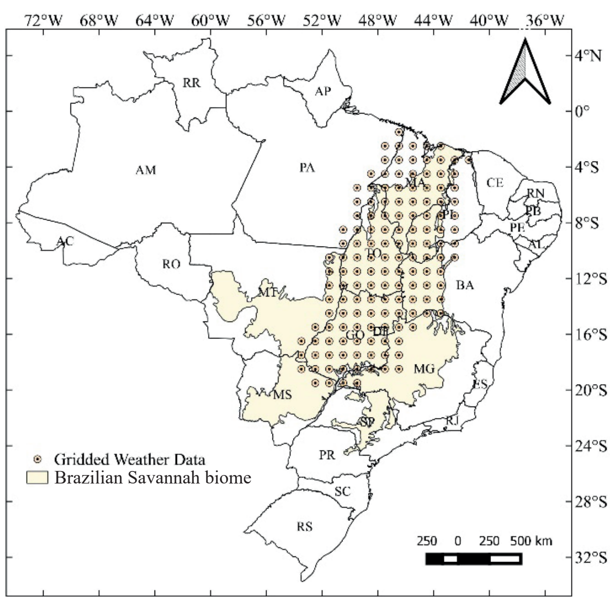

Figure 3. Location of the gridded weather data for the agro-climatic zoning of bamboo in Brazil.

The spatial suitability (suitable, marginal and unsuitable) was determined considering the classification and the linear interpolation between neighbor weather points. The county was classified based on the predominant suitability for agro-climatic zoning in the area, defined by weather points in their surroundings. The final map was plotted using the QGIS v. 3.01 software (QGIS Development Team 2018), classifying the county suitability into suitable, marginal due to air temperature, marginal due to water availability or unsuitable.

RESULTS AND DISCUSSION

The agro-climatic limits obtained for daily mean air temperature had an optimal range between 15.15 ºC and 35.33 ºC (Table 1), based on the center of origin of bamboo in southwest Asia. The lower limit for minimum and the upper limit for maximum air temperatures were, respectively, 12.07 ºC and 38.82 ºC (Table 1). These limits were close to the range observed for favorable net photosynthetic rates based on leaf temperature for bamboo (*Bambusa ventricosa*). The maximum net photosynthetic rates occurred within the range of 21.8-30.6 ºC, reducing to the half its maximum value when the leaf temperature was below 16.2 ºC and above 36.3 ºC (Gratani et al. 2008).

The center of origin of bamboo had a lower annual rainfall of 775 mm year^{-1}, limited to a maximum annual water deficit of 1,320 mm year^{-1}, and a maximum of eight consecutive months with rainfall of less than 40 mm (Table 1). Scurlock et al. (2000) described that some bamboo species can adapt to varying environments, but most need warm and humid conditions, with a mean annual temperature of at least 15-20 ºC and rainfall above 1,000 mm year^{-1}. There was no consensus as for the annual rainfall volume required by bamboo. There was a demand of 700 mm year^{-1} (Rojas-Sandoval & Acevedo-Rodriguez 2014) to 4,000 mm year^{-1} (Scurlock et al. 2000). The range can be associated with the potential crop evapotranspiration, in function of local climatic conditions.

The agro-climatic limits were similar to the values reported in the literature, although discrepancies can be found due to the definition of conditions for crop presence or high biomass

Table 1. Criteria and limits obtained for bamboo growth based on the center of origin.

Agro-climatic variables	Description	
	Air temperature (ºC)	
Mean	Optimal range	15.14-35.33
Minimum	Lower limit	12.07
Maximum	Upper limit	38.82
	Water	
Annual rainfall	Lower limit	775 mm $year^{-1}$
Annual water deficit	Upper limit	1,320 mm $year^{-1}$
Consecutive month with rainfall < 40 mm $month^{-1}$	Upper limit	8 months

production. The Bamboo Technical Support Group South Zone, from the Kerala Forest Research Institute (KFRI 2015), indicated that bamboo requires an optimal temperature range of 20-38 ºC for a maximum growth, with a mean annual temperature ranging between 8 ºC and 36 ºC. The annual rainfall requirement reported was 900-4,000 mm $year^{-1}$, higher than that defined in our study (Table 1). Such different levels of climatic adaptability can define the final biomass production, which may vary from 4.5 t ha^{-1} $year^{-1}$ to 47 t ha^{-1} $year^{-1}$ for aboveground biomass, respectively for central China and southern India (fertilized and irrigated areas) (Scurlock et al. 2000), in function of agro-climatic conditions.

Rojas-Sandoval & Acevedo-Rodriguez (2014) reported a broader range for optimal climatic conditions for bamboo growth. The mean annual air temperature ranged between 15 ºC and 40 ºC, values similar to those observed at the center of origin (Table 1). The mean maximum temperature of the hottest month (maximum of 50 ºC, higher than observed at the center of origin) and the mean minimum temperature of the coldest month (minimum of 10 ºC) were close to those analyzed in this study (Table 1). The authors reported that the absolute minimum temperature had a lower limit of -3 ºC. For rainfall, the limits indicated by Rojas-Sandoval & Acevedo-Rodriguez (2014) were similar to those of the center of origin, i.e., 700 mm $year^{-1}$ against 775 mm $year^{-1}$. In both cases, the maximum of eight consecutive months with a rainfall of less than 40 mm $month^{-1}$ was established as the limit.

Based on previous agro-climatic criteria (Table 1), the central-north region of the Brazilian Savannah was classified into four suitability types. The main area suitable for bamboo growth included most of the Goiás, Tocantins and Maranhão states (Figure 4), where all limits from Table 1 occurred for more than 95 % of the analyzed period. This showed the potential of bamboo growth along the central-north region of the Brazilian Savannah. This higher suitability can be verified by the presence of more than 230 species of bamboo in Brazil (Tombolato et al. 2012).

The southwest of the Goiás state was classified as marginal, because it reached the low air temperature limit: for more than 5 % of the days, the minimum air temperature was below 12.07 ºC. In this region, the agro-climatic zoning for jatropha was classified as suitable, attending the optimal range for annual mean air temperature (23-27 ºC) (Yamada & Sentelhas 2014). For African mahogany, the classification was

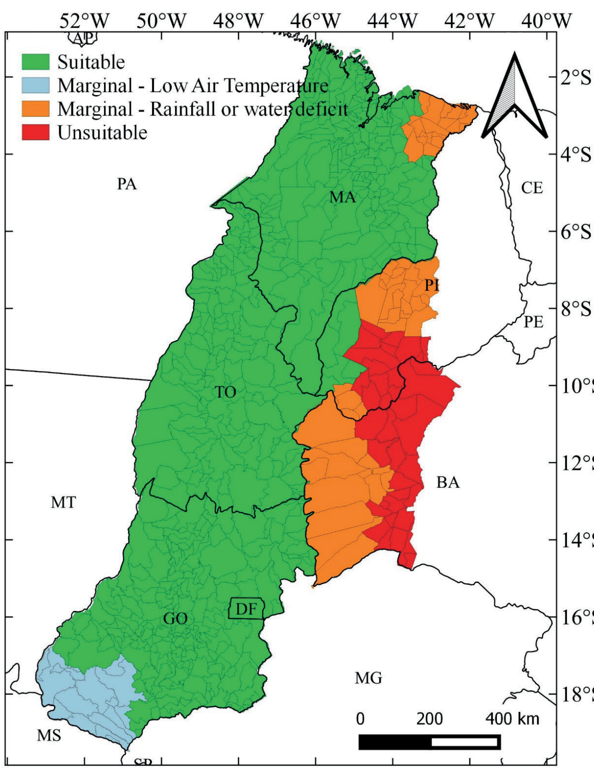

Figure 4. Agro-climatic zoning for bamboo (*Bambusa vulgaris*) in the central-north region of the Brazilian Savannah.

suitable, but with a restriction due to the mean annual air temperature below 23.5 ºC (Casaroli et al. 2018). In addition to the differences in crop limits, density, distribution and source of weather stations along the region may affect the areas of suitability transition (Xavier et al. 2015, Mourtzinis et al. 2017, Battisti et al. 2018).

The extreme west of the Bahia state, the center of Piauí and the northeast of Maranhão were classified as marginal, due to the low water availability along the year (Figure 4). In this area, the minimum annual rainfall and/or maximum annual water deficit were attended for, at least, 80 % of the years studied. Otherwise, the classification was unsuitable due to water unavailability from this area up to near the border of the semiarid of the northeast Brazil (Figure 4). In this unsuitable area, other perennial crops can be grown instead of bamboo; however, with restrictions. In this region, the area was classified as marginal for jatropha due to water deficit (Yamada & Sentelhas 2014), while African mahogany was classified as suitable, but with a medium restriction (Casaroli et al. 2018). Eucalyptus had a high, mean and low climatic adaptation, depending on the species (Flores et al. 2016).

The central-north region of the Brazilian Savannah had 74 % of the area classified as suitable for bamboo growth (Table 2). The low air temperature leads to a marginal suitability in 4.2 % of the area, condition that could not limit the bamboo growth, except for its maximum annual growth (Scurlock et al. 2000). The lower air temperature occurs during the dry season of the Brazilian Savannah biome (Brasil 2018), helping to reduce the crop evapotranspiration and stress by water deficit on crop growth (Piouceau et al. 2014, Mei et al. 2016).

The marginal area (due to water limitation) covered 12.9 % of the total area (Table 2). In this area, other bamboo species can be used instead of *B. vulgaris*. Sanquetta et al. (2015) highlighted that the *B. oldhammii* species has a higher drought tolerance than *B. vulgaris*, which can be used for food and woody peaks. Further analysis is required to understand how bamboo adapts during the dry period, such as leaf area reduction, and to determine the biomass production volume, which correlates with evapotranspiration (Piouceau et al. 2014). Finally, the unsuitable area represented 8.9 % of the analyzed area, where bamboo growth had a high risk of low water availability, which limits crop planting and biomass production.

Table 2. Classes of agro-climatic suitability for bamboo (*Bambusa vulgaris*) in the central-north region of the Brazilian Savannah.

Suitability	Percentage of the regions
Suitable	74.0
Marginal - air temperature	4.2
Marginal - water	12.9
Unsuitable	8.9
Total	100.0

CONCLUSION

The agro-climatic zoning indicated most of the central-north region of the Brazilian Savannah as suitable for growing the *Bambusa vulgaris* species (74 % of the total area), followed by marginal due to water deficit (12.9 %), unsuitable (8.9 %) and marginal due to air temperature (4.2 %).

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