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FORESTRY PRODUCTS AND *Eucalyptus* L'HERITIER PLANTATIONS IN NORTHEAST BRAZIL

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Abstract: Silviculture using species of the genus *Eucalyptus* L'Heritier in Brazil, is a highly technological and specialized activity, predominating the intensive system through clonal plantations for the cellulose fibre export market. The aim of this study is to evaluate the development of the productive and extensive arrangement of *Eucalyptus* spp. silviculture distributed throughout Northeast Brazil. We obtained data from the official platform of the 'Instituto Brasileiro de Geografia e Estatística – IBGE' on the number of municipalities, inhabitants, territorial extension of municipalities, and states in Northeast Brazil and data on planted areas and wood production volume, as well asfor the monetary value of *Eucalyptus* spp. silviculture production in Northeast Brazil for the year 2022. We compiled the data spreadsheet and conducted descriptive statistics, generating self-explanatory graphs and tables, using JASP 0.18® software. Using vector cartography in SHP format of the year 2022 obtained from the IBGE platform, for municipal and state territories in the Northeast region of Brazil, we created, a thematic map of the distribution of *Eucalyptus* spp. plantations in these territories with the aid of QGIS® 3.28 software. We observed that only 10 municipalities represent approximately 60% of the planted areas in each state. *Eucalyptus* spp. silviculture in the Northeast hasa positive regional socioeconomic impact by providing a clean energy matrix and the possibility of cultivation in small rural properties, outside large production centres. The states of Bahia and of Maranhão have shown the greatest gains in growth in the production of cellulose and charcoal. In contrast, greater attention should be given to the states of Ceará, Paraíba, Pernambuco and Rio Grande do Norte in order to better explore its potentials for the production of wood, among other products obtained of *Eucalyptus* spp. silvicultural.
Keywords: silviculture, wood sectors, myrtaceae, planted forests.

1. Introduction

The global forestry, through planted forests and responsible management practices, it is an important primary sub-sector of the world economy, meeting the growing global demand for wood products and generating impactful socio-environmental outcomes with highly positive returns (Payn *et al*., 2015; Mcewan *et al*., 2020). In Brazil, planted forests account for 91% of all wood produced for industrial purposes (Inoue, 2020).

The development of Brazilian silviculture, from the 1960s to the present day, has only been possible through investments in research across various silviculture fields. This has been further stimulated by the decreasing supply of wood from native forests, largely due to agricultural and livestock expansion, which has spurred the demand for planted forests (Inoue, 2020).

In the Northeast region of Brazil, the first investments in silviculture were made in the state of Bahia for the establishment of *Eucalyptus* L'Heritier plantations in the regions of the North Coast and Far South. These regions were included as two of the 15 Forest Districts envisioned by the Brazilian Institute of Forest Development (IBDF) in 1974, to be implemented by 1979, as a means of ensuring the continuous supply of wood and other forest products to industrial, steel, paper, and cellulose enterprises (Berutti,1976). Currently, Bahia hosts one of the largest industrial forestry sectors in Brazil.

Eucalyptus spp. silviculture in Brazil is a highly technological and specialized activity that dominates intensive systems via clonal plantations, meeting specific demands, especially for the industrial export market of cellulose fibre (Xavier *et al.,* 2010; Sperotto, 2014; Klein and Luna, 2022), making the cellulose production chain the most economically important feature of major industrial centres in the forestry sector in Brazil and with strong global competitiveness (Soares *et al.,* 2010; Klein and Luna, 2022; 2023). Intensive silviculture is based on producing the highest amount of wood, per unit area, in the shortest time frame, in the most economically (profitable) feasible manner and with the most suitable qualities for its final use and in a sustainable way (Ferreira, 1989; Flor, 2014).

Furthermore, planted forests of species within this genus are a renewable source for wood production and can be cultivated in various states of the country (Santos *et al*., 2017) with high production gains and productivity per planted area, reaching an average increase of up to 60 $m^{-3}ha^{-1}$ per year in productivity, superior to other countries and especially compared to other wood species (Stape *et al.,* 2010). Moreover, *Eucalyptus* spp. silviculture has been a generator of social inclusion and economic development in associated localities (Gomes *et al.*, 2006).

Among the microregions specialized in wood production, 92% utilize species of *Eucalyptus* spp. with a greater concentration in the Midwest region, mainly in Mato Grosso and Goiás, and in the Southern region, mainly in Rio Grande do Sul. For charcoal production from silviculture, 98.44% utilize *Eucalyptus* L'Heritier as the main species, with a higher concentration in the states of

Minas Gerais and Maranhão (Bichel and Telles, 2021). As such, the present study aims to evaluate the unfolding of the productive and extensive arrangement of *Eucalyptus* spp. silviculture distributed in Northeast Brazil.

2. Material and Methods

The Northeast region of Brazil has a territorial extension of 1,552,175.42 km² (Brazil, 2021a), and according to the Brazilian census, an estimated population of 57,667,842 inhabitants reside in this region (Brazil, 2021b). In 2010, 42.44% of the Northeast population (almost 24 million inhabitants) was concentrated in the semi-arid region, of which 38% (9.06 million) lived in rural areas (Brazil, 2014).

The average annual precipitation in the Northeast region is 1,053 (±237) mm, with average annualtemperatures ranging from 22°C to 25°C (Santos *et al.,* 2010; Silva *et al*., 2011). The main soils in the Northeast region, in terms of occupation and spatial distribution, are Oxisols, Entisols, and Ultisols (Marques *et al.,* 2014). The phytogeographic coverage of the region is distributed across four biomes (Caatinga, Cerrado, Atlantic Forest, and Amazon), present in the Northeast, with Caatinga and Cerrado covering the largest territorial area (Brazil, 2019).

Through the official platform of the 'Instituto Brasileiro de Geografia e Estatística - IBGE', data were obtained for the number of municipalities, territorial extension of municipalities, and territorial extension of states of the Northeast and Brazilian regions (Brazil,2022a); data regarding the number of inhabitants in municipalities and Northeast states of Brazil (Brazil, 2022b); and data regarding the areas with plantations, the volume ofwood production (firewood, charcoal, and logs), and the monetary value of *Eucalyptus* spp. silviculture production in Northeast Brazil (Brazil, 2022c), for the year 2022. With the program JASP 0.18.1® (JASP TEAM, 2023), was descriptive statistic performed, presenting them in self-explanatory graphs and tables.

Wood production data from *Eucalyptus* spp. and geographic data in vector format (SHP) of municipality and state territories in the Northeast region of Brazil were obtained from the IBGE platform (Brazil, 2022c, 2022d). A thematic map was created for plantations in municipalities of Northeast states through QGIS® software version 3.28 based on the Brazilian Geodetic System DATUM Sirgas 2000.

3. Results

Of the total areas with planted forests in Brazil (9,472,157 ha), 77.3% (7,317,653 ha) are occupied by plantations of species within the genus *Eucalyptus* L'Heritier. In the Northeast region, forest plantations with species from this genus extend over an area of 876,053 ha, which corresponds to 12% of the planted areas in Brazil (Fig. 1).

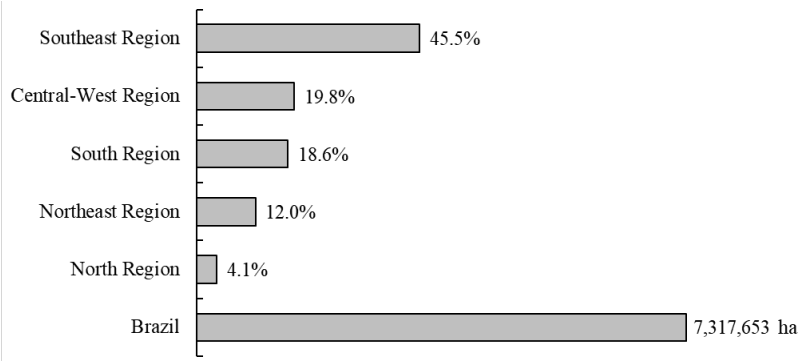

Figure 1 – Distribution of areas with forest plantations of species from the genus *Eucalyptus* L'Heritier in Brazilian regions.

Considering the wood sectors, the Northeast region's largest contribution to production in Brazil is represented by the log sector for paper and cellulose (11%). Meanwhile, logs for other uses represents the sector with the lowest participation (1.7%), with regard to national production (Tab. 1).

Table 1 – Wood production from *Eucalyptus* spp. silviculture in Brazilian regions.

Regions	Wood production							
	Firewood (m³)		Charcoal (t)		CP logs (m³)		OP logs (m³)	
North	91,750	0.2%	43,188	0.6%	4,000,703	4.9%	522,350	1.9%
Northeast	1,465,690	3.2%	395,423	5.6%	9,082,943	11.0%	466,665	1.7%
Southeast	10,448,037	23.0%	6,361,196	90.0%	37,112,948	45.1%	13,558,188	48.3%
South	26,380,332	58.0%	110,694	1.6%	14,502,731	17.6%	12,241,738	43.6%
Central-West	7,086,634	15.6%	157,254	2.2%	17,540,067	21.3%	1,300,711	4.6%
Brazil	45,472,443	100%	7,067,755	100%	82,239,392	100%	28,089,652	100%

Where: CP = cellulose and paper; OP = other purposes.

In terms of the monetary value of wood production, in 2022 *Eucalyptus* spp. silviculture in the Northeast region amounted to approximately 1.5 billion Brazilian reais (0.3 billion dollars), which corresponds to 7.3% of the national production value of

approximately 20.3 billion Brazilian reais (4.06 billion dollars). Together, the South and Southeast regions account for nearly 77,3% of the national monetary value of production, taking the lead in practically all sectors (Tab. 2).

Table 3 – Territorial extension and number of municipalities with planted *Eucalyptus* spp. forests distributed across Northeast Brazilian states.

Overall coverage of the territorial extension and area with *Eucalyptus* spp. plantations						
State	Number of Municipalities			Territorial extension (ha)		
	Total	With Plantations		Total	Planted Area	
BA	416	110	(26.44%)	56,476,045	564,456	(1.00%)
MA	217	57	(26.27%)	32,965,154	252,105	(0.76%)
AL	102	54	(52.94%)	2,783,066	24,277	(0.87%)
PI	224	28	(12.50%)	25,175,548	25,182	(0.10%)
SE	75	22	(29.33%)	2,193,819	6,171	(0.28%)
PB	223	10	(4.48%)	5,646,724	1,033	(0.02%)
PE	185	10	(5.41%)	9,806,788	1,142	(0.01%)
CE	184	6	(3.26%)	14,889,444	1,687	(0.01%)
RN	167	0	(0.00%)	5,280,960	0	(0.00%)
NE	1,793	297	(16.56%)	155,217,548	876,053	(0.56%)

Specific coverage of areas and municipalities *Eucalyptus* L'Heritier plantations							
State	Municipalities (n°)		Extension of areas (ha)				
			Total area		Max.	Min.	Average
BA	110	(37.0%)	564,456	(64.4%)	79,449	5	5,131.4
MA	57	(19.2%)	252,105	(28.8%)	46,939	9	4,422.9
AL	54	(18.2%)	24,277	(2.8%)	9,600	3	449.5
PI	28	(9.4%)	25,182	(2.9%)	3,451	23	899.3
SE	22	(7.4%)	6,171	(0.7%)	2,578	2	280.5
PB	10	(3.4%)	1,033	(0.1%)	420	1	103.3
PE	10	(3.4%)	1,142	(0.1%)	373	13	114.2
CE	6	(2.0%)	1,687	(0.2%)	742	2	281.2
RN	0	(0.0%)	0	(0.0%)	0	0	0
NE	297	100%	876,053	100%	79,449	1	2,950.01

Where: BA = Bahia; MA = Maranhão; PI = Piauí; AL = Alagoas; SE = Sergipe; CE = Ceará; PB = Paraíba; PE = Pernambuco; RN = Rio Grande do Norte; NE = Northeast; ha = hectare.

Bahia and Maranhão present the highest number of municipalities and concentration of are as planted with *Eucalyptus* spp., together representing 93.2% of the plantations and 52.7% of the total number of municipalities participating in silviculture. Ceará accounts for the lowest number of municipalities, and Paraíba has the smallest planted area, Rio Grande do Norte was excluded as it does not have plantations of this species in its territory.

Proportionally, Alagoas (52.94%) and Sergipe (29.33%) have the highest relative number of municipalities with *Eucalyptus* spp. plantations among Northeast states, followed by Bahia (26.44%) and Maranhão (26.27%). In terms of relative area planted, Bahia (1.00%), Alagoas (0.87%), and Maranhão (0.76%) are the most representative, presenting the largest plantations of *Eucalyptus* spp. in the Northeast.

On the other hand, the top ten municipalities with the largest land areas planted with *Eucalyptus* spp. in each state account for an average of 76.8% (±31.7%) of the total planted areas. It is important to note that three states have fewer than 10 municipalities cultivating this species, namely Pernambuco (n=10), Paraíba (n=10), and Ceará (n=6), with the exclusion of Rio Grande do Norte (Tab. 4).

Table 4 – The top ten municipalities with the largest areas of *Eucalyptus* spp. plantations among the Northeast states of Brazil.

Bahia		Alagoas		Maranhão	
Municipalities	Area (ha)	Municipalities	Area (ha)	Municipalities	Area (ha)
Caravelas	79,449	Maceió	9,600	Açailândia	46,939
Mucuri	58,158	Atalaia	2,300	Itinga do Maranhão	27,423
Nova Viçosa	57,043	Flexeiras	2,200	Bom Jardim	19,616
Alcobaça	45,663	Maragogi	1,500	Grajaú	18,757
Entre Rios	22,245	Messias	1,050	Santa Quitéria do Maranhão	16,471
Santa Cruz Cabrália	21,865	Paripueira	1,000	São Pedro da Água Branca	14,305
Eunápolis	19,620	Capela	800	Bom Jesus das Selvas	13,318
Belmonte	18,772	Viçosa	720	Urbano Santos	8,750
Porto Seguro	16,993	Porto Calvo	650	Imperatriz	7,817
Itagimirim	13,990	Murici	500	Estreito	6,815
62.7%		83.7%		71.5%	
Piauí		Sergipe		Pernambuco*	
Municipalities	Area (ha)	Municipalities	Area (ha)	Municipalities	Area (ha)
Elesbão Veloso	3,451	Itaporanga d'Ajuda	2,578	Lagoa de Itaenga	373
Passagem Franca do Piauí	3,204	Cristinápolis	664	Carpina	252
Jerumenha	2,500	Estância	660	Chã de Alegria	176
Uruçuí	2,259	São Cristóvão	450	Tracunhaém	167
Antônio Almeida	2,100	Neópolis	410	Paudalho	65
Francisco Ayres	2,000	Indiaroba	265	Exu	39
Marcos Parente	1,600	Japaratuba	244	Barra de Guabiraba	20
Regeneração	1,527	Santa Luzia do Itanhy	182	Barreiros	20
Boa Hora	900	Japoatã	142	São José da Coroa Grande	17
Hugo Napoleão	735	Salgado	120	Nazaré da Mata	13
80.5%		92.6%		100%	
Paraíba*		Ceará*		Rio Grande do Norte**	
Municipalities	Area (ha)	Municipalities	Area (ha)	Municipalities	Area (ha)
Rio Tinto	420	Acaraú	742	-	-
Mamanguape	380	Marco	650	-	-
Santa Rita	100	Jardim	243	-	-
Cruz do Espírito Santo	60	Santana do Cariri	40	-	-
Cuitegi	23	Crato	10	-	-
Baía da Traição	20	Aracati	2	-	-
Marcação	10	-	-	-	-
Mulungu	10	-	-	-	-
Mataraca	9	-	-	-	-
Jacaraú	1	-	-	-	-
100%		100%		0%	

Where: ha = hectare; (*): total number of municipalities with plantations; (**): no plantations.

As seen in Fig. 2, the distribution of municipalities with *Eucalyptus* spp. plantations by state in the Northeast is highly concentrated, with a notable lack of plantationsin the more inland locations of the region.

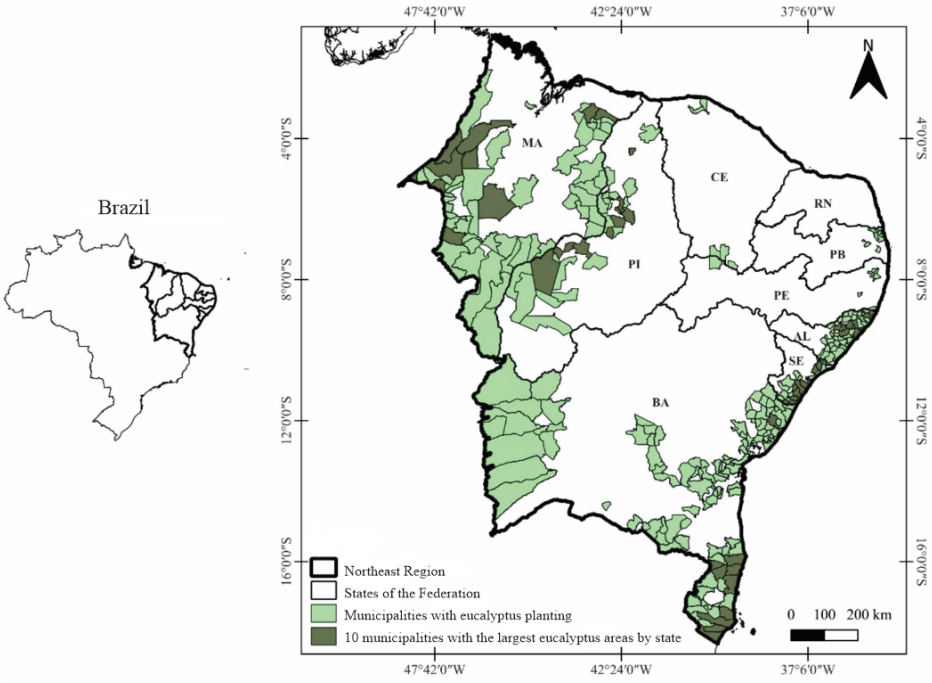

Figure 2 – Distribution of municipalities with *Eucalyptus* spp. plantations based on Northeast states in Brazil.

The states with the highest participation in wood production in the Northeast region of Brazil are Bahia and Maranhão, primarily for logs for paper and cellulose (where Bahia represents 59.64% and Maranhão 40.30%) and charcoal production (where Maranhão accounts for 53.58% and Bahia 39.92%). In terms of firewood production, Bahia accounts for almost the entire volume (78.27%). Alagoas stands out for logs for other purposes, accounting for 81.08% of production participation, followed by Bahia with 15.72% (Tab. 5).

Table 5 – Production of lignocellulosic biomass (firewood, logs for PC and OP) and charcoal from *Eucalyptus* spp. silviculture among Northeast states of Brazil.

State	Firewood (m³)		PC Logs (m³)		OP Logs (m³)		Charcoal (t)	
BA	1,147,142	78.27%	5,416,651	59.64%	73,376	15.72%	157,848	39.92%
MA	55,415	3.78%	3,660,292	40.30%	0	0.00%	211,849	53.58%
AL	26,255	1.79%	0	0.00%	378,370	81.08%	87	0.02%
PI	99,300	6.77%	0	0.00%	9,091	1.95%	25,618	6.48%
SE	135,802	9.27%	0	0.00%	5,453	1.17%	3	0.00%
PB	160	0.01%	6,000	0.07%	0	0.00%	0	0.00%
PE	1,351	0.09%	0	0.00%	40	0.01%	0	0.00%
CE	265	0.02%	0	0.00%	335	0.07%	18	0.00%
RN	0	0.00%	0	0.00%	0	0.00%	0	0.00%
Overall	1,465,690	100%	9,082,943	100%	466,665	100%	395,423	100%

Where: BA = Bahia; MA = Maranhão; PI = Piauí; AL = Alagoas; SE = Sergipe; CE = Ceará; PB = Paraíba; PE = Pernambuco; RN = Rio Grande do Norte; m³ = volume in cubic meters; (t) = mass in tons; PC = cellulose and paper; OP = other purposes.

4. Discussion

Occupying only 0.56% of the region's territory and concentrating just over 16% of Northeast municipalities, *Eucalyptus* spp. silviculture in Northeast Brazil, still appears to be in its early stages. Compared to other Brazilian regions, it ranks second to last in terms of plantation area size, where its most productive sectoris the second-largest producer of charcoal, led by Maranhão and Bahia.

As shown in our results, the structural organisation of the forestry sector, organisedas a strategic planning model aimed at industrial purposes, catering heavily to major players in the cellulose and steel industries, has become a productive hub with a high concentration of labour, production factors, and capital. The concentration is so significant that the ten leading municipalities in each state with *Eucalyptus* spp. plantations account for more than 70% of the plantation areas in these states. Consequently, there is a significant gap in more remote areas of the Northeast with municipalities lacking forest plantations, even in Bahia and Maranhão, which have a high prominence in silviculture.

In this way, it could be strategically interesting for industrial sectors that consume wood for fuel, to expand *Eucalyptus* spp. silviculture to other regions of the Northeast since the centralized and under-pulverized, the forestry sector ends up excluding other market niches and consumption, especially for local energy supplies.

Therefore, a more evenly distributed expansion of planted forests would provide better economic, social, technological, and environmental gains for the entire Northeast region, as wood material from the sustainable forest management of the Caatinga (MFSC) alone is insufficient (Gadelha et al., 2015). Although MFSC plays an important socio-environmental role in the region, managing the cutting down of woody vegetation to contribute to income generation, occupation, and the conservation of natural ecosystems (Gama, 2021). Being possible from forest plantations in degraded areas and abandoned pastures (Tomasella *et al*., 2018; Santos *et al*., 2022; Gama *et al*., 2022; Silva *et al*., 2023), taking into account the availability of soils structurally favorable to eucalyptus silviculture (Gama and Jesus, 2020), contributing to offsetting impacts on natural forests (Eisfeld *et al*., 2017; Bichel and Telles, 2021).

Thus, the lack of participatory actions in public policies and their dissociation with private initiatives is one of the factors contributing to the lack of expansion of *Eucalyptus* spp. silviculture beyond the major producing centres. This includes the demotivating effect of excessive bureaucracy in accessing credit through available financing lines in programs such as 'Programa Nacional de Fortalecimento da Agricultura Familiar - Pronaf Floresta', both by regional financing agencies like 'Banco do Nordeste' (BNE, 2023) and nationally by 'Banco do Brasil' (BB, 2023). Added to this is the difficulty of obtaining information and guidance from lending institutions and the absence of campaigns, mainly by public agencies, to promote and encourage *Eucalyptus* spp. silviculture in the region.

Such conditions, if addressed effectively, are crucial for establishing chains of woody biomass production that can supply the local market in various microregions of the Northeast with reliable materials. Especially the energy sector, where there is still a lack of technical order in the productive sector and cultural issues (prejudice and misinformation) in the consumer sector regarding the planted forest energy matrix, which still need to be overcome (Moreira, 2011; Gama *et al*., 2023).

It is important to understand that the current intensive silvicultural model already meets a specific cycle of production and industrial demand, considering that the log sector for paper and cellulose has received the most investment, with the expansion of parks and technological modernization, led by Maranhão and Bahia (Sant, 2009; Marques, 2015; Oliveira *et al*., 2018; Babilônia and Wander, 2021; ABAF, 2022), for example. Therefore, it is now up to the forestry sector to assume a prominent role in the more isolated microregions of the region, especially through extensive silviculture, which is, according to authors like Boligon (2011) and Flor (2014), a low-cost activity that can be adopted for small to medium areas and small rural properties. In addition to the more efficient use of land area, extensive silviculture is advantageous due to its low initial investment and financial return at the end of the production period (Boligon, 2011).

On the other hand, the different demands for woodsectors are often conflicting and related to industrial and forestry activities (Gomes *et al*., 2006), which tend to increasingly stimulate the sector. Another motivating factor for forest expansion is the fact that up until 2012, Brazil's planted forest deficit for charcoal production was estimated at 600 thousand hectares, considering the different rotations in which the populations were found and their productivity (Carneiro *et al*., 2012). However, according to Valverde *et al*. (2004), reforestation projects are characterized by high technical and economic risk to which they are subject. Most of the time, due to their long-term nature, the risks (fires, pest attacks, diseases, disasters, and market threats, for example) associated with the planning horizon affect the viability and attractiveness of the project.

Another characteristic that needs to be overcome is the low price of the product (wood), due to the existence of a market condition where competition is imperfect, detrimental in the short term to rural producers, andto companies and consumers in the medium to long term (Valverde *et al*., 2004). Therefore, the costs and benefits of planting *Eucalyptus* spp., as stated by Kaur and Monga (2021), require careful evaluation based on detailed studies of the site with due consideration to environmental and socioeconomic needs. Decisions such as cultivation and management must be made, and the social and ecological implications of each decision, as well as the economic implications, must be weighed.

One of the great challenges of the forestry sector is to achieve a balance between the different demands, often conflicting and related to its industrial and forestry activities (Gomes *et al.,* 2006). Although for Soares *et al.* (2010), wood from intensive forestry, despite obtaining domestic prices lower than international prices, contributes to the transfer of income from producers to society.

Therefore, from the perspective of a policy of expanding silviculture activities with *Eucalyptus* spp. species beyond the major centres of the Northeast region, in addition to the effective participation of public policies, the implementation of projects that are suitable for the socioeconomic and edaphoclimatic reality of each microregion is necessary so that technical recommendations and silvicultural guidelines are correctly implemented.

5. Conclusions

Despite its low national participation, *Eucalyptus* spp. silviculture in Northeast Brazil is a potential sector for regional development.

The expansion of *Eucalyptus* spp. silvicultural activity in the Northeast, beyond the major production centres, is a viable economic alternative to serving small rural producers, local consumers, and mitigating the impacts of wood extraction on native forests.

The states of Bahia and of Maranhão have shown the greatest gains in growth in the production of cellulose and charcoal. In contrast, greater attention should be given to the states of Ceará, Paraíba, Pernambuco and Rio Grande do Norte e in order to better explore its potentials for the production of wood, among other products obtained of *Eucalyptus* spp. silvicultural.

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