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The mortality of *Caryocar brasiliense* in northern Minas Gerais State, Brazil

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ABSTRACT. The purpose of this work was to study the percentage of healthy trees, living trees and healthy branches and the renewal (natural propagation) of *Caryocar brasiliense* associated with the properties of soil, the floristic diversity and the canopy size of this plant. Lower proportions of live *C. brasiliense* trees and of healthy branches were found in the Savanna of Ibiracatu, where only 30% of the trees were healthy and without visible signs of attack by wood borers and by *Phomopsis* sp. We observed that *C. brasiliense* trees in areas where the soils contained higher levels of summed chemical bases and total sand (fine + gross) were less healthy. Moreover, the areas whose soils contained higher levels of aluminum and clay had a higher percentage of healthy *C. brasiliense* trees and branches. Smaller percentages of live and healthy trees and healthy branches were noted in areas with higher floristic diversity. Overall, the higher mortality of *C. brasiliense* trees may be associated with a higher pH and a lower content of aluminum, silt and clay, with competition with other tree species for nutrients, water and light, with the attack of Cossidae and particularly with the attack of fungi, *Phomopsis* sp.

Keywords: pequi, canopy size, floristic diversity, Cossidae, *Phomopsis* sp.

Mortalidade de *Caryocar brasiliense* no norte do Estado de Minas Gerais, Brasil

RESUMO. O objetivo deste trabalho foi estudar a percentagem de árvores sadias, vivas, galhos sadios e taxa natural de regeneração (propagação natural) de *Caryocar brasiliense*, associando com propriedades do solo, diversidade florística e tamanho de copa desta planta. As menores percentagens de árvores vivas de *C. brasiliense* e de galhos sadios foram observadas no cerrado de Ibiracatu, onde somente 30% destas estavam saudáveis, sem sinais visíveis de ataque do broqueador de tronco (Lepidoptera: Cossidae) e do fungo *Phomopsis* sp. As árvores de *C. brasiliense* localizadas em áreas cujos solos continham maiores níveis de soma de bases e areia total (fina + grossa) estavam menos saudáveis. Além disso, as áreas cujos solos continham maiores níveis de alumínio e de argila apresentaram maiores percentagens de árvores de *C. brasiliense* sadias e de galhos sadios. As menores percentagens de árvores vivas e sadias e com galhos vigorosos foram notados em áreas com maior diversidade florística. A maior mortalidade de árvores de *C. brasiliense* pode estar associado com maior pH e menor conteúdo de alumínio, de silte e argila, aliado com a competição com outras espécies florestais por nutrientes, água e luz, associado com ataque de Cossidae e principalmente do fungo *Phomopsis* sp.

Palavras-chave: pequi, tamanho de copa, diversidade florística, Cossidae, *Phomopsis* sp.

Introduction

The Savanna ecosystem occupies approximately 23% of the total area of Brazil and is high in plant diversity. The Savanna plant *Caryocar brasiliense* has a broad distribution in this ecosystem (ALMEIDA et al., 1998). Its fruits are used as food, in the production of cosmetics and lubricants and in the pharmaceutical industry (ARAÚJO, 1995). These fruits also represent the main source of income for many communities. However, uncontrolled harvesting has a strong effect on the propagation of *C. brasiliense*. Approximately 8.0 and 11.0% of plants up to 1.0 m in height (a relatively small percentage) and 60.0 and 45.0% taller than 3.0 m (reproductive phase) were observed in the Savanna and pasture areas, respectively (LEITE et al., 2006).

This information indicates that fruit collectors remove virtually all fruits from the tree. By doing so, they significantly reduce the propagation of *C. brasiliense* in the Savanna areas of Brazil (LEITE et al., 2006). Although the Savanna areas have been deforested, the *C. brasiliense* trees are left in the field. This situation increases their mortality (personal

communication from collectors of *C. brasiliense* fruits) and the chance that they will be attacked by insects (LOPES et al., 2003; LEITE et al., 2007, 2009, 2011a, b, c and d).

Some studies have associated the mortality of *C. brasiliense* trees with the attacks of wood borers on the trunks (Lepidoptera: Cossidae) (LEITE et al., 2011b) and of the fungus *Phomopsis* sp. on the branches. However, we do not know the actual levels of mortality of *C. brasiliense* trees or the identity of other factors that may be involved in this mortality.

Several factors, such as the size of the tree canopy (FAN et al., 2008; ITO; KOBAYASHI, 1993; LEITE et al., 2011b; McCULLOUGH; SIEGERT, 2007; ZANUNCIO et al., 2002), the presence of environmental stresses (FREDERICKS; JENKINS, 1998; HANKS et al., 1999; LEITE et al., 2006, 2011b) and the floristic diversity (HEITZMAN, 2003; LEITE et al., 2011b) of the area, may directly or indirectly affect the plants and their herbivores and diseases.

The objective of this work was to study the percentage of healthy trees, live trees and healthy branches and the renewal (natural propagation) of *C. brasiliense* associated with the properties of soil, the floristic diversity and the canopy size of this plant in six Savanna and pasture areas of northern Minas Gerais State, Brazil.

Material and methods

This work was conducted in the Municipalities of Montes Claros and Ibiracatu, northern Minas Gerais State, Brazil, in October 2006. The study investigated one area of Savanna vegetation *sensu stricto* and three areas with pastures (prior Savanna) in Montes Claros and one Savanna vegetation *sensu stricto* and one pasture (prior Savanna) in Ibiracatu. Both municipalities have a tropical climate (Aw, Köppen classification) with a dry winter and a rainy summer. These areas exhibit different characteristics of soil and floristic diversity. The geographical coordinates, altitude, soil type, physiochemical characteristics of the soil, floristic density, crown height and crown width were recorded in each of the areas studied (Tables 1, 2, and 3).

The treatments used in the study consisted of the six areas (two savannas and four pastures). The experimental design was completely random and used 32 repetitions (32 trees per area). A total of 192 *C. brasiliense* trees were evaluated. In each area (~160 ha), we walked (~1600 m) in a straight line through the middle of the area.

Randomly every 50 meters, we selected a *C. brasiliense* tree and evaluated the following characteristics: tree health (without trunk borer attack, with live branches); whether the tree was alive; branch health (not dry or with early symptoms of fungal attack); the height and width of the canopy; and the trunk diameter at breast height (DBH) (by using a tape measure). We calculated the percentage of healthy trees and live trees in each area and the percentage of healthy branches per tree. Every 300 meters along the survey line, we evaluated the renewal (natural propagation) of *C. brasiliense* and the floristic diversity in an area of 1000 m^2 by counting the number of trees groves^{-1} (> 2.0 m high) and shrubs (0.50 – 2.0 m high). The number of herbs (< 0.50 m high) and the percentage of cover were measured by placing a square at each of six points in each of the six 1000 m^2 areas.

Table 1. Coordinates and the altitudes of the areas, percentages of living trees, healthy trees as a percentage of total trees, percentage of healthy branches per tree, density ha^{-1}, height and width (m) of the crown, diameter at breast height (cm), trees ha^{-1}, soil covered per plant (%), number of herbs (< 0.50 m high), shrubs (0.50 – 2.0 m high) and trees + groves^{-1} (> 2.0 m high) ha^{-1} in six areas of the municipalities of Montes Claros and Ibiracatu, State of Minas Gerais, Brazil.

	Montes Claros				Ibiracatu	
Parameters evaluated	Savanna	Pasture 1	Pasture 2	Pasture 3	Savanna	Pasture
Longitude	43º 55' 7.3" W	43º 57' 31.4" W	43º 53' 21.6" W	43º 53' 27.4" W	44º 09' 38.2" W	44º 10' 25.8" W
Latitude	16º 44' 55.6"S	16º 46' 16.1"S	16º 53' 45.2"S	16º 53' 42.1"S	15º 42' 29.5"S	15º 41' 35.5"S
Altitude	943 m	940m	999m	1009m	817m	806m
Living trees (%)	100.00 a	95.00 a	100.00 a	100.00 a	62.00 b	100.00 a
Healthy trees (%)	85.00 b	93.00 a	71.00 b	95.00 a	30.00 c	65.00 b
Healthy branches (%)	90.20 a	93.24 a	94.99 a	86.64 a	45.25 b	96.05 a
Density of *C. brasiliense* ha^{-1}	17.00 b	42.30 a	36.50 a	45.80 a	53.16 a	33.00 a
Height of the crown of *C. brasiliense*	4.07 b	6.89 a	4.04 b	5.06 b	6.31 a	6.86 a
Width of the crown of *C. brasiliense*	2.87 c	6.87 a	4.73 b	5.89 b	6.08 a	7.11 a
DBH of *C. brasiliense*	17.53 b	28.45 a	21.95 b	18.57 b	27.26 a	26.63 a
Soil covering (%)	44.87 c	84.19 a	30.83 c	53.33 b	11.67 d	99.33 a
Herbs	5.78 c	0.19 e	11.67 b	10.33 b	3.33 d	30.00 a
Shrubs	23.51 c	4.76 d	38.00 c	79.00 b	121.33 a	1.33 d
Trees + groves^{-1}	8.76 b	2.76 c	6.50 b	14.00 b	40.33 a	1.00 c

*Means followed by the same letter per line do not differ between them by the test of Scott-Knott at 5% probability.

A total of 36 soil samples (0-20 cm deep) were collected, with six samples per area. The physical and chemical characteristics of the samples were evaluated at the Laboratory of Soil Analysis of the ICA/UFMG according to the methodology of Embrapa (1997). The samples were collected beneath the *C. brasiliense* canopies.

The data were examined with an analysis of variance and regression analysis ($p < 0.05$) was applied to relate the characteristics of the *C. brasiliense* trees to soil attributes and floristic diversity. The data were transformed using $\sqrt{X + 0.5}$ and examined with an analysis of variance and Scott-Knott test ($p < 0.05$).

Results and discussion

A relatively low proportion of living *C. brasiliense* trees were found in the Savanna of Ibiracatu. Only 30% of these trees were healthy, showing no visible signs of wood borer attack on their trunks (Lepidoptera: Cossidae) or of *Phomopsis* sp. attack on their branches (Fungi). The trees at these sites had a lower percentage of healthy branches than the percentage found for other areas (Table 1). 91% of the *C. brasiliense* trees surveyed in the Ibiracatu municipality, both in the Savanna and in the pasture, showed symptoms of attack by *Phomopsis* sp. or had branches with dry tips (data non showed). An additional finding was that this fungus attacked 85% of the *C. brasiliense* seedlings (data non showed). We did not detect significant effects of the height or width of the *C. brasiliense* canopy or of the DBH on the percentages of healthy trees, live trees or healthy branches/*C. brasiliense* tree (Table 2). However, LEITE et al. (2011b) has observed higher numbers of pupae and of sawdust produced by Cossidae in *C. brasiliense* trees having a DBH of over 30 cm.

The *C. brasiliense* trees having a greater canopy height and width, a greater DBH and a higher frequency of plants in the larger floristic-diversity size categories occurred in pasture 1 of Montes Claros and in Savanna and pasture in Ibiracatu. Moreover, *C. brasiliense* trees of smaller sizes and associated with higher frequencies of plants in the smaller floristic-diversity size categories were located in the Savanna of Montes Claros (Tables 1 and 2).

Table 2. The percentage of living trees, healthy trees as a percentage of total trees, percentage of healthy branches tree^{-1} and frequency (%) of *C. brasiliense* trees per category in the six study areas of the Municipality of Montes Claros and Ibiracatu, State of Minas Gerais, Brazil.

	Category per height of the crown of *Caryocar brasiliense* (m)					
	0.50 – 1.99	2.00 – 2.99	3.00 – 4.99	5.00 – 6.99	7.00 – 8.99	> 9.00
Living trees (%)*	100.00	95.00	92.00	95.00	100.00	95.00
Healthy trees (%)*	100.00	85.00	74.00	82.00	83.00	84.00
Healthy branches (%)*	97.89	85.08	80.24	87.58	91.18	88.35
	Frequency of *C. brasiliense* trees					
Savanna (Montes Claros)	0.00	25.00	58.33	8.33	8.33	0.00
Pasture 1 (Montes Claros)	2.33	2.33	13.95	44.19	11.63	25.58
Pasture 2 (Montes Claros)	6.25	6.25	53.13	18.75	9.38	6.25
Pasture 3 (Montes Claros)	7.58	13.64	22.73	18.18	21.21	16.67
Savanna (Ibiracatu)	0.00	10.00	30.00	20.00	15.00	25.00
Pasture (Ibiracatu)	5.00	15.00	15.00	10.00	15.00	40.00
	Category per width of the crown of *Caryocar brasiliense* (m)					
	0.80 – 1.99	2.00 – 4.99	5.00 – 6.99	7.00 – 8.99	9.0 – 10.99	> 11.00
Living trees (%)*	83.00	91.00	95.00	100.00	97.00	100.00
Healthy trees (%)*	83.00	80.00	76.00	83.00	85.00	84.00
Healthy branches (%)*	82.17	78.37	85.68	94.79	88.77	92.58
	Frequency of *C. brasiliense* trees					
Savanna (Montes Claros)	0.00	66.67	25.00	8.33	0.00	0.00
Pasture 1 (Montes Claros)	6.98	13.95	27.91	25.58	16.28	9.30
Pasture 2 (Montes Claros)	3.13	28.13	25.00	15.63	18.75	9.38
Pasture 3 (Montes Claros)	6.06	28.79	16.67	16.67	24.24	7.58
Savanna (Ibiracatu)	5.00	35.00	25.00	10.00	15.00	10.00
Pasture (Ibiracatu)	15.00	10.00	15.00	30.00	5.00	25.00
	Category per diameter of the trunk at breast height of *C. brasiliense* (cm)					
	1.00 – 9.9	10.0 – 19.9	20.0 – 29.9	30.0 – 39.9	40.0 – 59.9	> 60.0
Living trees (%)*	98.00	90.00	98.00	97.00	96.00	100.00
Healthy trees (%)*	93.00	76.00	87.00	80.00	74.00	71.00
Healthy branches (%)*	92.00	79.40	86.60	91.36	86.96	96.88
	Frequency of *C. brasiliense* trees					
Savanna (Montes Claros)	33.33	50.00	0.00	0.00	8.33	8.33
Pasture 1 (Montes Claros)	2.33	13.95	27.91	27.91	23.26	2.33
Pasture 2 (Montes Claros)	15.63	34.38	6.25	15.63	18.75	9.38
Pasture 3 (Montes Claros)	19.70	31.82	30.30	13.64	19.70	0.00
Savanna (Ibiracatu)	10.00	30.00	30.00	10.00	10.00	10.00
Pasture (Ibiracatu)	25.00	5.00	25.00	35.00	5.00	5.00

Means followed by the same letter per line do not differ between them by the test of Scott-Knott at 5% probability. *Non significant by ANOVA ($p > 0.05$).

Table 3. Physical and chemical data from soil analyses for the study period in the six areas of the municipalities of Montes Claros and Ibiracatu, State of Minas Gerais, Brazil.

	Montes Claros				Ibiracatu	
Parameters of the soil	Savanna	Pasture 1	Pasture 2	Pasture 3	Savanna	Pasture
pH in water	4.85c	4.87c	5.40a	5.17b	5.50a	5.60a
Phosphorus-Mehlich 1 (mg dm^{-3})	0.80c	0.59c	1.33c	4.30a	1.00c	2.63b
Phosphorus-remaining (mg L^{-1})	40.76a	17.64d	28.30c	30.53c	35.17b	40.07a
Potassium (mg dm^{-3})	28.25b	62.92a	7.33c	24.00b	17.00c	26.33b
Calcium ($cmol_c$ dm^{-3})	0.20b	0.71a	0.47a	0.30b	0.40b	0.50a
Magnesium ($cmol_c$ dm^{-3})	0.10b	0.37a	0.23a	0.17b	0.23a	0.30a
Aluminum ($cmol_c$ dm^{-3})	0.68b	1.06a	0.59b	0.68b	0.38c	0.39c
H + Al ($cmol_c$ dm^{-3})	5.19b	10.93a	2.93c	3.19c	2.00c	1.96c
Summ of bases ($cmol_c$ dm^{-3})	0.37c	1.23a	0.72c	0.53c	0.68c	0.87b
t ($cmol_c$ dm^{-3})**	1.05b	2.30a	1.31b	1.21b	1.06b	1.26b
m (%)**	63.58a	47.75b	52.67b	58.00a	36.67c	32.33c
T ($cmol_c$ dm^{-3})**	5.56b	12.17a	3.65c	3.72c	2.68c	2.82c
V (%)**	6.66d	11.08d	17.33c	13.67c	25.33b	31.33a
Organic matter (dag kg^{-1})	1.11b	8.77a	2.33b	2.94b	2.20b	2.46b
Gross sand (dag kg^{-1})***	20.92d	5.75e	26.27c	36.33b	32.67b	48.33a
Fine sand (dag kg^{-1})	53.92a	30.33c	57.73a	49.67a	54.67a	40.33b
Silt (dag kg^{-1})	10.83b	24.83a	7.33c	6.67c	7.33c	7.33c
Clay (dag kg^{-1})	14.33b	39.00a	8.67c	7.33c	5.33d	4.00d
Texture	Sandy	Loamier	Sandy	Sandy	Sandy	Sandy
Soil classification	Dystrophic Red Yellow Latosol					

*Means followed by the same small letter per line do not differ between them by the test of Scott-Knott at 1% probability. **t= capacity of cationic exchange, m= aluminum saturation in the capacity of cationic exchange; T= cation exchange capacity at natural pH 7.0; V= percentage of soil base saturation of the capacity of cationic exchange a pH 7.0. ***Gross sand (2 – 0.2 mm) (dag kg^{-1}), Fine sand (0.2 – 0.02 mm) (dag kg^{-1}), Silt (0.02 – 0.002 mm) (dag kg^{-1}), Clay (< 0.002 mm) (dag kg^{-1}).

The study areas showed a low rate of natural regeneration of *C. brasiliense* (a low percentage of seedlings). The study found that the percentages of plants below 2.0 m and above 3.0 m in height (reproductive phase) at the Montes Claros sites were as follows: Savanna, 0.0 and 75.0%, respectively; pasture 1, 2.3 and 95.4%, respectively; pasture 2, 6.3 and 87.5%, respectively; and pasture 3, 7.6 and 78.2%, respectively. The corresponding values for Ibiracatu were 0.0 and 90.0%, respectively, in Savanna and 5.0 and 80.0%, respectively, in pasture (Table 2). A low rate of regeneration has also been observed by LEITE et al. (2006) in other areas of Montes Claros.

We observed that *C. brasiliense* trees in areas whose soils contained higher total levels of bases (calcium + magnesium + potassium) and total sand (fine + gross) were less healthy. Moreover, the areas whose soils contained higher levels of aluminum and clay had a higher percentage of healthy *C. brasiliense* trees and healthy branches (Figure 1). Higher values of the summed bases and of aluminum and silt and clay and lower values of fine and gross sand were observed in pasture 1 in Montes Claros (Table 3).

Smaller percentages of living and healthy trees and healthy branches were observed in areas with higher floristic diversity (Figure 1). The lowest density of *C. brasiliense* trees ha^{-1} was observed in the Savanna in Montes Claros (Table 1). Higher numbers of trees $groves^{-1}$ of other species and shrubs were noted in the Savanna in Ibiracatu. A higher percentage of plant cover (less bare soil) was found in pasture 1 in Montes Claros and in pasture in Ibiracatu (Table 1).

C. brasiliense is a tree typical of the Brazilian Savanna. The Savanna soils are generally deep and loamy (providing an excellent storage capacity for rainwater), poor in nutrients, rich in aluminum and generally exhibit an acidic pH (SOUSA; LOBATO, 2004). These properties favor the development and productivity of this species (LEITE et al., 2006). Of the six areas studied, pasture 1 in Montes Claros was the only area with clay soil, higher acidic pH and higher aluminum content. Likely because of these characteristics, it was also the area that had trees with the greatest canopy height and width and the greatest DBH as well as a high percentage of living and healthy trees. In contrast, the Savanna in Ibiracatu has a relatively sandy soil with a less acidic pH and lower aluminum content. These characteristics make the *C. brasiliense* trees more vulnerable to attack by the trunk wood borer (LEITE et al., 2011b) and by the fungus *Phomopsis* sp. LEITE et al. (2011b) has observed higher numbers of cossid pupae and more sawdust produced by Cossidae in *C. brasiliense* in soils that had higher levels of potassium, calcium, magnesium, summed bases, cationic exchange capacity and organic matter and lower amounts of fine sand.

The Brazilian Savanna has been deforested for grain and cattle production (AGUIAR; CAMARGO, 2004), besides reforestation with eucalyptus (ZANUNCIO et al., 2002). However, the *C. brasiliense* tree is protected by federal laws and is left in deforested areas of the Brazilian Savanna (LEITE et al., 2006). Farmers have left reserve forest areas in which the soils exhibit poor physical structure (more sandy or stony), as noted in areas of Savanna in Ibiracatu and Montes Claros.

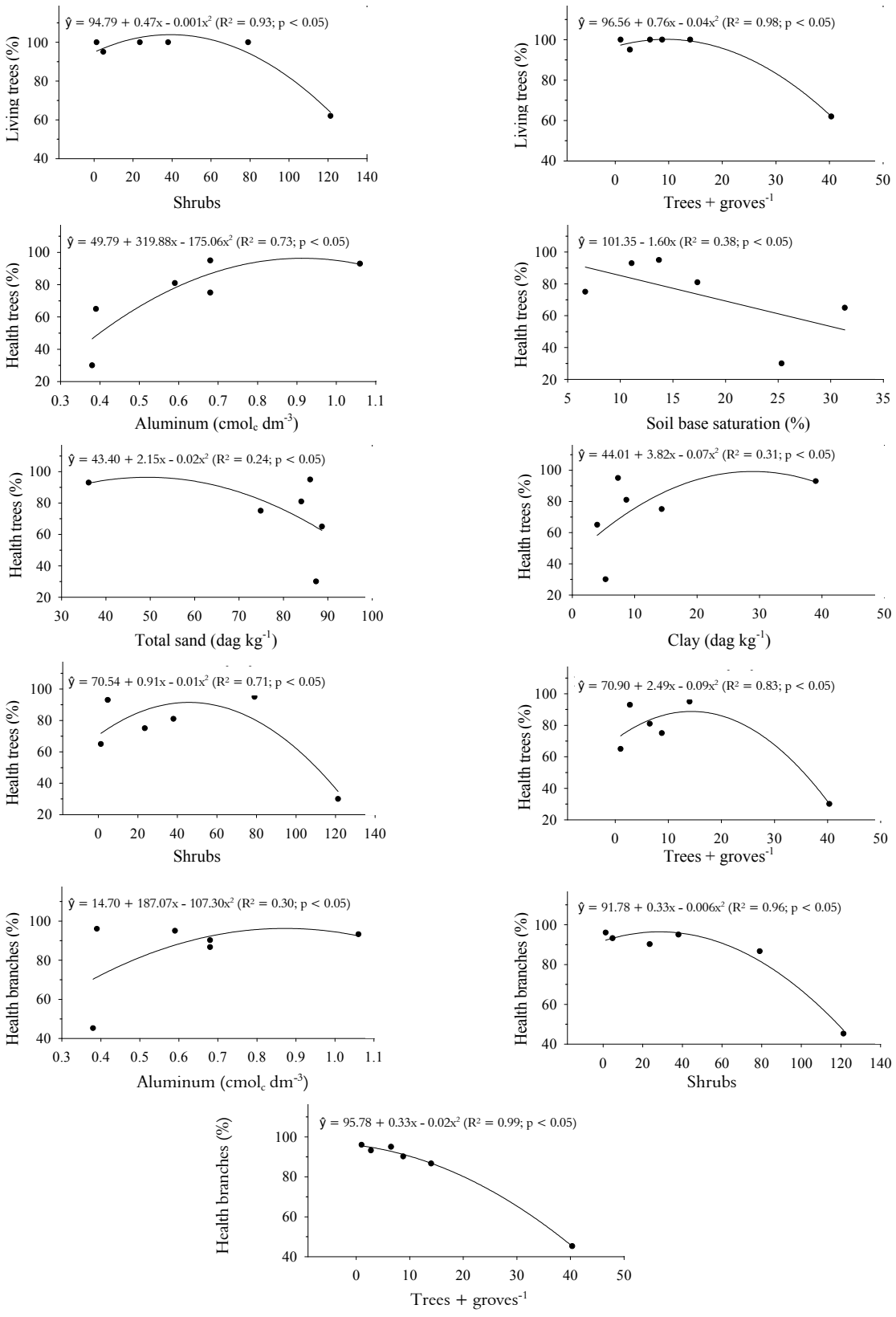

Figure 1. Percentage of living *Caryocar brasiliense* trees relative to total *C. brasiliense* trees as a function of the densities of shrubs and trees + groves^{-1}; the percentage of healthy *C. brasiliense* trees relative to total *C. brasiliense* trees as a function of aluminum, soil base saturation, total sand (fine + gross), clay and densities of shrubs and trees + groves^{-1}; and the percentage of healthy branches of *C. brasiliense* per *C. brasiliense* tree as a function of soil aluminum levels and the densities of shrubs and trees + groves^{-1}.

These soils reduce the production and natural regeneration of *C. brasiliense* (LEITE et al., 2006). In pastures, the rate of natural regeneration (seedlings) of *C. brasiliense* is also low. Although the soils contain more clay, the seedlings of the tree are constantly pruned by using hooks, are burned during the cleaning of the pasture or are eaten by cattle (LEITE et al., 2006). Moreover, in both the pasture and the Savanna the fruit collectors remove virtually all of the fruits of the *C. brasiliense*. Thus, they reduce the natural propagation of this plant considerably. These factors can result in a serious risk of extinction for *C. brasiliense* (LEITE et al., 2006).

C. brasiliense is a typical Savanna tree. Savanna *sensu stricto* is characterized by the predominance of the herb-shrub stratum and by the presence of a few tree species (ALMEIDA et al., 1998). This pattern may explain our observation that a higher percentage of dead and diseased *C. brasiliense* trees was associated with increased numbers of groves and trees. The reason for this association may be increased competition for nutrients, water and light in areas where soils are sandier. Furthermore, the more humid microclimate produced by vegetation growing around the *C. brasiliense* trees may favor the fungus *Phomopsis* sp. to a greater extent than the microclimate of more open and sunny areas (i.e., pasture). In addition, other trees can be natural hosts of the fungus (e.g., *Hancornia speciosa* Gomez, *Myracrodruon urundeuva* Fr. All.) (ANJOS et al., 2001) and can serve as a source of infection for other plants.

However, areas with lower floristic diversity, particularly areas that have few trees of other species, may cause the attacks of Cossidae to be concentrated on the trunks of *C. brasiliense* (LEITE et al., 2011b). The damage to the trunk of *C. brasiliense* caused by this insect can be serious and can lead to death (LEITE et al., 2011b). Nevertheless, we do not believe that this insect is the main source of the mortality of *C. brasiliense* in the areas studied, especially in the Savanna in Ibiracatu. However, this area does show evidence of past insect attacks on *C. brasiliense* trees. The area has a relatively high incidence, among the areas studied, of hollow trunks with damage by this insect (LEITE et al., 2011b). However, we think that one of the major sources of mortality of *C. brasiliense* is the fungus *Phomopsis* sp., which is the cause of a disease that kills the tips of the branches of this plant (CARVALHO, 2007) and attacks its leaves (ANJOS et al., 2001). This source of mortality must be considered along with the presence of very sandy soil and a greater competition for nutrients, water and light with other trees. However, the biggest problem observed in this study is not simply the mortality of *C. brasiliense* but the fact that this mortality reflects the general idea that the Savanna is a 'patient' that has been depleted and degraded in the north of Minas Gerais State.

Conclusion

Caryocar brasiliense trees, in areas where the soils contained higher levels of summed chemical bases and total sand, are less healthy. Smaller percentages of live and healthy trees and healthy branches are noted in areas with higher floristic diversity. Overall, the higher mortality of *C. brasiliense* trees may be associated with a higher pH and a lower content of aluminum, silt and clay, with competition with other tree species for nutrients, water and light, with the attack of Cossidae and particularly with the attack of fungi, *Phomopsis* sp.

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