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Growth of *Hymenaea stigonocarpa* as a function of the addition of residues in degraded soil

Kellian K. G. S. Mizobata[1], Cinthia M. Santos[2], Kátia L. Maltoni[3],
Gláucia A. Faria[3] & Ana M. R. Cassiolato[3]

[1] Universidade Estadual Paulista "Júlio de Mesquita Filho"/Faculdade de Engenharia/Programa de Pós-Graduação em Agronomia. Ilha Solteira, SP. E-mail: kelliankenji@gmail.com (Corresponding author)
[2] Universidade de São Paulo/Escola Superior de Agricultura "Luiz de Queiroz"/Programa de Pós-Graduação em Recursos Florestais. Piracicaba, SP. E-mail: cinthia_biounesp@yahoo.com.br
[3] Universidade Estadual Paulista. Ilha Solteira, SP. E-mail: maltoni@agr.feis.unesp.br; glaucia@mat.feis.unesp.br; anamaria@bio.feis.unesp.br

Key words:
aquatic macrophytes
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savannah

ABSTRACT

In areas where soil surface horizons were removed, the main edaphic problems are reduced amounts of organic matter and nutrients. Revegetation, especially with native species, has been indicated to recover these areas. Under this perspective, the present research has been developed to evaluate the contribution of organic and agro-industrial residues, as conditioners of soil fertility and their effects on initial growth of 'Jatobá-do-cerrado' seedlings. The treatments consisted of 4 agro-industrial residue doses (0, 15, 30 and 45 Mg ha^{-1}) and 4 organic residue doses (0, 8, 16 and 32 Mg ha^{-1}), with 16 treatments and 10 replicates. After 8 months of development, the soil was evaluated for phosphorus, organic matter, hydrogen potential, potassium, calcium, magnesium, potential acidity, aluminum and sum of bases, and plants were evaluated for leaf chlorophyll, height, collar diameter, fresh and dry matter of shoots and roots, and root length. The addition of residues to the degraded soil increased the fertility by raising calcium and magnesium levels. Agro-industrial residues contributed to increasing height, shoot dry matter and chlorophyll of *H. stigonocarpa*, while organic residues improved shoot fresh matter and chlorophyll.

Palavras-chave:
macrófitas aquáticas
cinza
jatobá-do-cerrado
subsolo exposto
cerrado

Crescimento de *Hymenaea stigonocarpa* em função da adição de resíduos em solo degradado

RESUMO

Dentre os principais problemas edáficos observados em áreas de empréstimo se encontram as quantidades reduzidas de matéria orgânica e nutrientes. Para a recuperação dessas áreas a revegetação tem sido indicada especialmente com espécies nativas. Nesta perspectiva desenvolveu-se o presente trabalho para avaliar a contribuição de resíduos, um orgânico e um agroindustrial, como condicionantes da fertilidade do solo e seus efeitos sobre o crescimento de mudas de jatobá-do-cerrado. Os tratamentos consistiram de 4 doses (0, 15, 30 e 45 Mg ha^{-1}) de resíduo agroindustrial e 4 doses (0, 8, 16 e 32 Mg ha^{-1}) de resíduo orgânico com 16 tratamentos e 10 repetições. Transcorridos 8 meses o solo foi avaliado para fósforo, matéria orgânica, potencial de hidrogênio, potássio, cálcio, magnésio, acidez potencial e alumínio e as plantas para clorofila foliar, altura, diâmetro do coleto, massa fresca e seca da parte aérea do sistema radicular e comprimento de raízes. A adição dos resíduos ao solo degradado incrementou a fertilidade elevando os teores de cálcio e magnésio. O resíduo agroindustrial promoveu incrementos em altura, massa seca da parte aérea e clorofila enquanto o resíduo orgânico influenciou a massa fresca da parte aérea e a clorofila.

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INTRODUCTION

With the growing occupation of the Cerrado, the increase in degraded areas is inevitable and nowadays only part of its original cover is left. However, researches on the recovery of degraded areas are still incipient and scarce (Durigan et al., 2011).

The low contents of organic matter and nutrients in degraded areas hamper the establishment of vegetation (Rodrigues et al., 2007). Planting seedlings and establishing/maintaining natural regeneration, or the combination of both, according to Durigan et al. (2011), are methods used in the recovery of degraded or disturbed environments.

Revegetation allows the production and introduction of organic matter in the soil, which favors multiplication, diversification of microbial community and the reestablishment of the interrelationship of the vegetation with soil morphology, chemistry and biology (Pulleman et al., 2008).

For the introduction of vegetation in degraded soils with low natural fertility and under demarked rainfall regime, it is essential to use mineral and organic inputs (Corrêa et al., 2010) and the use of organic residues may be indicated as a viable option.

The chemical and physical adjustment of the soil or substrate and the selection of species suitable to revegetation are very important and depend on specific characteristics of the environment (Rodrigues et al., 2007). Native species have been recommended for these revegetation processes (Pinheiro et al., 2009), mostly due to the high scarcity of nutrients and high aluminum contents associated with acidity, which are common phenomena in Brazilian Cerrado areas.

Aquatic macrophytes have generated problems in the process of energy generation, because of their abundant occurrence in the reservoirs (Velini et al., 2005).

The procedures of removal of these macrophytes from water bodies require the adequate definition of the deposition area or the use of this biomass. Considering the current legislation (Pompêo, 2008), the possibilities are: disposal in landfills, use as animal feed, with considerations on risks to animal health, and the use as organic fertilizer. The ash, derived from the burning of sugarcane bagasse in boilers during the process of sugar and alcohol production, is another residue that could be used as an alternative to improve soil fertility conditions. This ash urgently needs a destination, since it has been applied to the soil as a source of fertilizer and may vary in composition from region to region.

The use of ash as an input in the agricultural production process can be considered as environmentally and economically viable (Feitosa et al., 2009), for being a source of macro and micronutrients and allowing water retention, which improves crop development and reduces negative environmental impacts.

In the Southeast region of Mato Grosso do Sul, it is common the occurrence of *Hymenaea stigonocarpa* Mart. ex Hayne, also known as 'Jatobá-do-cerrado' (Carvalho, 2007; Oliveira, 2011). It is an arboreal species with economic potential (Lorenzi, 2009), because its wood can be employed in civil and naval construction (Moraes et al., 2007; Lorenzi, 2009) and its farinaceous pulp is well appreciated by rural populations, fresh or in the form of jelly, liquor, cakes etc. (Cohen, 2010; Oliveira, 2011). This tree is ornamental, can be used for urban afforestation and also for the recovery of degraded areas, for being a leguminous plant and shows potential use in animal nutrition (Lorenzi, 2009).

With the presence of macrophytes (organic residue) and ash (agro-industrial residue) without adequate destination in the region, the need for the recovery of degraded areas with subsoil exposure in the Cerrado and the availability of *H. stigonocarpa* seeds, this study aimed to evaluate the contribution of organic and agro-industrial residues as soil fertility conditioners and their effects on the growth of seedlings of *Hymenaea stigonocarpa* Mart. ex Hayne.

MATERIAL AND METHODS

The experiment was carried out in a protected environment, at the São Paulo State University – UNESP, Campus of Ilha Solteira. The soil material used had sandy clay loam texture (sand = 519 g kg^{-1}, silt = 195 g kg^{-1} and clay = 286 g kg^{-1}) and fertility with available P = 3.0 mg dm^{-3}; organic matter (OM) = 10 g dm^{-3}; pH $_{(CaCl2)}$ = 4.3; K^+ = 0.9 $mmol_c$ dm^{-3}; Ca^{2+} = 3.0 $mmol_c$ dm^{-3}; Mg^{2+} = 2.0 $mmol_c$ dm^{-3}; $H^+ + Al^{3+}$ = 22 $mmol_c$ dm^{-3}; Al^{3+} = 4.0 $mmol_c$ dm^{-3}; SB = 5.9 $mmol_c$ dm^{-3}; CEC = 27.9 $mmol_c$ dm^{-3} and V = 21%.

This material was collected in Selvíria-MS, in the layer of 0.0-0.20 m, in an area degraded by the construction of the Hydroelectric Power Plant of Ilha Solteira-SP, which removed the superficial soil profiles. Then, the material was sieved (4-mm mesh) and placed in plastic bags for seedlings (3 L) and received different doses of aquatic macrophytes as organic residue (OR) and different doses of ash from the burning of sugarcane bagasse, as agro-industrial residue (AR).

The OR was composed of aquatic macrophytes, mostly *Eichhornia crassipes* (common water hyacinth), which were collected in the Hydroelectric Power Plant of Jupiá (CESP in Três Lagoas/MS) and showed the following composition: N = 12.81 g kg^{-1}; P = 1.57 g kg^{-1}; K^+ = 2.19 g kg^{-1}; Ca^{2+} = 49.75 g kg^{-1}; Mg^{2+} = 5.51 g kg^{-1} and S = 1.48 g kg^{-1} (Malavolta et al., 1997). The AR, composed of ashes, was obtained at the Alcoolvale: Açúcar e Álcool S.A., in Aparecida do Tabuado (MS), and the ash subjected to fertility analysis showed: P_{resin} = 167 $mmol_c$ dm^{-3}; OM = 28 g; pH $_{(CaCl2)}$ = 8.9; K^+ = 36.6 $mmol_c$ dm^{-3}; Ca^{2+} = 242 $mmol_c$ dm^{-3}; Mg^{2+} = 23 $mmol_c$ dm^{-3}; $H^+ + Al^{3+}$ = 8; Al^{3+} = 0; SB = 301.6 $mmol_c$ dm^{-3} (Raij et al., 2001). The total analysis of AR, performed at the Campinas Agronomic Institute, R&D Center of Soils and Natural Resources, Laboratory of Fertilizers and Residues, showed: P = 0.86 g kg^{-1}; K = 1617 mg kg^{-1}, Ca = 5.3 g kg^{-1}; Mg = 1.1 g kg^{-1}; Zn = 12.4 g kg^{-1}; C = 570.0 g kg^{-1} and Al = 1710 mg kg^{-1}.

Both residues were air-dried, the OR was passed in a chopper and both were incorporated to the soil material 60 days before the introduction of *H. stigonocarpa* seedlings. The treatments consisted of 4 OR doses (0; 8; 16 and 32 Mg ha^{-1}) and 4 AR doses (0; 15; 30 and 45 Mg ha^{-1}) and their combinations, totaling 16 treatments, with 10 replicates each.

H. stigonocarpa seeds underwent a process of mechanical scarification (rupture of the pericarp), disinfection using 0.1%

sodium hypochlorite and remained immersed in deionized water for 24 h, before being planted in trays (washed sand), where they remained for 60 days until the transplantation to the experimental units.

After 8 months of the introduction of seedlings in the experimental units, they were evaluated for height, collar diameter and chlorophyll (indirect measurement performed with a Falker chlorophyll meter). Plant shoots were collected for the evaluation of shoot fresh and dry matter. The roots were manually separated from the soil and evaluated for length and root fresh and dry matter. After homogenizing the soil material, one sample was collected per experimental unit and subjected to fertility analysis, as previously described.

The experimental design was completely randomized in a 4 x 4 factorial scheme, represented by 4 doses of AR and 4 doses of OR, with 10 replicates. The results were evaluated through analysis of variance (ANOVA) and, in the case of significant interaction between AR and OR doses, multiple regressions were performed and a response surface graph was presented. The analyses were performed using the programs SISVAR (Ferreira, 2011) and Statistica 7.0 (Statsoft, 2004).

Results and Discussion

The results show that both the application of AR and OR influenced soil fertility with interaction of effects for all the analyzed variables, except for K$^+$ (Table 1), which evidences the importance of the association of organic and mineral materials to improve soil fertility conditions (Medina et al., 2010; Aranda et al., 2015).

AR application did not influence K$^+$ behavior in the soil; however, OR application caused positive effects on K$^+$. Calgaro et al. (2008), in an experiment with addition of a similar organic residue, observed increments in K$^+$, corroborating the results of the present study (Table 1). OR promoted significant increments in K$^+$ ($\hat{Y}^{**} = 0.7008 + 0.0708x - 0.0017x^2$, $R^2 = 0.9501$) with maximum point at 20.82 Mg ha^{-1} of OR, suggesting that this dose is sufficient to reach the maximum release of K$^+$ in the evaluated degraded soil.

The addition of 16 Mg ha^{-1} of OR increased K$^+$ contents from 0.7 to 1.3 mmol$_c$ dm^{-3}, compared with its absence. Although with values still low, the results for the application of OR are promising as soil chemical conditioner for K$^+$ in areas of revegetation (Carvalho, 2007). Other authors also cite the importance of using organic residue as source of K$^+$ and mention that the application of 6 to 10 Mg ha^{-1} of organic residue from olive oil production, in areas under olive cultivation, increased K$^+$ contents in the soil from 1.9 to 5.7 mmol$_c$ dm^{-3} (Aranda et al., 2015).

The highest P contents were observed in the associations of higher OR doses and intermediate AR doses (Figure 1A), which is related to the amount of P found in the initial characterization of the residues. The highest OM contents were observed at the highest AR doses, which is explained by the C content in the ash of sugarcane bagasse (570 g kg^{-1}) that was not totally carbonized (Carrier et al., 2012; Balakrishnan & Batra, 2011). Horta et al. (2010), in an experiment with simultaneous application of ash and sulfur to the soil, observed positive effect of the ash on OM content and explained that the residue was not totally carbonized and still had the organic fraction preserved.

The positive effect observed with AR addition does not show interaction with OR doses after 8 months, due to the OR composition (Figure 1B). Observations like these were reported by Silva et al. (2008), who reported no significant increments in OM contents related to the addition of organic residues in degraded soil, which evidences the importance of AR in supplying C to the soil.

On the other hand, pH and Ca^{2+} showed similar behavior with the addition of AR. The increase in pH and Ca^{2+} in the soil may bring benefits to the seedlings, considering the importance to plant nutrition (Viani et al., 2014). However, pH and Ca^{2+} were not considerably influenced by the applied OR (Figure 1C and 1D).

AR addition contributed to the increase in Ca^{2+}, because it contains 5.3 g of Ca^{2+} kg^{-1}; similar values were reported by Balakrishnan & Batra (2011) and Carrier et al. (2012) in analysis of ash from sugarcane bagasse.

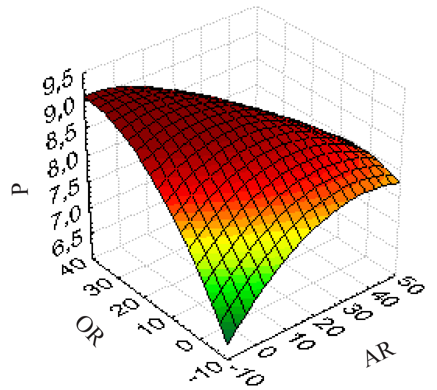
Table 1. Mean values of phosphorus (P), organic matter (OM), hydrogen potential (pH), potassium (K$^+$), calcium (Ca^{2+}), magnesium (Mg^{2+}), potential acidity (H+Al), aluminum (Al^{3+}), F probability and coefficient of variation (CV) for the soil under different doses of agro-industrial (AR) and organic (OR) residues

Source of variation	P mg dm^{-3}	OM g dm^{-3}	pH CaCl$_2$	K$^+$	Ca^{2+}	Mg^{2+}	H + Al	Al^{3+}
				mmol$_c$ dm^{-3}				
AR doses (Mg ha^{-1})								
0	8.5	7.8	4.4	1.4	2.0	1.9	21.2	4.4
15	8.5	8.3	4.8	1.1	4.3	2.3	17.8	2.4
30	8.6	8.8	5.0	1.0	6.3	2.8	17.2	0.5
45	7.9	10.4	5.2	1.0	10.3	3.2	15.6	0.1
OR doses (Mg ha^{-1})								
0	8.2	7.9	4.5	0.7	4.8	1.8	19.5	3.0
8	8.3	8.9	4.8	1.3	5.7	2.6	17.7	1.7
16	8.7	9.5	5.1	1.3	6.5	3.0	17.2	1.3
32	8.4	9.1	4.9	1.3	5.9	2.8	17.4	1.4
F probability								
AR	18.22**	28.84**	15.33**	2.52^{ns}	164.33**	58.11**	99.45**	284.46**
OR	9.33**	10.39**	8.67**	6.07**	6.27**	56.33**	20.28**	43.46**
AR x OR	10.82**	8.11**	2.67*	1.43^{ns}	2.31*	8.04**	4.67**	7.13**
CV (%)	3	8	6	38	17	10	5	22

^{ns}Not significant; ** and *Significant for $P < 0.01$ and 0.05, respectively

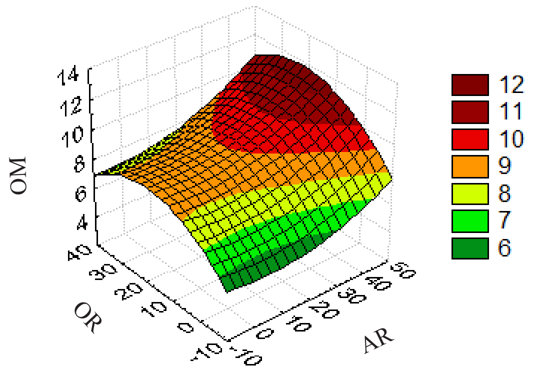
A.

$P = 7{,}7732+0{,}0409x+0{,}0752y-0{,}0007x^2-0{,}0013xy-0{,}0011y^2$



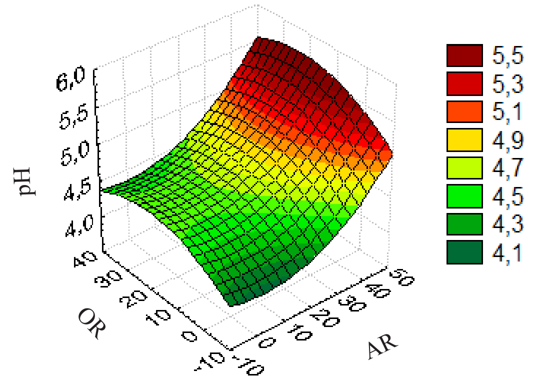
B.

$OM = 7{,}0784-0{,}0053x+0{,}1501y+0{,}0012x^2+0{,}0004xy-0{,}0038y^2$



C.

$pH = 4{,}3164-0{,}0017x+0{,}0217y+0{,}0005x+6{,}3492E^{-5}xy-0{,}0005y^2$



D.

$Ca = 0{,}6995+0{,}1129x+0{,}1962y+0{,}0019x^2-0{,}0014xy-0{,}004y^2$

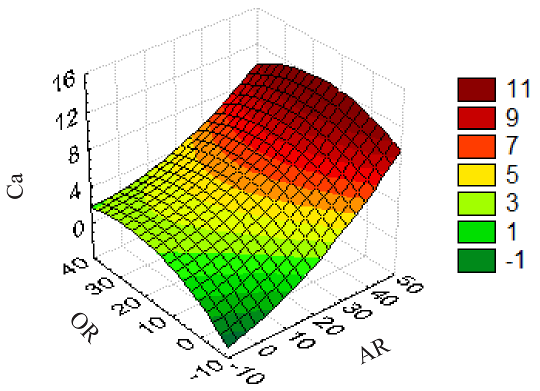


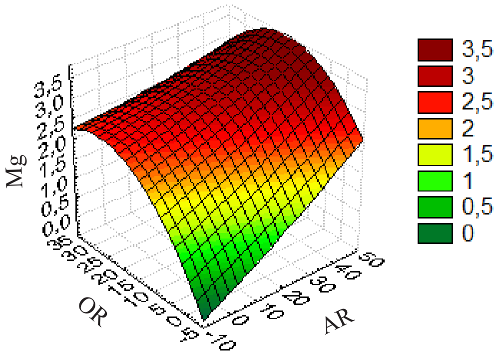
Figure 1. Response surface for P (A), OM (B), pH (C) and Ca^{2+} (D), for soil under different doses of agro-industrial (AR) and organic (OR) residues

With small variation, Mg^{+2} had its behavior influenced by both residues (AR and OR), whose highest contents in the soil occurred at the highest doses of both residues (Figure 2A). These results are consistent with those of Santos et al. (2014), who reported beneficial effects on the supply of Mg^{+2} to the substrate as higher proportions of organic residues were added.

The lowest H + Al is associated to the lowest contents of exchangeable Al^{3+}, which were found at the highest AR doses, as expected and also reported by Silva et al. (2006), since the potential acidity refers to the total H in covalent bond plus Al^{3+} (sum of exchangeable and non-exchangeable acidity). The highest AR doses also promoted the increase in pH with consequent reduction in exchangeable Al^{3+} (Figure 2B, 2C).

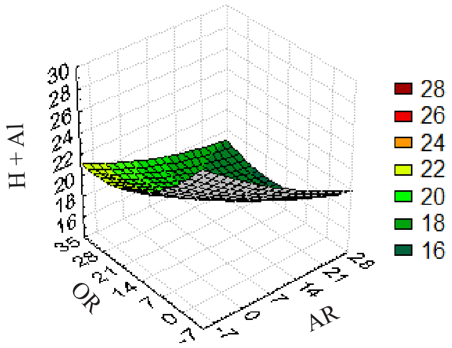
A.

$Mg = 0{,}8754+0{,}0358x+0{,}1445y+9{,}2593E^{-5}x^2-0{,}0008xy-0{,}003y^2$



B.

$H+AL = 23{,}3725-0{,}2435x-0{,}3032y+0{,}0019x^2+0{,}0028xy+0{,}0055y^2$



C.

$AL = 6{,}0245-0{,}1987x-0{,}2014y+0{,}0018x^2+0{,}0014xy+0{,}0038y^2$

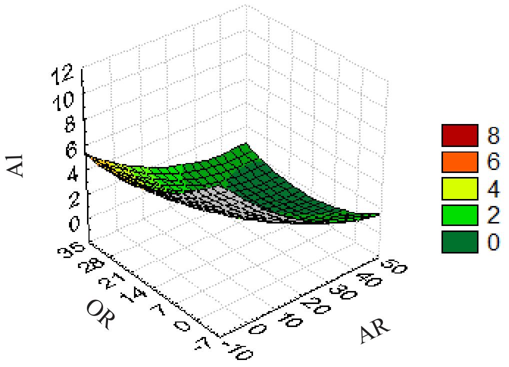


Figure 2. Response surface for Mg^{2+} (A), H+Al (B) and Al^{3+} (C), for soil under different doses of agro-industrial (AR) and organic (OR) residues

Table 2. Mean values of height (HGT), collar diameter (CD), leaf chlorophyll content (CLOR), shoot fresh (SFM) and dry (SDM) matter, root fresh (RFM) and dry (RDM) matter, root length (RL), F probability and coefficient of variation (CV) for seedlings of *Hymenaea stigonocarpa*, in a degraded soil under different doses of agro-industrial (AR) and organic (OR) residues

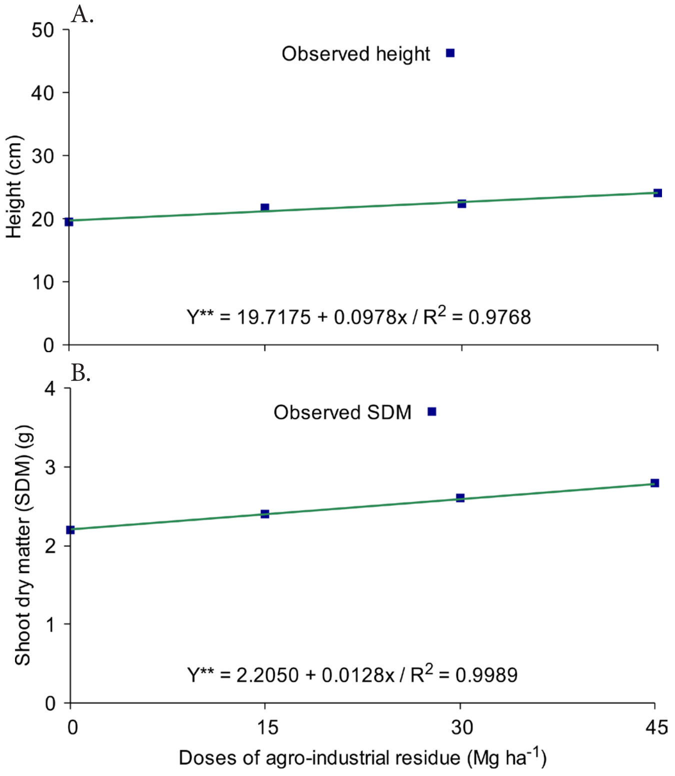
Source of variation	HGT (cm)	CD (mm)	CLOR	SFM	SDM	RFM	RDM	RL (cm)
				(g)				
AR doses (Mg ha^{-1})								
0	19.45	5.9	27.55	4.15	2.22	11.15	7.38	25.76
15	21.70	5.9	32.80	4.58	2.38	10.85	7.13	28.93
30	22.43	6.4	35.23	5.05	2.58	12.13	7.98	27.65
45	24.10	6.2	40.65	4.98	2.80	11.83	7.35	27.60
OR doses (Mg ha^{-1})								
0	21.45	6.2	32.00	3.98	2.20	9.98	6.55	27.10
8	22.40	6.1	32.05	4.98	2.53	11.65	7.53	26.75
16	21.83	6.0	36.05	5.00	2.63	12.10	7.83	27.50
32	22.00	6.2	33.13	4.80	2.63	12.23	7.93	28.75
F probability								
AR	14.370^{**}	1.840^{ns}	309.885^{**}	2.220^{ns}	3.379^{*}	0.898^{ns}	0.773^{ns}	2.457^{ns}
OR	0.601^{ns}	0.329^{ns}	35.118^{**}	3.016^{*}	2.203^{ns}	2.789^{*}	2.30^{ns}	1.125^{ns}
AR x OR	1.742^{ns}	0.832^{ns}	27.995^{**}	0.995^{ns}	0.838^{ns}	0.224^{ns}	1.355^{ns}	1.546^{ns}
CV (%)	15	18	6	38	34	34	35	19

^{ns}Not significant; ** and *Significant for $P < 0.01$ and 0.05, respectively

AR addition had positive influence on height, chlorophyll and shoot dry matter of the seedlings, while OR incorporation influenced chlorophyll and shoot and root fresh matter, and their interaction influenced only the behavior of chlorophyll (Table 2).

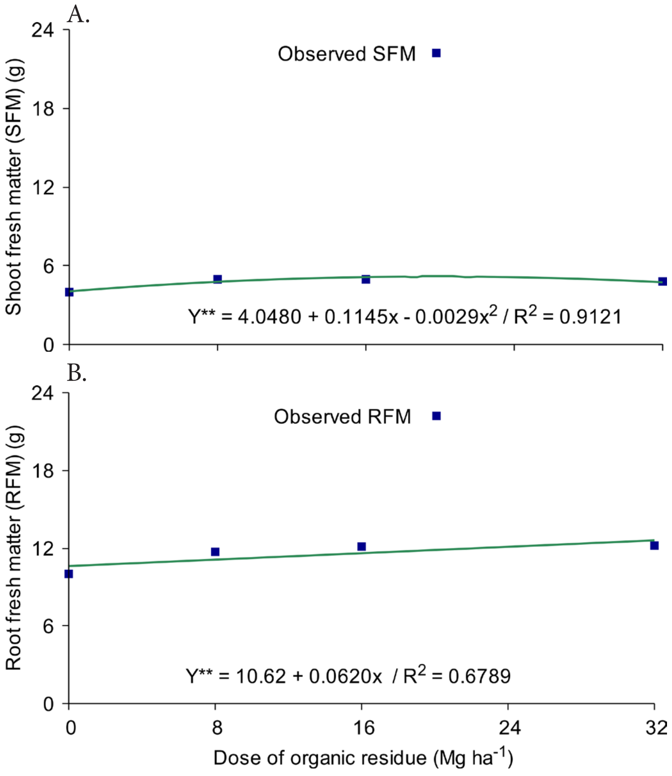
The application of different AR doses produced positive effects, with linear increasing behavior for height and shoot dry matter, as also observed by Ramos et al. (2009) in the bean crop receiving composted cotton residue (Figure 3). Considering the chemical conditions of the applied AR, the observed response is easily explained, because there was addition of nutrients to the soil (Carrier et al., 2012; Ram & Masto, 2014), which improved its chemical attributes. Similarly, Rodrigues et al. (2007) also observed better plant response with the addition of residues.

With the application of OR, root fresh matter increased linearly (Figure 4) with approximate increments of 0.62 g every 10 Mg ha^{-1} of OR, which evidences its importance as a supplier of nutrients and also in the improvement that occurs in the soil material with the addition of organic matter. This is corroborated by Medina et al. (2010), who applied different



**Significant for $t < 0.01$

Figure 3. Height (A) and shoot dry matter (B) of *Hymenaea stigonocarpa* in response to different doses of agro-industrial residue



** Significant for $t < 0.01$

Figure 4. Shoot fresh matter (A) and root fresh matter (B) of *Hymenaea stigonocarpa* in response to different doses of organic residue

Table 3. Follow-up analysis of the interaction organic residue (OR) x agro-industrial residue (AR) with the regression equations for chlorophyll as a function of OR and AR doses, their significance, coefficient of determination (R^2), maximum point (MP) and values of $Pr > Fc$ of linear and quadratic models and the deviation

AR doses (Mg ha^{-1})	Regression equations for OR inside AR doses	R^2	MP	Linear	Quadratic	Deviation
0	$\hat{Y}^{**} = 22.9427 + 0.8873x - 0.0233x^2$	0.7599	19.0408	0.000	0.000	0.000
15	$\hat{Y}^{**} = 34.1300 + 0.1956x - 0.0121\ x^2$	0.9996	8.0826	0.000	0.000	0.865
30	$\hat{Y}^{ns}$			0.307	0.154	0.092
45	$\hat{Y}^{**} = 34.9609 + 0.9799x - 0.0239x^2$	0.8742	20.5000	0.000	0.000	0.000
OR doses (Mg ha^{-1})	**Regression equations for AR inside OR doses**					
0	$\hat{Y}^{**} = 24.1600 + 0.8073x - 0.0131x^2$	0.9849	30.8129	0.000	0.000	0.062
8	$\hat{Y}^{**} = 27.1300 + 0.3520x$	0.9250		0.000	0.198	0.000
16	$\hat{Y}^{**} = 33.6100 - 0.2027x + 0.0089x^2$	0.9200	11.3876	0.000	0.000	0.000
32	$\hat{Y}^{**} = 25.3400 + 0.3460x$	0.9210		0.000	0.000	0.017

^{ns}Not significant; ** and *Significant for $t < 0.01$ and 0.05, respectively; Values of $Pr > Fc$ equal to or higher than 0.05 indicate significant difference at 0.05 and values lower than 0.01 indicate significant difference at 0.01

organic residues to the soil and observed significant alterations in soil fertility, which reflects in yield increase.

Shoot fresh matter showed quadratic response to OR application, with maximum point at 19.7 Mg ha^{-1} (Figure 4). This behavior indicates that there is no need for the use of larger amounts of OR for the production of fresh biomass of *H. stigonocarpa*, which can be an indication of low nutritional requirement by the plant (Carvalho, 2007; Viani et al., 2014).

The follow-up analysis of the interaction AR x OR for chlorophyll (Table 3) shows that, in the absence of AR, 19.04 Mg ha^{-1} of OR are necessary for the maximum point and, at the dose of 45 Mg ha^{-1} of AR, the maximum point is reached with 20.5 Mg ha^{-1} of OR, with superior values of chlorophyll.

Evaluating the application of AR as a function of different doses of OR for chlorophyll, it is observed that, in the absence of OR, 30 Mg ha^{-1} of AR were necessary for the maximum point and, in the presence of 16 Mg ha^{-1} of OR, only 11 Mg ha^{-1} of AR are sufficient, obtaining higher maximum values. This suggests the application of 45 Mg ha^{-1} of AR and 16 Mg ha^{-1} of OR for obtaining the best results of chlorophyll, without interfering with plant growth (Table 3).

CONCLUSIONS

1. The combined addition of organic and agro-industrial residues increased the contents of P, OM, Ca^{2+} and Mg^{2+}, increased pH and reduced H + Al and Al^{3+} in the degraded soil.

2. K^+ increased only in the presence of organic residue.

3. AR application promoted linear increments in height and shoot dry matter of *H. stigonocarpa*.

4. The applied organic residue promoted increments in shoot fresh matter and its quadratic behavior indicates the dose of 20 Mg ha^{-1} as sufficient.

5. *H. stigonocarpa* proved to be a plant with low nutritional requirement.

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