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Vegetative ash biomass as a potential source of silicon for soils in eucalyptus plantation

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Abstract

In face of the need to broaden the knowledge about the effects of ashes in eucalypt plantations, this study evaluated the use of ashes in two typical Brazilian soils for forest plantations. The experiment was done in a greenhouse, from November 19 to December 19 (2014), in Uberlândia, MG. The ashes were obtained from eucalypt wood and bark, eucalypt twigs and leaves, pine wood and bark and sugar cane bagasse, applied to a sandy soil (experiment 1) or to a clayey one (experiment 2). In each experiment, incubation tests were done in a completely randomized design as 4×2+1 factorial consisting of four ash sources. Vegetative ash biomass from eucalypt wood and bark (EWB), eucalypt twigs and leaves (ETL), pine wood and bark (PWB) and sugar cane bagasse (SCB), two doses (200 and 400 kg ha^{-1}), and a control (with no silicon source), with three replications. Soluble silicon, pH, and exchangeable Ca and Mg were determined after incubating the soils for 30 days. PWB supplied more Si to both soils. The SCB did not increase Ca and Mg to either soil, regardless of the dose. The ashes that most reduced soil acidity in the sandy soil were those of eucalypt, at 400 kg ha^{-1}, while no pH change was observed in the clayey one. The best silicon source evaluated for both soils was pine wood and bark (PWB) at 400 kg ha^{-1}; however, EWB and ETL should be used whenever available.

Keywords: ashes; eucalypts; forest biomass; pines; wollastonite.
Abbreviations: AEI_Agricultural efficacy index; ETL_eucalypt twigs and leaves; EWB_eucalypt wood and bark; LVd_Distrophyc Oxisol; PWB_pine wood and bark; RQo_Ustox typical soil; SCB_sugar cane bagasse.

Introduction

Economically important forest species are mostly used for industrial processes, such as pulp and mechanically processed timber and for energy production, by the combustion of vegetative biomass. One of the main environment problems arising from this process is the large volume of residues produced and their proper disposal (Maeda et al., 2008).Thus, the use of industrial waste as fertilizers becomes a sustainable manner of providing an adequate destination for it, and can reduce the demand of chemical fertilizers (Bonfim-Silva et al., 2013).

Vegetative ash is a type of industrial residue resulting from the combustion of vegetative biomass for the generation of energy or steam. It has been suggested for use as fertilizer in crops, such as Pines (Maeda et al., 2008) and Eucalypt (Silva et al., 2009), as well as in grapes (Piva et al., 2014), and radishes (Bonfim-Silva et al., 2015), among others. Biomass ash can improve soil physical properties, changing aeration, water retention ability, and salinity (Demeyer et al., 2001). Moreover, the greatest benefits of this byproduct is the reduction of soil acidity, which involves a decrease in H+Al contents while increases pH, and improves fertility by increasing calcium, magnesium, phosphorus and potassium contents (Sofiatti et al., 2007; Maeda et al., 2008; Ferreira et al., 2012; Silva et al., 2009).

Gullón (2004) also states that such residues can be good alternatives for the correction of soil acidity, with results similar to those of liming, among which, ashes resulting from the incineration of eucalypt or other wooden sources used as raw materials for energy production in many enterprises (Gullón, 2004).

The importance of eucalypt plantations for the renewable energy sector with the need to assure more efficient plantations (in the sense of obtaining high yields with more sustainable production techniques), corroborate the possibility and advantages of using alternative sources for the correction of soils, favoring the development of plantations, such as ashes originating from the combustion of its own wood (Müller, 2005).

Another element that deserves mention in the context of improving conditioning of acidic soils is silicon, which plays a significant role on physiological, structural and biochemical development of plants (Fonseca et al., 2009).

Despite the known effects of silicon for cultivated plants, there are no reports about the potential of vegetative ash biomass as silicon sources. The effect of vegetative ash biomass on the soil varies according to ash composition and amount applied and soil type, among other factors (Gullón, 2004; Pitman, 2006). Moreover, even if soil acidity reduction is intrinsically related to the correction of the 'deficit' of essential elements, such as calcium and

magnesium (Maeda et al., 2008), the effect of silicon must be taken into account.
Lima Filho (2008) states that silicon is an important element for soil management, and those vegetative ashes are a source for this element since the Roman Empire. Rice, and other cereal, husk ashes are mention by that author as the first silicate fertilizer used by mankind.
Since ashes from different vegetative sources, containing different proportions of wood, bark and leaves, may supply different amounts of silicon along with other nutrients, and may have different impact on soil properties, this study evaluated the potential of vegetative ash biomass from different forest species and sugar cane bagasse as silicon source and as soil acidity reduction agents.

Results and Discussion

Chemical characterization in sandy and clayey soils as a function of ash types

Silicon availability for both soils (LVd and RQo) varied according to ash composition (Table 1). In general, only eucalypt ash (consisting of twigs and leaves) and pine increased Si contents in relation to the control (Table 2).
For the sandy soil, regardless of dose (200 or 400 kg ha^{-1}) the ash of pine wood and bark (PWB) had 23% more available Si than the ash of eucalypt twigs and leaves (ETL). Greater Si availability was found after PWB application, at the greatest dose (400 kg ha^{-1}), in the clayey soil. Among all ashes, the one from PWB had the lowest total Si (1%). In spite of that, all that silicon was soluble (1%), justifying the greater presence of this element in soil after the application of either dose in comparison with the other sources.
For both soil types (LVd and RQo), Ca and Mg contents were affected by ash sources and doses applied, except for the sugarcane bagasse (SCB). Regardless of the dose (200 or 400 kg ha^{-1}), these ashes did not increase Ca and Mg contents in comparison with the control.
Oliveira (2015) found that Ca, Mg, K and Na contents were not affected by the application of different doses of SCB. According to that author, this effect can be explained by the concentration of these nutrients in the chemical composition of SCB ash.
In contrast, at the greatest dose (400 kg ha^{-1}) both eucalypt ashes and pine ash supplied more Ca and Mg to both soils. The eucalypt ashes supplied, on average, 23and 17% more Ca to Sandy and clayey soils, respectively, in comparison with pine ashes.
Among the eucalypt ashes, the one comprised of twigs and leaves (ETL) supplied 41 and 49% more Mg to sandy and clayey soils, respectively, in relation to the ash from eucalypt wood and bark (EWB). Pine ash (PWB) supplied Mg similarly to the eucalypt twig and leaves (ETL) one.
In general, only eucalypt ashes, at the greatest dose (400 kg ha^{-1}) reduced Sandy soil acidity, in comparison with the control. The ash EWB raised pH from 4.01 to 5.47; while ETL raised it to 6.27. In contrast, the ashes did not increase pH in the clayey soil. It is important to highlight that eucalypt ashes supplied more Ca. According to Chirenje and Ma (2002), calcium present in the ashes promotes an alkaline action, contributing for the soil acidity correction.

The application of increasing Wollastonite doses to soils LVd and RQo promoted a linear increase in silicon contents (Fig 1A, Fig 1B).

Equivalent dose of Wollastonite and Agricultural Efficacy Index as a function of different ashes applied to sandy and clayey soils.

Efficacy was done with values of the equation obtained by the regressions, as functions of different ashes applied to sandy and clayey soils (Table 3).
In general, in the sandy soil, at the dose 200 kg ha^{-1}, the ashes presented greater Agricultural Efficacy Index than Wollastonite, since values above 100% efficacy of the standard source were obtained. In this soil, silicon availability provided by the ashes was more effective than the standard source since doses, of the standard, above 200 kg ha^{-1} would be required to achieve similar values as the ashes. In contrast, at 400 kg ha^{-1} this pattern reverses, and the efficacy of silicon supply in relation to Wollastonite decreases, remaining near to (such as 73.25% for EWB) or above 100%.
Such results indicate that, at the dose 200 kg ha^{-1}, the ash sources present good perspective as alternative fertilizers. However, this trend was not observed with sugarcane bagasse, demonstrating the low efficacy of this ash in supplying silicon to either soil.
In contrast, in the clayey soil, Wollastonite had lower equivalent doses than any of the ashes, confirming the superiority of the standard source in supplying Si to this soil (Table 3).
It was noteworthy that pine ash supplied more silicon to sandy soil (AEI= 579.2%) and clayey soil (AEI= 71.7 %), in comparison with the same dose (200 kg ha^{-1}) of the standard source Wollastonite.
In general, the use of vegetative ash biomass as fertilizer is an excellent alternative, both from the agricultural and environmental standpoints. All the ashes evaluated in this study could be applied to soils for agricultural purposes, and is a sustainable manner of disposing of residues. Moreover, soil chemical properties (pH, Ca, Mg, Si) improved with the use of eucalypt (EWB; ETL) and pine (PWB) ashes in both doses (200 and 400 kg ha^{-1}) used, although pine ash (PWB) provided greater amounts of Si at the dose of 400 kg ha^{-1}.

Material sand methods

Local of experiment

The experiment was done in a greenhouse, located at 18°91'86" S and 48°27'72" W, at an altitude of 800 m, at the Institute of Agricultural Sciences of Universidade Federal de Uberlândia (ICIAG), Campus Umuarama, from November 19 to December 19, 2014 in Uberlândia-MG.

Vegetative ash biomass and control

Vegetative ashes biomass from three different industries, which use eucalypt wood and bark (EWB), eucalypt twigs and leaves (ETL), pine wood and bark (PWB) or sugar cane bagasse (SCB) in their boiler plants were evaluated (Table1). Also, a control treatment (with no fertilizer), and a standard

Table 1. Chemical analysis of vegetative ash biomass.

Analyses	DRY BASIS – 110ºC	[1]EWB	ETL	PWB	SCB
Calcium (total Ca)	%	17.65	23.70	1.62	1.20
Magnesium (total Mg)	%	2.53	7.16	0.69	0.81
Total Si	%	12.00	7.00	1.00	16.00
Soluble Si	%	3.00	3.00	1.00	3.00
NATURAL MOISTURE					
pH $CaCL^2$ 0.01M		12.00	8.90	10.20	8.90

[1]Ash sources: eucalypt wood and bark (EWB), eucalypt twigs and leaves (ETL), pine wood and bark (PWB) and sugar cane bagasse (SCB).

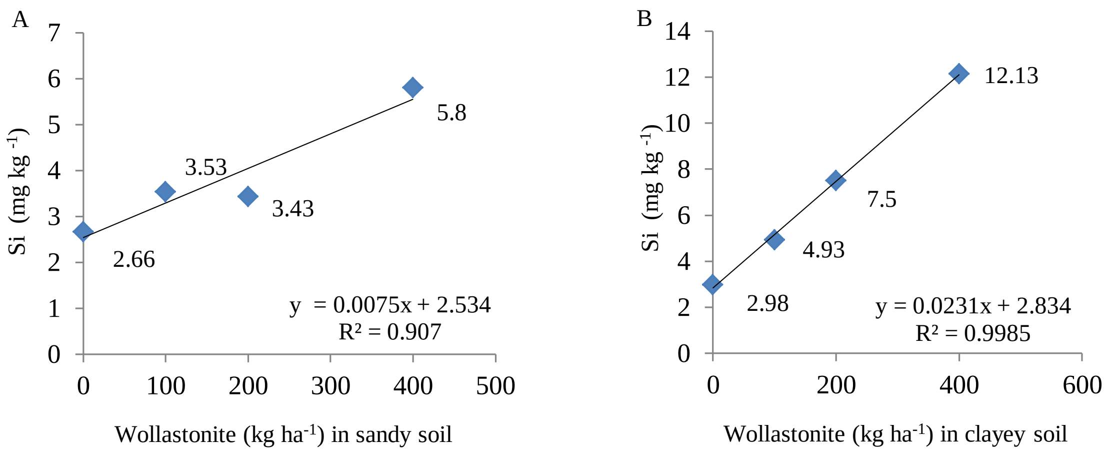

Fig 1. Silicon contents, extracted with $CaCl_2$ (0.01 mol L^{-1}), in sandy (A) and clayey (B) soils, as a function on increasing Wollastonite doses, after incubation for 30 days.

Table 2. Averages of pH, Ca, Mg and Si in Sandy and clayey soils as a function of different ash types in comparison with the control.

Ash	pH			Ca (cmolcdm^{-3})		Mg (cmolc dm^{-3})		Si (mg kg^{-1})		
	Doses (kg ha^{-1})		Average	Doses (kg ha^{-1})		Doses (kg ha^{-1})		Doses (kg ha^{-1})		Average
	200	400		200	400	200	400	200	400	
SANDY SOIL										
[1]EWB	4.28^{ns}	5.47*	4.87 a	1.36abB*	2.08 aA*	0.27 bB*	0.41 bA*	4.3^{ns}	4.96^{ns}	4.63 bc
ETL	4.71^{ns}	6.27*	5.49 a	1.60 aB*	2.29 aA*	0.47 aB*	0.70 aA*	5.72*	6.47*	6.09 b
PWB	4.52^{ns}	5.22^{ns}	4.87 a	1.14 bB*	1.69 bA*	0.37 abB*	0.65 aA*	7.12*	8.77*	7.95 a
SCB	3.98^{ns}	4.07^{ns}	4.02 b	0.66 cA^{ns}	0.65 cA^{ns}	0.14 cA^{ns}	0.16 cA^{ns}	2.94^{ns}	3.19^{ns}	3.07 c
Average	4.37 B	5.26 A		-		-		4.6	5.32	
Control	4.01			0.73		0.13		2.66		
CLAYEY SOIL										
EWB	5.53^{ns}	5.98^{ns}		1.07 bB*	1.81 aA*	0.21 cB*	0.32 cA*	4.10 bcA^{ns}	3.93 bA^{ns}	
ETL	5.09^{ns}	6.49^{ns}		1.59 aB*	1.96 aA*	0.50 aB*	0.63 aA*	5.38 abA*	4.92 bA*	
PWB	5.03^{ns}	4.82^{ns}		1.13 bB*	1.57 bA*	0.35 bB*	0.55 bA*	6.22 aB*	7.97 aA*	
SCB	5.01^{ns}	5.01^{ns}		0.65 cA^{ns}	0.62 cA^{ns}	0.14 dA^{ns}	0.15 dA^{ns}	3.67 cA^{ns}	3.97 bA^{ns}	
Average				-		-		-		
Control	5.18			0.59		0.13		2.98		

Averages followed by the same letter, lower case in the column and upper case ones in the row, do not differ by the Tukey test at 0.05 significance. *: significantly different from the control by the Dunnett test at 0.05 significance; ns: non significant by the Dunnet test. [1]Ash sources: eucalypt wood and bark (EWB), eucalypt twigs and leaves (ETL), pine wood and bark (PWB) and sugar cane bagasse (SCB). There are two statistical tests applied here. Tukey's test compared all the treatments among themselves, and upper case letters compare averages in the row, while lower case letters compare averages in the columns. Dunnett's test compared each treatment with the control, thus the symbol * refers to significant difference between that treatment and the control, while ns denoted that there is no significant difference of that treatment with the control.

Table 3. Equivalent dose of Wollastonite (W) and Agricultural Efficacy Index (AEI), as a function of different ashes applied to sandy and clayey soils.

Ash	Dose (kg ha^{-1})	Sandy Soil Si (mg kg^{-1})	Sandy Soil W[1] (kg ha^{-1})	Sandy Soil AEI[2] (%)	Clayey Soil Si (mg kg^{-1})	Clayey Soil W[1] (kg ha^{-1})	Clayey Soil AEI[2] (%)
[1]EWB	200	4.30	235.47	212.99	4.10	39.44	24.78
	400	4.96	323.47	73.25	3.93	34.14	10.38
ETL	200	5.72	424.80	397.40	5.38	79.31	53.10
	400	6.47	524.80	121.34	4.92	64.98	21.20
PWB	200	7.12	611.47	579.22	6.22	105.48	71.68
	400	8.77	831.47	194.59	7.97	160.00	54.54
SCB	200	2.94	54.13	36.36	3.67	26.04	15.27
	400	3.19	87.47	16.88	3.97	35.39	10.82

[1]W: Equivalent dose of Wollastonite, given by the equations y= 0.0075x + 2.534 and y= 0.0231x + 2.834 for sandy and clayey soils, respectively; AEI: Agricultural Efficacy Index of ashes in relation to Wollastonite. [1]Ash sources: eucalypt wood and bark (EWB), eucalypt twigs and leaves (ETL), pine wood and bark (PWB) and sugar cane bagasse (SCB).

Table 4. Chemical characterization of the samples of a distrophyc Oxisol soil (LVd) and a Ustox typical soil (RQo) used in the incubation experiments.

Soil	Si	Ca	Mg
	mg dm^{-3}	-------------cmol$_c$dm^{-3}---------	
LVd	6.0	0.1	0.1
RQo	3.1	0.1	0.1

Ca, Mg = (KCl 1 N); Si = ($CaCl_2$ 0,01mol L^{-1})

Table 5. Amount of silicon (Si), Calcium (Ca) and Magnesium (Mg) of each ash source added to the an Oxisol soil (LVd) and an Ustox typical soil (RQo) to obtain the doses evaluated.

Source/Material	Si Dose	Amount of source	Amount of Cain the source	Amount of Mg in the source
	kg ha^{-1}	g/300g soil	g/300g soil	g/300g soil
[1]Control	0	0	0	0
Wollastonite	100	0.072	0.022	0.001
Wollastonite	200	0.145	0.044	0.002
Wollastonite	400	0.290	0.088	0.003
EWB	200	0.250	0.044	0.006
EWB	400	0.500	0.088	0.013
ETL	200	0.429	0.102	0.031
ETL	400	0.857	0.203	0.061
PWB	200	3.000	0.049	0.021
PWB	400	6.000	0.097	0.041
SCB	200	0.188	0.002	0.002
SCB	400	0.375	0.005	0.003

[1]Ash sources: eucalypt wood and bark (EWB), eucalypt twigs and leaves (ETL), pine wood and bark (PWB) and sugar cane bagasse (SCB).

treatment for supplying silicon to soils (Calcium Silicate - $CaSiO_3$ - Wollastonite) were used.

Wollastonite is classified as a natural calcium metasilicate containing high levels of $CaSiO_3$ and high purity, used worldwide as the standard source of silicon for Si experiments (Ramos, 2005).

Experimental procedures

Vegetative ashes biomass and Wollastonite were applied to two soil types: distrophyc Oxisol soil (LVd) and a Ustox typical soil (RQo), for the incubation test (MAPA, 2010). Before ash addition, silicon contents were 6.0 and 3.1 mg dm^{-3} for the LVd and RQo, respectively, and0.1 cmol$_c$dm^{-3} of Ca and Mg for both soils (Table 4).

Ashes and Wollastonite were ground to pass through a 50 mesh sieve before addition into 300 g of air dried fine soil, and were homogenized and moistened to field capacity. The ash doses added to the soils were based on total silicon contents, applied at the doses of 200 and 400 kg ha^{-1}. Wollastonite was applied at the doses of 100, 200 and 400 kg ha^{-1} (Table 5).

After reaction with the soil for 30 days (incubation period), the samples were dried and sieved, and soluble Si determined by extraction with $CaCl_2$ 0.01 mol L^{-1}, according to Korndörfer et al. (2004). The analyses of pH in $CaCl_2$ 0.01 mol L^{-1}, and exchangeable Ca and Mg followed the method described by EMBRAPA (1997).

Experimental design and statistical analysis

The experimental design of both experiments (LVd and RQo) was completely randomized, as a 4x2+1 factorial, with four ash sources (EWB, ETL, PWB, and SCB) and two doses (200 and 400 kg ha^{-1}) and a control (with no Si source), with three replications. Each experimental unit consisted of a plastic pot containing 300g of air dried and sieved soil, capped with a perforated lid.

The assumptions of homogeneity of variances (Levene's test) and normality of residues (Shapiro-Wilk's test) were confirmed, and the data analyzed with two independent purposes. First, the performance of the sources in supplying Si to the soil and their effect on soil acidity reduction; and second, the efficacy of the ashes in relation to Wollastonite.

For the first analysis, qualitative data (ash sources) were subjected to the analysis of variance (F=0.05), and the averages compared by the Tukey test ($p \leq 0.05$), and for the control treatment, Dunnett's test ($p \leq 0.05$) was applied. The second analysis, the study comparing with Wollastonite doses, was done by regression analysis to obtain a standard curve for Wollastonite and, from this standard curve, the corresponding reactivity of the sources evaluated was estimated. Thus, with the values of the curve, the relative efficacy of the sources in relation to Wollastonite was calculated for both soil types.

This evaluation applied the concept of Agricultural Efficacy Index (AEI), described by Goedert et al. (1986), in which AEI is determined based on the production differential achieved between the sources compared with the same dose of a standard source. In this study, production was expressed as pH and nutrient (Ca, Mg or Si) concentration found in the soil.

$$AEI = \frac{[X(Treatment) - X(Control)]}{[X(Wallastonite) - X(Control)]}$$

Where: X= Variable analyzed (pH, Ca, Mg or Si) at the dose under analysis (200 or 400 kg ha^{-1}).

The qualitative analyses were done with Sisvar (Ferreira, 2011) and Assistat (Silva et al., 2009).

Conclusion

The use of ashes from pine and eucalypt twigs and leaves increased soil contents of Si, Ca and Mg. Pine ashes supplied more Si to both soils. In contrast, ashes from eucalypt supplied more Ca and Mg. Sugarcane bagasse ash did not increase Ca and Mg availability, regardless of the dose. Sandy soil acidity was reduced after application of eucalypt ashes at the greatest dose (400 kg ha^{-1}), while no significant pH change was observed in the clayey soil.

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