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ORIGINAL ARTICLE

Filter cake enhances soil fertility and initial growth of wheat cultivated in a sandy Ultisol

Torta de filtro incrementa a fertilidade do solo e o desenvolvimento inicial de trigo cultivado em Argissolo arenoso

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ABSTRACT: The use of mineral fertilizer on wheat is frequent, which can cause complications to crop and environment. That said, the use of organic fertilizers are welcome, as filter cake, a by-product from processing sugar-cane, which provides nutrients, increasing the soil pH and neutralizing the aluminum exchangeable. The objective was to evaluate the soil fertility and initial development of wheat as a function of the filter cake rates and to indicate a proper rate of filter cake for wheat plants grown in a sandy Ultisol from Northwest of the State of Paraná. Coodetec CD104 wheat variety planted on PVC columns measuring 200mm x 20cm, added the rates of 0, 5, 10, 20, 40 and, 80 g dm^{-3} of filter cake on each column. Filter cake fertilization increased phosphorus available and soil pH ($CaCl_2$), as consequence, provided a significant increase in the number of tillers, fresh and dry shoots mass and on total root length, with maximum development of the crop using filter cake at rate of 76.26 g dm^{-3} (equivalent of 152.52 t ha^{-1}).

KEYWORDS
Fertilizing indicators
Industrial by-products
Organic fertilizers
Triticum aestivum

RESUMO: *O uso de adubação química na cultura do trigo é frequente e pode acarretar complicações à cultura e ao ambiente. Diante disso, a utilização de adubos orgânicos é bem vista, como a torta de filtro, um produto secundário do processamento da cana-de-açúcar que fornece nutrientes, eleva o pH e neutraliza o alumínio no solo. Este trabalho objetivou avaliar a fertilidade do solo e o desenvolvimento inicial de trigo em função de doses de torta de filtro e indicar uma dose efetiva de torta de filtro para plantas de trigo cultivadas em um Argissolo arenoso do Noroeste do estado do Paraná. Semeou-se a variedade Coodetec CD 104 em colunas de PVC, medindo 200 mm x 20 cm, e adicionaram-se 0, 5, 10, 20, 40 e 80 g.dm^{-3} de torta de filtro em cada coluna. A fertilização com torta de filtro aumentou o nível de fósforo e o pH $CaCl_2$ no solo, em consequência, promoveu um acúmulo significativo no número de perfilhos, na massa fresca e seca de plantas e no comprimento total de raízes, com o máximo desempenho da cultura quando se utilizou a dose de 76,26 g.dm^{-3} (equivalente a 152,52 t.ha^{-1}) de torta de filtro.*

PALAVRAS-CHAVE
Indicadores de fertilização
Resíduos industriais
Fertilizantes orgânicos
Triticum aestivum

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1 Introduction

To raise wheat crop productivity in the world, it has been used mineral fertilizers on crops (Fornasieri Filho, 2008). However, these products usually present high cost and, when used higher doses than recommended, can cause contamination to the environment by the possible leaching of nitrates into groundwater (Teixeira Filho et al., 2010), and complications in cultivation, as damping and difficulties of mechanized harvesting (Fornasieri Filho, 2008). Through that, it justifies seeking alternatives like organic fertilizers that can provide nutrients for the development of commercially valuable crops.

The filter cake is obtained in the filtering process during the refinement of sugar, at a rate of 30kg of filter cake each tonne of sugar (Adorna et al., 2013). This residue can be used as a fertilizer because it is rich in nutrients such as phosphorus (1.1%), nitrogen (2.0%) (Vitti et al., 2006; Fravet et al., 2010), potassium (0.3%), magnesium (0.6%) and calcium (2.1%) (Prado et al., 2013). The use of filter cake as fertilizer can contribute to the reduction of fertilizer costs and viability of this industrial by-product in agriculture. Thus, the filter cake can be used for the recovery of soil fertility, replacing totally or partially the use of the mineral fertilizers (Santos et al., 2011; Prado et al., 2013).

In addition to the increase of nutrients in the soil, the filter cake is capable of reducing the Al^{+3} exchangeable (Nolla et al., 2015), by its adsorption on the surface of the organic matter (Hoyt & Turner, 1975). Fertilization with filter cake can also raise the soil pH (Nolla et al., 2015), unlike the amide and ammonium fertilizers that cause soil acidity (Almeida Junior et al., 2011). The filter cake can also benefit some soil physical properties, such as index stability and weight average diameter of aggregates (Vasconcelos et al., 2010). However, the indiscriminate application of by-products of organic and industrial sources on the soil can cause an increase of heavy metals on soil (Singh & Agrawal, 2008), justifying studies testing proper rates of this fertilizer.

The wheat crop is responsive to high nutrients available in the soil, which has shown positive responses to organic fertilizers, especially sources with high phosphorus concentration like filter cake, which is capable of raising the available phosphorus on soil (Almeida Júnior et al., 2011) and, the development of crops, as maize crops (González et al., 2013), sugarcane (Almeida Júnior et al., 2011) and also in the lettuce crops (Santi et al., 2013).

The phosphorus is the most important nutrient to improve highest development on wheat crop (Massaroto et al., 2007). However, there are few studies in the literature using filter cake as fertilizer in the wheat crop, which justifies research to establish parameters for the use of filter cake in attempt to increase the wheat growth.

The objective was to evaluate the soil fertility and initial development of wheat as a function of the filter cake rates and indicate a proper rate of filter cake for wheat plants grown in a sandy Ultisol from Northwest of State of Paraná.

2 Materials and Methods

The experiment was carried out at open field, from March to June, 2015, on the experimental area of Umuarama Regional Campus of the State University of Maringá, located at S 23º47'20.4"; W 53º15'25.2" and altitude of 396m above sea level. The climate area is classified as Cfa - with hot summer, annual rainfall between 1300-1600mm and, annual mean temperature between 20-22 °C (Alvares et al., 2013).

The soil used in the experiment was a typical Red Ultisol with sandy texture (Table 1), which filled 20cm diameter x 20cm height PVC columns.

The soil acidity correction was performed with addition of 1.03g of lime dm^{-3} (100% PRNT), enough rate to increase bases saturation to 70% (Aguiar et al., 2014), the columns were incubated (with moisture near of field capacity) by 45 days to lime reaction and then the treatments where applied. The treatments consisted of filter cake rates of 0, 5, 10, 20, 40 and 80 g dm^{-3} (representing the addition of 0; 10; 20; 40; 80 and 160 t ha^{-1}, respectively), totalizing 24 experimental units. The columns were incubated for another 15 days to accelerate the reaction of the filter cake applied.

The experimental design used was the randomized block with four replications.

The wheat variety used was Coodetec CD 104. The sowing was initiated on March 15th, 2015. Twelve (12) days after sowing, rouging of plants was performed, keeping nine plants in each column (equivalent to 300 plants m^{-2}). The seeds were treated with an insecticide composed by Imidacloprid 150 g L^{-1} + Thiodicarb 450 g L^{-1}, at a rate of 2 mL of the commercial product per 1 kg of seeds.

The columns were irrigated during the cultivation period with the application of 1.000 mLper column (equivalent to 8mm precipitation) three times a week. After 45 days of sowing, the plants were cut to the ground and it were evaluated the fresh and dry shoots production, average of plant height and the total number of tillers in the column. The soil and roots were separated, obtained a dry and fresh weight of the root system. When the fresh root mass was evaluated, a sample of root system was picked up, which was frozen for later determination of the root system length (Tennant, 1975) and estimate the average radius of roots (Barber, 1995).

Table 1. Soil chemical attributes and sand content (0-20 cm) of a Ultisol used in the experiment[1].

Tabela 1. Atributos químicos e físicos de um Argissolo utilizado no experimento.

pH	Ca^{+2}	Mg^{+2}	K^{+}	SB	Al^{+3}	$H^{+}+Al^{+3}$	CEC	P	Clay	Silt	Sand
$CaCl_2$	$cmol_c\ dm^{-3}$							mg dm^{-3}	%		
4.10	0.34	0.13	0.04	0.93	0.93	3.18	3.69	3.14	24.16	1.28	78.56

[1]SB: sum of bases, $H^{+}+Al^{+3}$: potential acidity, CEC: cationic exchange capacity at pH 7.0. Extractors: P and K Mehlich-1; Ca^{+2}, Mg^{+} and Al^{+3} KCl 1 mol L^{-1}; Soil particle size analysis based on Bouyoucos (1926).

The soil samples of experimental units were taken at depths from 0 to 10cm, dried and sieved (2mm). It was analyzed soil pH in the water and calcium chloride; exchangeable aluminum (Al^{+3}), using the KCl extractant (1 mol L^{-1}); phosphorous (P) and potassium (K) available, using the Mehlich-1 (HCl 0.05mol L^{-1} + H_2SO_4 0.0125 mol L^{-1}) extractant. The soil analysis followed the methodology from Embrapa (2011).

The results were submitted to analysis of variance by F test and when significant, the values were submitted to regression analysis which was tested the adjustments to linear and quadratic models.

3 Results and Discussion

For soil variables availed, the variance analysis showed significance to phosphorus (P) available and pH in $CaCl_2$ as a function of filter cake rates (Figure 1), but it did not to potassium (K), exchangeable aluminum (Al^{+3}) and pH in H_2O. The regression analysis for the pH $CaCl_2$ and phosphorus available has proceeded. There was a significant adjustment to the linear model at 1% probability for both variables (Figure 1A and Figure 1B).

The addition of filter cake rates increased linearly the pH in $CaCl_2$ and P available (Figure 1A and 1B, respectively), thus not reaching the stability with evaluated rates, indicating that the increase in those parameters should continue progressing linearly with increasing rates of the filter cake. When the pH was increased over 6.0 (what occurred in this experiment due to addition of lime, and potentiated by higher filter cake rates) the level of toxic aluminum (Al^{+3}), was reduced to zero, due the increase of radical anions (OH^-) promoted by lime and filter cake, that now are free in the soil (Furtini Neto et al., 2001).

The opposite results in pH, which the pH in $CaCl_2$ were positive significant to addition of filter cake rates, and the pH in H_2O, were not significant (H_2O), can be explained due to the more accurate analysis provided by the $CaCl_2$ solvent, which has a salt content more stable than the H_2O as solvent (Furtini Neto et al., 2001).

The raise of the pH in $CaCl_2$ as the filter cake rates increased (Figure 1A), can be explained by the release of carbon dioxide (CO_2) provided by the filter cake organic matter's degradation. After the degradation, the free protons at soils, as H^+, for example, are consumed to compensate this CO_2 intake. That effect, unbalance the concentration of anions and protons, resulting in a higher concentration of hydroxyls (OH^-) in the soil, increasing the pH (Nolla et al., 2015). The present results of the pH as a function of filter cake rates corroborate with Arreola-Enriquez et al. (2004), who observed a progressive increase in pH when using higher filter cake doses at a 6.0 pH and, 38% clay soil, cultivating sugarcane.

There was a linear increase in the phosphorus available according to the filter cake rates applied in the soil (Figure 1B). This is explained by the high phosphorus -concentration in the filter cake used (Table 2) that is released during the organic matter mineralization process, that releases P to soil solution (Novais et al., 2007). The highlight observed in this experiment, was the fast availability of this element by filter cake, which even with the short period of evaluation of this experiment (45 days after applying the filter cake), there was a significant increase in the phosphorus available in the soil. That fast release agrees with Arreola-Enriquez et al. (2004), who observed the release of more than 60% of P content from filter cake to the soil, at the first year of evaluation.

On analysis of potassium levels significance were not found on filter cake doses evaluated. This could be explained by the irrigation used, which may have lixiviated the potassium released by the filter cake and by the low K content of the filter cake

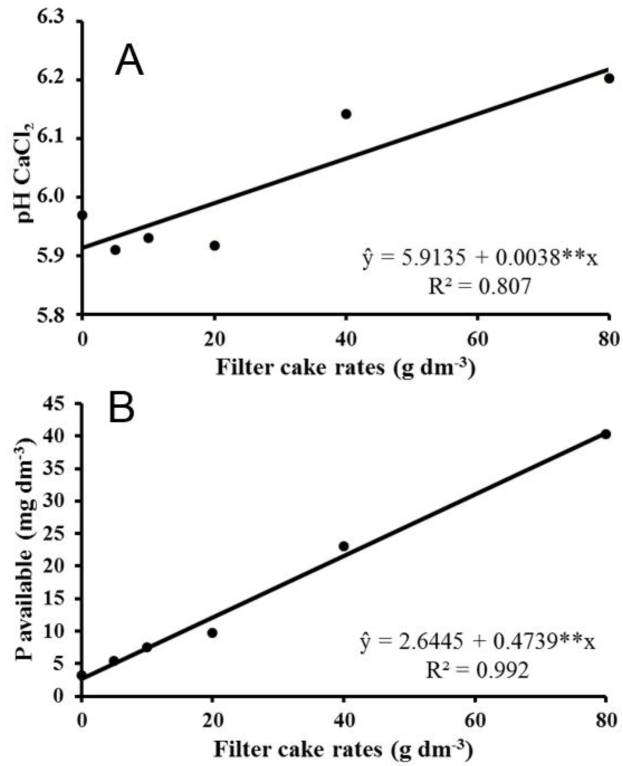

Figure 1. (A) pH in $CaCl_2$ and (B) phosphorous available (mg dm^{-3}) as a function of filter cake rates (g dm^{-3}) applied in the soil. **: $p \leq 0.01$ model adjustment significance.

Figura 1. (A) pH em $CaCl_2$ e (B) fósforo disponível (mg dm^{-3}) em função de doses de torta de filtro (g dm^{-3}) aplicadas no solo. **: $p \leq 0.01$ significância do ajuste ao modelo.

Table 2. Concentrations of organic matter (OM), pH, mineral nutrients and C/N ratio quantified in the filter cake of sugarcane plant from Umuarama-Paraná region, Brazil, used in the experiment.

Tabela 2. Concentração de matéria orgânica (OM), pH, nutrientes minerais e relação C/N na torta de filtro oriunda de uma usina de cana-de-açúcar da região de Umuarama-Paraná, Brasil, usada no experimento.

Determinations	Filter Cake
OM (%)	16.00
pH H_2O	7.00
N (%)	0.23
P (%)	0.92
K (%)	0.06
Ca (%)	2.12
Mg (%)	0.41
S (%)	0.01
C/N Relation	40.0

used (Table 2), which represents only 42% of the K content of the filter cake used by Almeida Júnior et al. (2011), who observed increase on K content of the soil, using filter cake rates at a 40% clay soil.

The radicular system was benefited by the addition of filter cake on the soil, resulting in quadratic adjust model significant response to the roots fresh (Figure 2A) and dry (Figure 2B) mass and, at total roots length (Figure 2C). That benefit was probably due to increase in phosphorus available in the soil (Figure 1B), which induces a better root development.

The phosphorus is an important element for radicular system development (Malavolta et al., 2002), because it is an immobile element in the soil and, when deficient in the soil, it forces the plants to redirect the carbohydrates to roots expansion, turning that in to a leach of the plant (Araújo & Machado, 2006). That importance can be observed at the initial development of wheat plants (Tinoco et al., 2014). Adding to that, one of the characteristic symptoms of phosphorus deficiency in plants presents itself as a reduction in the development of the radicular system (Grant et al., 2001).

The effect observed in this experiment was potentiated because the positive effect of fertilization with phosphorus in grasses is enhanced when the soil has low phosphorus available (Sant'Ana et al., 2003), as occurred in this present experiment (Table 1).

For the shoots variables evaluated, it was found significance for Fresh (Figure 3A) and Dry (Figure 3B) shoots mass and, for the Average plant height (Figure 3C) and for the Total number of tillers (Figure 3D), which were all enhanced as the filter cake rates raised, resulting in a quadratic adjust model for all variables. The phosphorus is crucial to plant development because it acts on photosynthesis, plant respiration, transportation of energy, division and growth of plant cells (Dechen & Nachtigall, 2006).

The results observed corroborate Silva et al. (2010), who observed higher height of wheat plants due to the increase in phosphorus fertilizer dose applied on the soil which has initially, 30% clay and, 65 mg dm^{-3} of P available.

The higher P available on the soil probably favored the development of wheat plants, because when the soil is deficient on P, the number of tillers is reduced (Araújo & Machado, 2006).

With the values observed in the experiment, it is possible to determinate the optimal rate of the filter cake for the best development of the wheat plants (Table 3), using the derivative of the regression equation Roots fresh (Figure 2A) and Dried (Figure 2B) mass and Average plant height (Figure 3C). The optimum estimated rate of filter cake was 76.22 g dm^{-3} (equivalent to 152.24 t ha^{-1}). The optimum estimated rate is also higher than other crops recommendations, like the data provided by Fravet et al. (2010), using an already cultivated Oxisol that contents 35.3% of clay, settled the best sugarcane yield with the filter cake application of 57t ha^{-1}. Silva et al. (2013) evaluated the effect of filter cake applied at a Oxisol with 66.4% of clay, under the lettuce cultivation, had the best

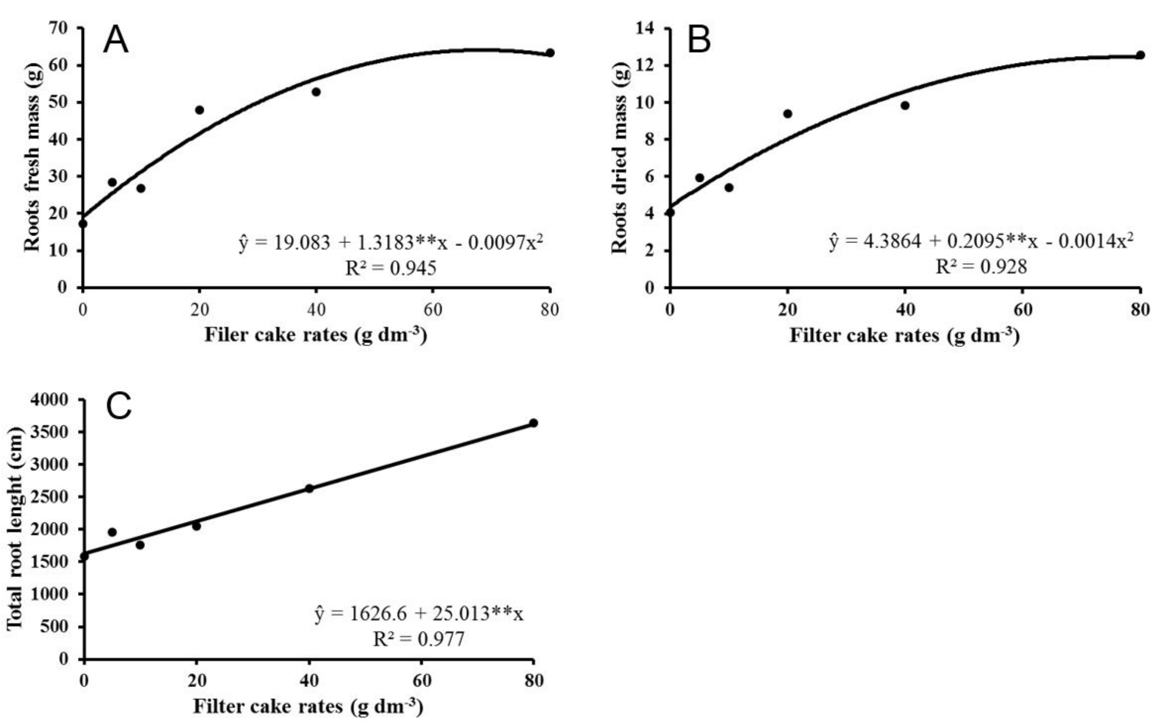

Figure 2. (A) Roots fresh and (B) Dry mass (g $column^{-1}$) and (C) Total root length (cm) of wheat plants as a function of filter cake rates (g dm^{-3}) applied in the soil. **: $p \leq 0.01$ model adjustment significance.

Figura 2. (A) Massa fresca e (B) seca (g $coluna^{-1}$) e (C) Comprimento total de raízes (cm) de plantas de trigo em função de doses de torta de filtro (g dm^{-3}) aplicadas no solo. **: $p \leq 0.01$ significância do ajuste ao modelo.

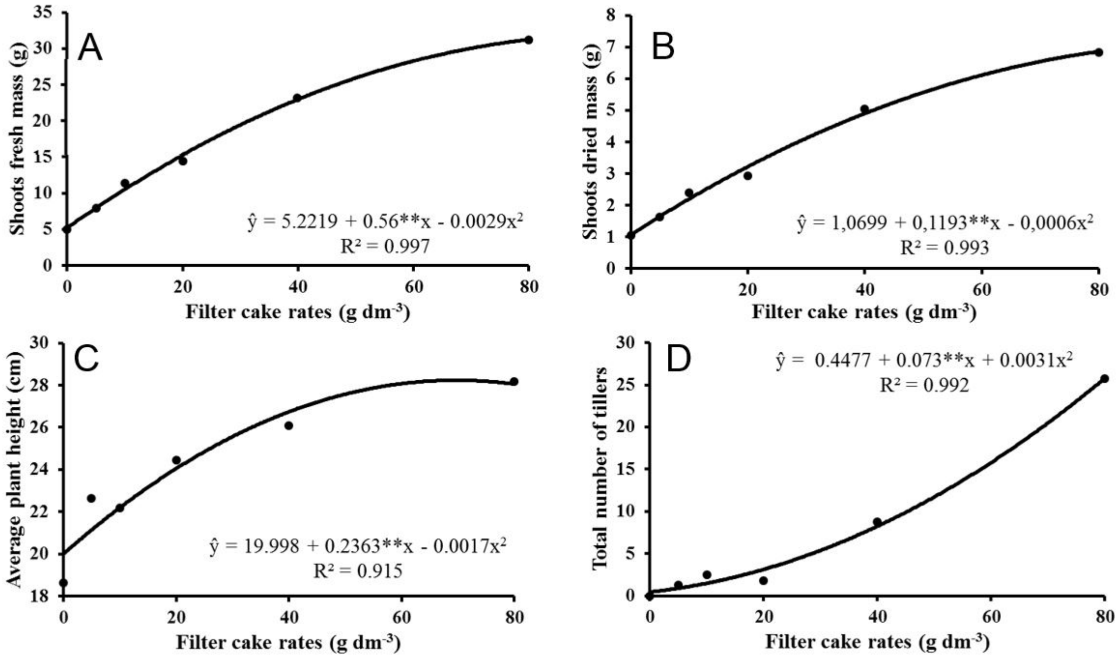

Figure 3. (A) Shoots fresh (g column^{-1}) and (B) Dried mass (g column^{-1}), (C) Average plant height (cm) and, (D) Total number of tillers of wheat plants as a function of filter cake rates applied in the soil. **: $p \leq 0.01$ model adjustment significance.

Figura 3. (A) Massa fresca (g coluna^{-1}) e (B) Seca da parte aérea (g coluna^{-1}), (C) Altura média de plantas (cm) e (D) Número total de perfilhos de plantas de trigo em função de doses de torta filtro aplicadas no solo. Em que: **: $p \leq 0.01$ significância do ajuste ao modelo.

Table 3. Reference values of the filter cake rates at maximum efficiency reached by the fresh and dry mass of roots and average plant height of wheat grown in a sandy Ultisol from the region of Umuarama, State of Paraná, Brazil.

Tabela 3. Valores de referência de uso de torta de filtro nas máximas eficiências obtidas através da massa fresca e seca de raízes e da altura média de plantas de trigo cultivado em um Argissolo arenoso da região de Umuarama, estado do Paraná, Brasil.

Variable	Regression equation	Optimum rate (g dm^{-3})	Optimum dose (t ha^{-1})
Root fresh mass	$\hat{y} = 19.083 + 1.3183x - 0.097x^2$	68.24	136.48
Dried root mass	$\hat{y} = 4.3864 + 0.2095x - 0.014x^2$	87.25	174.50
Fresh aerial plant mass		-	-
Dried aerial plant mass		-	-
Average plant height	$\hat{y} = 19.998 + 0.2363x - 0.017x^2$	72.87	145.75
Total number of tillers		-	-
Average		76.12	152.24

crop yield at 30 t ha^{-1} dose. That result shows the wheat plants at the native soil of Umuarama region, that have a lower clay content (Table 2) and therefore they have a higher need of filter cake dose to achieve its top productivity potential.

4 Conclusions

This research showed that the filter cake fertilizer was able to elevate the phosphorus available and the pH in $CaCl_2$ of the soil. Both phosphorus available and the pH enhanced the growth of wheat plants by increasing the root system, resulting in a better development of shoots. The maximum development of the wheat plants by the filter cake application was 76.22 g dm^{-3} (equivalent to 152.24 t ha^{-1}) on a non-cultivated Ultisol from Umuarama–PR.

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