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ORIGINAL PAPER

Residual Contribution of Green Manure to Humic Fractions and Soil Fertility

Bianca de Jesus Souza[1] · Davi Lopes do Carmo[1] · Ricardo Henrique Silva Santos[2] · Teógenes Senna de Oliveira[3] · Raphael Bragança Alves Fernandes[3]

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Abstract

Green manure (GM) of jack bean can improve the quality of soil organic matter and increase soil fertility. The objective of this study was to evaluate the residual contributions of fertilisation with jack bean (*Canavalia ensiformis*) to (i) organic carbon (OC) and total nitrogen (TN) contents in the soil and in the humic fractions, (ii) the percentages of nitrogen (N) derived from GM (NdGM) applied at different seasons and rates and (iii) the chemical attributes of the soil at different depths. The treatments consisted of two rates of GM required by the coffee tree (146 and 584 g pot^{-1} of the dry mass of jack bean), two application seasons and one control. Seasons refer to fertilisations with enrichment of ^{15}N for each rate, applied in 2009 and 2010. Soil samples were collected at four depths for analysis of humic substances (HSs), NdGM and chemical attributes. In general, the organic carbon and total nitrogen contents in the soil and in the humic fractions increased with green manure fertilisation. We found higher percentages of residual nitrogen for the highest rate applied in 2010, 1 year after the first season in 2009. The humic substances, organic carbon and total nitrogen contents in the soil and organic carbon and total nitrogen contents in the humic fractions increased to a depth of 0.40 m in soil fertilised with jack bean. The residual nitrogen from jack bean in the soil is dependent on the rate and seasons of application. The residual contributions of the fertilisation with jack bean in the chemical attributes of the soil are dependent on the applied rate and the soil depth.

Keywords Oxisols · Nutrient recycling · Biological nitrogen fixation · Humic substances · *Canavalia ensiformis* · ^{15}N isotope

1 Introduction

In tropical regions, conventional soil management decreases the quantity and quality of organic matter. As a result, soil fertility is reduced, compromising the sustainable production of crops. Studies have pointed out this scenario (Spaccini et al. 2006; Navarrete and Tsutsuki 2008), which indicates inadequate soil management. In this sense, sustainable soil management practices need to be further developed and evaluated.

Green manure (GM) refers to the cultivation of plant species for the production of biomass to be deposited and/or incorporated into the soil, thereby increasing soil organic matter (SOM) contents, recycling nutrients and protecting the soil (Souza et al. 2012). In cases where GM consists of legumes, the nutrient supply through recycling is highlighted, especially in terms of biological nitrogen fixation (Sulieman and Tran 2014; Ciaccia et al. 2017). This approach reduces the costs and impacts of synthetic N fertilisation (Hödtke et al. 2016; Zhang et al. 2018). In general, the recovery of N from GM by crops is below 30% (Crews and Peoples 2005; Ambrosano et al. 2011), leaving significant amounts of residual nitrogen in the soil (Weber and Mielniczuk 2009; Mendonça et al. 2015).

Jack bean (*Canavalia ensiformis* (L) DC.) is among the most efficient legumes in terms of biomass production and N inputs into tropical soils (Fageria et al. 2013). It is characterised by a short growing cycle, an upright posture, and adapts to adverse soil and climatic conditions (Teodoro et al. 2011). The contributions of legume residues to soils are widely studied, but there are few studies evaluating the

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✉ Davi Lopes do Carmo
davigoldan@yahoo.com.br

[1] Programa de Pós-Graduação em Agroecologia, Universidade Federal de Viçosa, Viçosa, Brazil

[2] Departamento de Fitotecnia, Universidade Federal de Viçosa, Viçosa, Brazil

[3] Departamento de Solos, Universidade Federal de Viçosa, Viçosa, Brazil

residual contributions of jack bean to humic fractions and soil fertility. To accurately evaluate the residual nitrogen from GM and its soil profile dynamics, there is a fundamental requirement for the use of ^{15}N as a tracer (Ambrosano et al. 2011). In such cases, GM material is grown using fertiliser sufficiently enriched in ^{15}N, so as to detect soil recovery of residual nitrogen and its dynamics in the soil-plant system (Ambrosano et al. 2003).

Soil organic matter is crucial to sustainable agriculture due to its ability to act on the chemical, physical and biological attributes of soil (Chivenge et al. 2007; Johnston et al. 2009). It consists of 75% humic substances (HSs) (Santos et al. 2010), which are considered the main soil C reserve (Sutton and Sposito 2005). Humic substances are composed of colloidal materials such as humic acid (HA), fulvic acid (FA) and humin (H), with molecules that vary in elemental composition (C, H, N, O and S), molecular mass, the degree of polymerisation and the presence of functional groups, with the potential to develop electric charges (Stevenson 1994). These humic fractions have been used as parameters for the evaluation of organic matter quality and soil management (Guimarães et al. 2013).

In this sense, GM with jack bean can maintain and/or increase SOM and increase soil fertility, thereby reducing the dependence on industrial mineral fertilisers. In this context, the objective of this study was to evaluate the residual contributions of fertilisation with jack bean residuals to (i) organic carbon (OC) and total nitrogen (TN) contents in the soil and in the humic fractions, (ii) the percentages of nitrogen (N) derived from GM (NdGM) applied at different seasons and rates and (iii) the chemical attributes of the soil at different depths.

2 Material and Methods

The study was performed at the Campus of the Universidade Federal de Viçosa, in Zona da Mata, State of Minas Gerais, Brazil, located at 20° 45′ 14″ S and 42° 52′ 53″ W, at 650 m above sea level. According to the Köppen-Geiger classification, the climate is tropical, with cold and dry winters and hot and rainy summers. The average annual temperature is 19.4 °C, with a minimum of 14.8 °C and a maximum of 26.4 °C. Average annual precipitation is 1221 mm.

2.1 Experimental Conditions

The experiment was conducted in 60-L pots with one coffee plant (*Coffea arabica*, cv. Oeiras) per pot, in a drained environment. Coffee seedlings were transplanted with three pairs of leaves in March 2009 and were harvested in July 2011. The soil was composed of a B horizon of red-yellow oxisols from the region of Viçosa, Minas Gerais, located at 20° 45′ 24.23″ S and 42° 50′ 32.51″ W. Initial chemical characterisation, according to the protocols described in Silva (2009), provided the following results: pH in water = 6.4; P (Mehlich-1) = 4.4 mg dm^{-3}; K^{+} = 43.0 mg dm^{-3}; Ca^{2+} = 0.96 cmol$_c$ dm^{-3}; Mg^{2+} = 0.23 cmol$_c$ dm^{-3}; Al^{3+} = 0.0 cmol$_c$ dm^{-3}; H + Al = 1.0 cmol$_c$ dm^{-3}; effective cation exchange capacity (eCEC) = 1.3 cmol$_c$ dm^{-3}; CEC at pH 7 = 2.3 cmol$_c$ dm^{-3}; base saturation (BS) = 56.0% and OM = 26 g kg^{-1}. The granulometric composition was 58 g kg^{-1} silt, 382 g kg^{-1} clay and 560 g kg^{-1} sand, according to the pipette method (silt and clay) and sieving (sand), following the methodologies described in Teixeira et al. (2017).

The experiment was designed in randomised blocks, with five treatments and four replications. The treatments consisted of two rates of GM (146 and 584 g pot^{-1} of the dry mass of jack bean), two application seasons and one control (without GM). Each treatment was associated with 30% of mineral fertilisation required by the coffee tree. Seasons refer to fertilisations with enrichment of ^{15}N for each rate, applied in December 2009 and 2010. In the control, only 30% of the mineral fertilisation required for the coffee tree was applied, according to the recommendations of Guimarães et al. (1999), aiming to meet the minimum nutritional requirements for the survival of the plants until the end of the experiment. N concentrations, moisture content and details of the production of the enriched GM are presented in Araújo et al. (2014). Table 1 shows a description of the treatments and the contributions of N.

Prior to seedling transplanting, 63 g of P_2O_5 in the form of superphosphate (75%) and magnesium thermophosphate (25%) were applied to each pot, according to the recommendations for coffee plants (Guimarães et al. 1999). After the implementation of the experiment, all treatments received 30% of mineral fertilisation, according to Guimarães et al. (1999), based on the results of the soil analysis. For this, annually, four samples were collected per pot to a depth of 0.20 m. Liming was applied by applying 21 g pot^{-1} of dolomitic limestone and 20 g pot^{-1} of gypsum in August 2009. In September 2010 and January 2011, more rates of 27 g pot^{-1} of dolomitic limestone were applied. Post-planting (2009), first year (2009/2010) and production (2010/2011) fertilisation corresponded to 4.5, 6.3 and 9.0 g pot^{-1} of N with urea and 4.5, 9.0 and 9.3 g pot^{-1} of K_2O with potassium sulphate. In the first year, fertilisation and production were carried out between October and February, divided into eight plots. Micronutrients were applied with FTE BR 12® (Zn 9%, B 1.8%, Cu 0.8%, Mn 2%) at a rate of 9 g pot^{-1} per year. Fertilisers were applied to the soil surface, without incorporation.

2.2 Contribution of Green Manure Residuals to the Soil

After the completion of the first coffee study in July 2011, the pots remained unchanged with the coffee plants for 2 years, without fertilisation. This period was considered sufficient to

Table 1 Mineral fertilisation, rates of GM marked with ^{15}N in alternate years and N supply in each treatment

Treatment	Mineral fertilisation	Rate of GM[1]		Total N contribution
		1° (2009)	2° (2010)	
	%	g pots^{-1}		
GM146/1	30	146 (^{15}N)	146	22.5
GM146/2	30	146	146 (^{15}N)	22.5
GM584/1	30	584 (^{15}N)	584	48.8
GM584/2	30	584	584 (^{15}N)	48.8
Mineral fertilisation				
Control	30	6.3	9.0	15.3

[1] *GM* green manure (146 and 584 g pot^{-1} of the dry mass of jack bean)

extract the maximum nutrients from the soil and to evaluate the residual contribution of fertilisation with jack bean on humic fractions and soil fertility. In July 2013, soil samples were collected from each pot at four depths (0–0.5, 0.5–0.10, 0.10–0.20 and 0.20–0.40 m), using a trick probe type. At each depth, five samples were taken to obtain a composite sample. The samples were then dried in the shade and passed through a 2-mm sieve for analysis.

We measured the following soil attributes: pH in water, Ca^{2+}, Mg^{2+}, Al^{3+}, BS, eCEC and CEC at pH 7, K^{+}, P (Mehlich-1), P-remaining, following the protocols described in Silva (2009). The organic carbon was determined via wet oxidation of organic matter (Yeomans and Bremner 1988), and TN in the soil was determined according to the Kjeldahl method (Bremner and Mulvaney 1982). For the evaluation of soil humic substances, extraction and quantitative fractionation fulvic acids (FA), humic acids (HA) and humin (H) were used, based on the solubility in acidic and alkaline media according to the method of Swift (1996), adapted by Mendonça and Matos (2005). After fractionation, the organic carbon and total nitrogen contents were determined for each fraction (FA, HA and H), according to Yeomans and Bremner (1988) and Bremner and Mulvaney (1982). Concentrations of HSs were calculated using the formula [(C-FA + C-HA + C-H)/OC] × 100. In addition, we calculated the HA/FA ratio.

The presence of the ^{15}N isotope in the soil was analysed by mass spectrometry at the Center for Nuclear Energy in Agriculture-CENA, Piracicaba-SP, Brazil. The soil samples were crushed in a ball mill, passed through a 0.2-mm (60 mesh) sieve and packed in *Eppendorf* tubes. The percentage NdGM in the soil was calculated using the formula:

$$\%\mathrm{NdGM} = \left[\left({}^{15}\mathrm{N\ a.e.soil}-0.3663\right)/{}^{15}\mathrm{N\ a.e.GM}\right] \times 100$$

where the % ^{15}N a.e. in the soil is the percentage of the excess ^{15}N atoms in soil, % ^{15}N a.e. in GM is the percentage of excess ^{15}N atoms in GM and 0.3663 the isotope ratio in the soil atmosphere.

2.3 Statistical Analyses

For data analysis, a randomised complete block design with subdivided plots and four replications was used. The main plot represented the control and two GM rates, while the subplots represented the four depths. Only in the variable NdGM in the soil, two treatments were considered in the main plot, represented by rates ^{15}N isotope-enriched GM and two seasons in the subplots. The results were submitted to analysis of variance, with the application of the *F* test ($p < 0.05$). When the *F* test was significant, the Scott-Knott test ($p < 0.05$) was performed using the SISVAR program (Ferreira 2014).

3 Results

3.1 Carbon and Nitrogen in the Soil and in the Humic Fractions

In general, the OC and TN contents in the soil and in the humic fractions increased with GM fertilisation at depths of 0–0.05, 0.05–0.10, 0.10–0.20 and 0.20–0.40 m, with the exception of OC at a depth of 0.20–0.40 m (Fig. 1). The highest GM rate, with the application of 584 g of the dry mass of jack bean per pot, increased the percentage of humic substances in the soil at the depths of 0–0.05, 0.05–0.10 and 0.10–0.20 m. At the depth of 0.20–0.40 m, GM rates did not influence the percentages of humic substances.

The GM 584 resulted in the highest increase of humic substances, with values ranging from 78.8 to 93.4% at depths of 0–0.05, 0.05–0.10 and 0.10–0.20 m, when compared with the control and with the GM 146 treatment. In the depth of 0.20–0.40 m, the GM rates did not differ from each other but were higher than the control. The humic substances fractions showed the following ranges: 3.1–8.0% for C-HA, 7.2–17.6 for C-FA and 74.4–89.3% for C-H. The concentrations of these fractions were higher in the treatments with GM, when compared with the control, in the four depths, with the exception of C-HA and C-FA, in the depth of 0.20–0.40 m, which

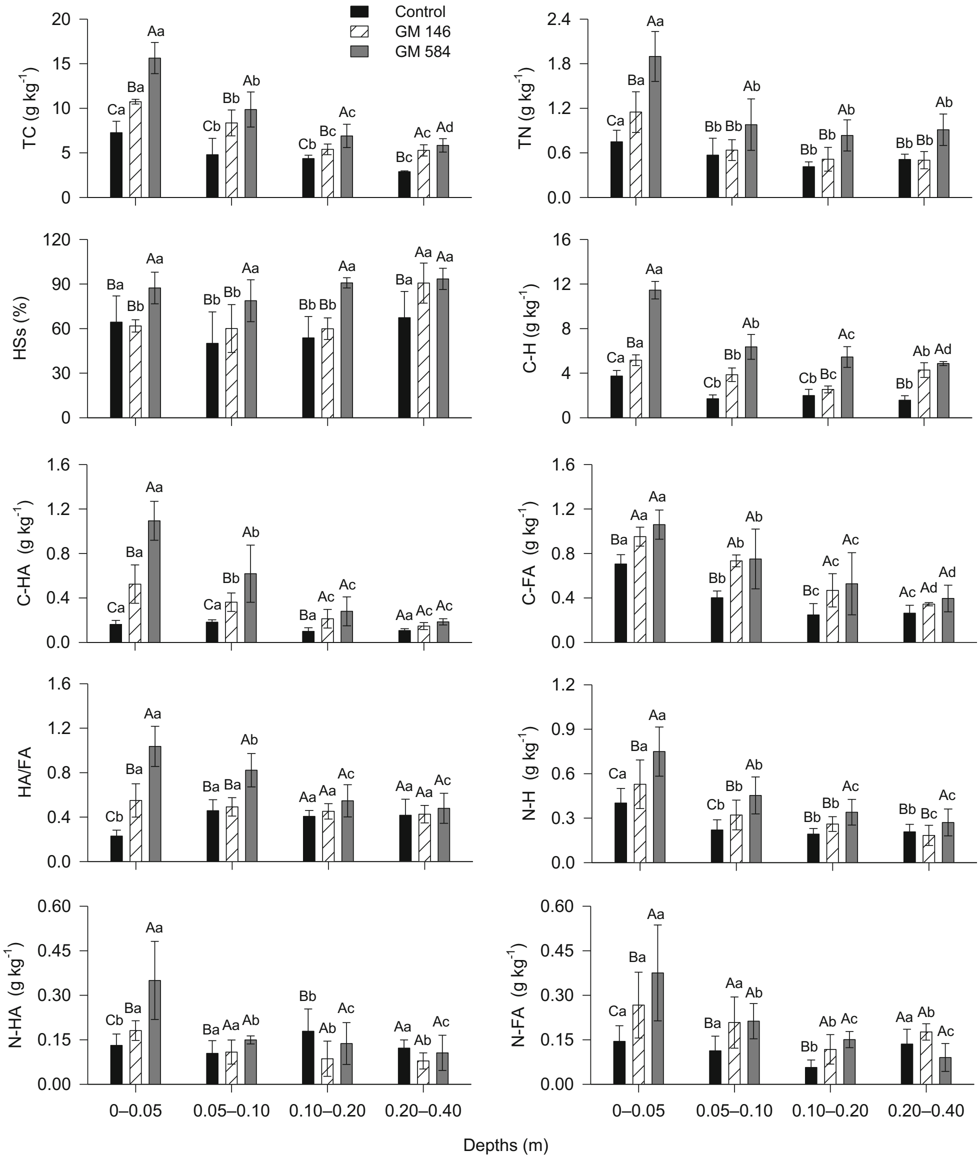

Fig. 1 Quantification of OC and TN in the soil and in the humic fractions of the organic matter of soils treated with GM of jack bean, at four depths. GM, green manure (146 and 584 g pot^{-1} of the dry mass of jack bean); OC, organic carbon; TN, total nitrogen; H, humin; HA, humic acids; FA, fulvic acids. Upper-case letters refer to the treatments at each depth and lower-case letters refer to the depths of each treatment. Values with the same letters did not differ significantly between treatments and between depths, according to the Scott-Knott test, at $p < 0.05$

showed no significant difference. The depth of 0–0.05 m presented the highest concentrations of C-HA, C-FA and C-H, except for C-HA for the control, which did not differ between depths.

N contents in the humic fractions were highest in the depth of 0–0.05 m and increased with the highest GM rates. The variations in each fraction corresponded to 41.4–59.2% for N-H, 17.0–41.1% for N-HA and 13.6–40.8% for N-FA. At the depths of 0.05–0.10, 0.10–0.20 and 0.20–0.40 m, the contents in the fractions did not present a logical trend according to the treatments, which can be justified by the variability of this element in the soil. In the three treatments and four depths, the values of the C-FA fraction were higher than those of the C-HA fraction, reflecting HA/FA ratios of less than one, except at depth of 0–0.05 m for the GM 584 treatment. At depths of 0–0.05 and 0.05–0.10 m, the HA/FA ratio was higher in the GM 584 treatment when compared with the lower rate of GM and with the control. At depths of 0.10–0.20 and 0.20–0.40 m, there was no difference between the treatments, with HA/FA ratios ranging from 0.41 to 0.54. Only for the GM 584, these ratios increased with depth, ranging from 1.04 to 0.82 at 0–0.05 and 0.05–0.10 m, respectively.

3.2 Residual Nitrogen from Green Manure

There was a difference in the residual nitrogen from jack bean between rates and application seasons in the previous crop (Fig. 2). We found higher percentages of residual nitrogen for the highest rate applied in 2010, 1 year after the first season in 2009. The results indicate a mean of 5.91 and 16.30% of residual nitrogen from jack bean for the rates of 146 and 584 g pot^{-1}, respectively, applied in 2009. Thus, when the GM rate was increased by four seasons, the residual nitrogen of this legume in the soil increased in average 36.29%. In the

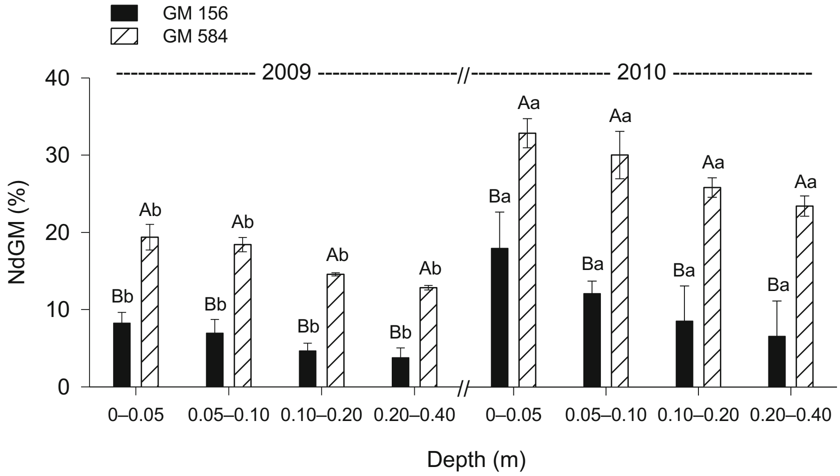

Fig. 2 Percentage of N derived from green manure (NdGM) in fertilised soil with two rates, in two seasons, with ^{15}N-labelled jack bean, at four depths. Upper-case letters refer to the rates GM (146 and 584 g pot^{-1} of the dry mass of jack bean) at each season and lower-case letters refer to the application seasons of ^{15}N-isotope-enriched jack bean at each rate, according to the Scott-Knott test, at $p < 0.05$

application of 2010, the average values were 11.24 and 27.91% for the rates of 146 and 584 g pot^{-1}, respectively. At the period of 1 year, less absorption by the coffee tree presented residual nitrogen superior in average 40.27%.

3.3 Soil Chemical Attributes

We observed changes in pH, BS and P, K^+, Ca^{2+}, Mg^{2+}, eCEC, CEC and P-rem contents of the soil fertilised with jack bean for two consecutive years in coffee cultivation (Fig. 3). Treatments with GM presented lower and higher values of pH and BS in the depths of 0–0.05 and 0.20–0.40 m, respectively, when compared with the control. At the depth of 0.05–0.10 m, the pH had the lowest value in the GM 146 treatment and BS did not differ between treatments, whereas at the depth of 0.10–0.20 m. The treatment GM 584 presented higher pH and BS values. The contents of Al^{3+}, in general, were zero, with no differences between treatments and depths.

The soil fertilised with the highest jack bean rates (GM 584); P contents decreased in all four depths. The GM 146 treatment presented higher contents of P in the depths of 0–0.05 and 0.05–0.10 m when compared with depths of 0.10–0.20 and 0.20–0.40 m, while GM 584 resulted in an inverse trend. Contents of K^+ varied, without a clear tendency, between treatments and depths, possibly because of the input of K via GM, the soil mobility and the varying K absorption. The eCEC was decreased in GM 146 in the depth of 0–0.05 m, increased in GM 584 at a depth of 0.10–0.20 m and increased for both rates in the depth of 0.20–0.40 m. The GM 584 treatment showed higher values of eCEC at the depths of 0–0.05, 0.05–0.10 and 0.10–0.20 m. In the treatment GM 146, there was no difference between depths. The CEC at pH 7 was increased in the depths of 0.05–0.10, 0.10–0.20 and 0.20–0.40 m for the two rates of jack bean; at the depth of 0–0.05 m, only the highest rate at CEC at pH 7 increased. Comparing the different depths, only GM 584 showed different values, with lower CEC values at pH 7 in the depths of 0.05–0.10 and 0.20–0.40 m.

The P-rem content changed in the depths of 0.05–0.10 and 0.20–0.40 m, with higher values for fertilised soils when compared with the control. Comparing the different depths, the P-rem value of the control was only higher in the depth of 0–0.05 m, whereas the treatments with GM presented higher values in the depths of 0–0.05 and 0.05–0.10 m.

4 Discussion

4.1 Residual Effect of Green Manuring on Carbon and Nitrogen Contents in the Soil

The increases in contents OC and TN in the soil are justified by the contributions of these elements from GM. Significant increases in organic matter and TN contents in soil fertilised with jack bean have also been observed by Hödtke et al. (2016). The increase of OC and TN contents in the deeper soil layers indicates that there was a vertical movement of organic matter from the GM. This result can be justified by watering the soil surface and facilitated by its texture. In general, the amount of C associated with humic substances varied from 50.1 to 93.4% of OC, indicating a high degree of humification (Guimarães et al. 2013). This might be due to the process of biosynthesis and re-synthesis of SOM and organic compounds added via GM (Zech et al. 1997). The humic substances are more stable fractions of SOM and accumulate significant amounts of C and N (Milori et al. 2002). In contrast, the non-humified fraction is represented by labile compounds, which are more easily used by soil microbiota (Schmidt et al. 2011). In addition, jack bean, for being leguminous, presents a high N content, an important factor for the decomposition and humification of SOM (Guimarães et al. 2013). The higher C-H content in the depth of 0–0.05 m may be related to the strong interaction between the organic and

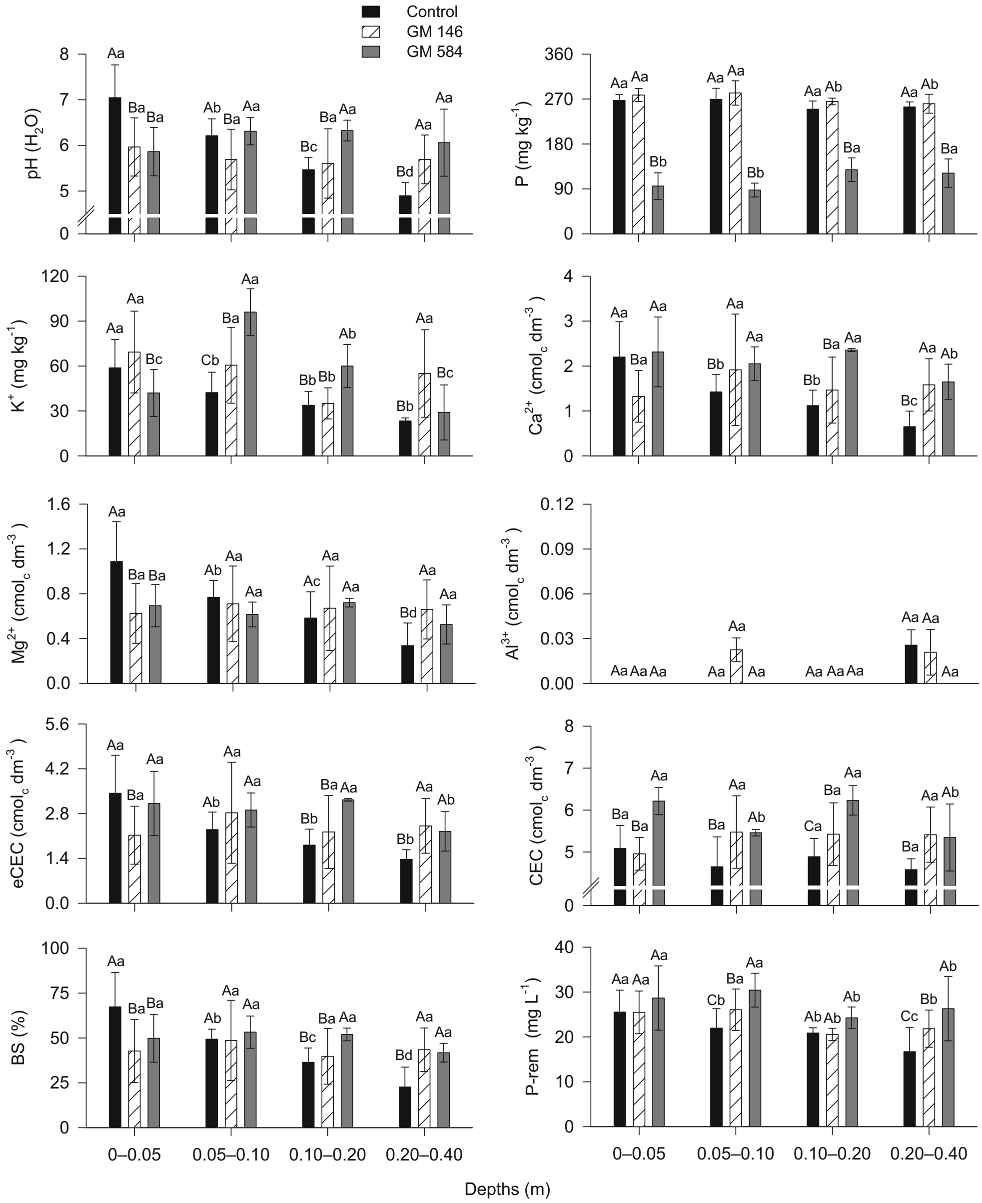

Fig. 3 Chemical attributes of soils treated with rates jack bean GM at four depths. GM, green manure (146 and 584 g pot^{-1} of the dry mass of jack bean); eCEC, effective cation exchange capacity; CEC, cation exchange capacity at pH 7; BS, base saturation; P-rem, remaining phosphorus. Upper-case letters refer to the treatments at each depth and lower-case letters refer to the depths of each treatment. Values with the same letter do not differ significantly between treatments and depths, according to the Scott-Knott test, at $p < 0.05$

mineral soil fractions and the jack bean biomass added, resulting in a high stability of SOM, with high proportions of recalcitrant compounds (Moraes et al. 2011). According to Stevenson (1994), C-H is the most stable and recalcitrant fraction.

The highest HA/FA ratios at depths of 0–0.05 and 0.05–0.10 m for GM 584 treatment may be associated to a more intense humification process, resulting from greater microbial activity and higher amounts of organic matter and oxygen (Xavier et al. 2013). On the other hand, in the depth of 0–0.05 m, the lowest HA/FA ratio in the control was found, with a value of 0.23, which indicates a lower degree of polymerisation of the humic components. This result may be associated with lower microbial activity, together with lower carbon contents available for the microorganisms, which, in turn, interferes with the formation of more condensed humic substances (Stevenson 1994; Zech et al. 1997), besides the absence of addition jack bean biomass added.

4.2 Effect of Rate and Seasons of Green Manure on Residual Nitrogen

The highest percentages of residual nitrogen for the highest jack bean rate applied in 2010 are due to the nitrogen contribution of this legume and a shorter absorption period of the coffee plants. This result demonstrated that both the rate and the absorption time interfere in the amount of residual nitrogen. It is observed that there are still considerable amounts of nitrogen of GM applied after 3 years and 7 months for application in 2009, at the lowest dose represented by the GM 146 treatment. These considerable contributions of the jack bean are mainly due to the reduction of the losses of nitrogen and the increase of its stock in the soil due to the increase of the amount of organic matter. The release of nitrogen from organic sources occurs more slowly in the final stage of decomposition, and the immobilisation and remineralisation of nitrogen by soil microbiota contribute to the reduction of soil losses and increase of the residual contribution (Abera et al. 2012).

4.3 Residual Contribution of Green Manure in the Soil Chemical Attributes

The lower values of pH and BS in the depth of 0–0.05 m are related to the uptake of bases by coffee and the movement of Ca^{2+} and Mg^{2+} in the soil profile. The movement of these bases in the soil profile justifies the highest values of pH and BS in the depth of 0.20–0.40 m. It is important to note that the coffee productivity previously cultivated plots differed significantly between treatments (Araújo et al. 2014).

In this sense, it should be mentioned that the productivity of the coffee in the GM 584 treatment was 2.7 times the productivity of the GM treatment 146 (Araújo et al. 2014). With this result, a higher acidification of the GM 584 was expected due to the extrusion of H^+ by the coffee plants and the absorption of cations such as Ca^{2+}, Mg^{2+} and K^+ (Haynes 1990). However, pH values were similar between GM treatments in the depths of 0–0.05 and 0.20–0.40 m and higher at the depths of 0.05–0.10 and 0.10–0.20 m for GM 584 treatment when compared with GM 146 treatment. It is likely that the highest rate of jack bean in GM 584 treatment was able to control the acidity generated by the complexation of H^+ and Al^{3+} by organic anionic compounds and the increases of Ca and Mg in the soil CEC provided by jack bean (Franchini et al. 2001; Franchini et al. 2003).

The increase of Ca^{2+} and Mg^{2+} contents at 0.20–0.40 m in the treatments with GM is related to the movement of these cations by organic acids, resulting from the decomposition of the jack bean. According to Franchini et al. (2003), organic anions of legumes and $Ca^{2\,+}$ and Mg^{2+} cations can form ionic pairs with zero or negative charge, which favours percolation in the soil profile. This result is relevant in conservation agriculture since it allows to improve the chemical conditions of the subsurface layers of the soil (> 0.20 m) without the use of machines to incorporate acidity ameliorants. The increase of these nutrients in the deeper layers of the soil favours the development the root system and, consequently, the absorption of water and nutrients (Caires et al. 2011; Carducci et al. 2014). Thus, GM can act as a soil conditioner, increasing the nutrient concentrations in the deeper layers of the soil and by correcting the acidity. Null content Al^{3+} is due to the neutralisation of this element by the complexation with organic acids anions and because of the pH values above 5.6 (Mendonça et al. 2006; Tejada et al. 2010).

The lower content of P presented for the highest jack bean rates (GM 584) is mainly due to higher productivity of previously cultivated coffee plants (Araújo et al. 2014), resulting in higher absorption of P. The changes in eCEC are mainly due to changes in K^+, Ca^{2+} and Mg^{2+} contents in the soil. The increases in CEC at pH 7 are related to the increases in organic carbon and humic fractions, provided by fertilisation with jack bean. In addition, this is the main factor regulating the generation of soil loads through humic fractions, which contributes to the increase of CEC (Valladares et al. 2007; Nelson and Su 2010) and consequently of nutrients retention (Moral and Rebollo 2017). The highest contents of P-rem may be related to higher contents of SOM, due to the presence of organic acids capable of blocking phosphate adsorption sites (Bhatti et al. 1998).

5 Conclusions

The content of humic substances, organic carbon and total nitrogen in the soil and organic carbon and total nitrogen in humic fractions increased to a depth of 0.40 m when green manure with jack beans was applied to the soil surface. In general, these attributes increased with increasing green manure rates.

The residual nitrogen from jack bean in the soil is dependent on the rate and seasons of application, with higher percentages for higher rates and shorter absorption period.

The residual contributions of the fertilisation with jack bean on soil chemical attributes depend on the applied rate. In general, soil fertility was maintained at depths of 0–0.05 and 0.05–0.10 m and increased in the subsoil > 0.10 m, with elevations in pH, base saturation, effective cation exchange capacity, cation exchange capacity at pH 7 and exchangeable calcium and magnesium and remaining phosphorus, with significant increases at 0.20–0.40 m.

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Compliance with Ethical Standards

Conflict of Interest The authors declare that they have no conflict of interest.

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