COVER CROPS USED AS GREEN MANURE IMPROVED SOIL FERTILITY AND SOIL C STOCKS IN A TROPICAL SANDY SOIL

CULTURAS DE COBERTURA USADAS COMO ADUBO VERDE MELHORARAM A FERTILIDADE DO SOLO E OS ESTOQUES DE C DO SOLO EM UM SOLO ARENOSO TROPICAL

CULTIVOS DE COBERTURA COMO ABONO VERDE MEJORARON LA FERTILIDAD DEL SUELO Y LAS RESERVAS DE C DEL SUELO EN UN SUELO ARENOSO TROPICAL

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ABSTRACT:

The use of cover crops as green manure was studied in a 6-year field experiment in a tropical sandy soil. Our aim was to assess whether Facabeae and Poaceae plants used as green manure can improve soil fertility and soil C stock by their biomass production and incorporation into soil profile. We compared the soil chemical properties, the aboveground and belowground growth rate of ten different cover crops used as green manure in a long-term field experiment. Our findings showed that *C. ensiformis* and *N. wightii* showed the highest aboveground and belowground growth rate, respectively. The incorporation into soil profile with *B. decumbens* and *P. glaucum* as green manure improved both the soil Ca^{2+}, and K^{+} contents. While the highest values of available P were found on plots where *C. ensiformis* was cultivated. For soil organic carbon stocks, we found the highest values on plots where *M. pruriens* and *D. lablab* were cultivated. Our results emphasized the importance to consider the Fabaceae plants (e.g., *C. ensiformis*, *D. lablab*, *M. pruriens*, and *N. wightii*) as soil conditioners against soil erosion, soil organic matter loss, low P fertility, and plant nutrient leaching. On the other hand, the Poaceae species (e.g., *B. decumbens*, and *P. glaucum*) can be considered as potential promoters of soil Ca^{2+} and K^{+} contents in tropical sandy soils.

KEYWORDS: Soil organic carbon. Fabaceae plants. Poaceae plants. Plant-soil feedback.

Resumo

O uso de culturas de cobertura como adubo verde foi estudado em um experimento de campo de 6 anos em solo arenoso tropical. Nosso objetivo era avaliar se as plantas Fabaceae e Poaceae usadas como adubo verde podem melhorar a fertilidade do solo e o estoque de solo C, no perfil do solo. Comparamos as propriedades químicas do solo, a taxa de crescimento acima do solo e subterrânea de dez culturas de cobertura usadas como adubo verde em um experimento de campo de longo prazo. Nossos achados mostraram que *C. ensiformis* e *N. wightii* apresentaram a maior taxa de crescimento acima do solo e subterrânea, respectivamente. A incorporação no perfil do solo com *B. decumbens* e *P. glaucum* como adubo verde melhorou tanto o teor de Ca^{2+} quanto K^{+} do solo. Enquanto os maiores valores de P disponíveis foram encontrados em parcelas onde *C. ensiformis* foi cultivado. Para os estoques de carbono orgânicos do solo, encontramos os maiores valores em parcelas onde *M. pruriens* e *D. lablab* foram cultivados. Nossos resultados enfatizaram a importância de considerar as plantas de Fabaceae (por exemplo, *C. ensiformis*, *D. lablab*, *M. pruriens* e *N. wightii*) como condicionadores de solo contra a erosão do solo, perda de matéria orgânica do solo, baixa fertilidade de P e lixiviação de nutrientes das plantas. Por outro lado, as espécies de Poaceae (por exemplo, *B. decumbens* e *P. glaucum*) podem ser consideradas como potenciais promotoras do conteúdo Ca^{2+} e K^{+} do solo em solos arenosos tropicais.

PALAVRAS CHAVE: Carbono orgânico do solo. Plantas Fabaceae. Plantas Poaceae. Feedback planta-solo.

Resumen

El uso de cultivos de cobertura como abono verde se estudió en un experimento de campo de 6 años en un suelo arenoso tropical. Nuestro objetivo fue evaluar si las plantas Fabaceae y Poaceae utilizadas como abono verde pueden mejorar la fertilidad del suelo y el stock de C del suelo por su producción al perfil del suelo. Comparamos las propriedades químicas del suelo, la tasa de crecimiento sobre el suelo y bajo tierra de diez cultivos de cobertura diferentes utilizados como abono verde en un experimento de campo a largo plazo. Nuestros hallazgos mostraron que *C. ensiformis* y *N. wightii* mostraron la tasa de crecimiento más alta sobre el suelo y bajo tierra, respectivamente. La incorporación al perfil del suelo con *B. decumbens* y *P. glaucum* como abono verde mejoró tanto el contenido de Ca^{2+} como el de K^{+} del suelo. Mientras que los valores más altos de P disponible se encontraron en parcelas donde se cultivó *C. ensiformis*. Para las reservas de carbono orgánico del suelo, encontramos los valores más altos en parcelas donde se cultivaron *M. pruriens* y *D. lablab*. Nuestros resultados enfatizaron la importancia de considerar las plantas de Fabaceae (por ejemplo, *C. ensiformis*, *D. lablab*, *M. pruriens* y *N. wightii*) como acondicionares del suelo contra la erosión del suelo, la pérdida de materia orgánica del suelo, la baja fertilidad de P e la lixiviación de nutrientes de las plantas. Por otro lado, las especies de Poaceae (por ejemplo, *B. decumbens* y *P. glaucum*) pueden considerarse como promotores potenciales del contenido de Ca^{2+} y K^{+} del suelo en suelos arenosos tropicales.

PALABRAS CLAVE: Carbono orgánico del suelo. Plantas fabaceae. Plantas poaceae. Retroalimentación planta-suelo.

1. Introduction

In Brazil, the last decade was characterized by an increase in the degraded areas around all the country because of the conventional monocropping systems without any program of soil and plant management (BRASIL NETO et al., 2021). Most of these degraded areas cover the sandy soils domain where negative soil processes have been reported, such as soil erosion, plant nutrient leaching, and soil C stock losses (SOUZA, Tancredo, et al., 2018; TITOVA & BALTRĖNAITĖ, 2020). Management practices as the use of cover crops as green manure may find sustainable ways to reduce these problems by favoring the use of organic sources and trying to recover soil fertility (SANCHES et al., 2021). Some studies were done considering the green manure as an interesting alternative to improve soil fertily, such as the use of cover crops (e.g., here acting as soil cover and reducing soil erosion and nutrient leaching) which their consecutive soil incorporation (e.g., here acting as green manure and improvind soil fertility and soil C stock). However, in the North-eastern Brazil, these kinds of reports have remained unclear (SOUZA & FREITAS, 2018; NONG et al., 2021; ROSA et al., 2021). Overall, positive plant-soil feedback (e.g., improved soil organic carbon pools, and soil Ca^{2+}, K^{+} and P contents) has been reported in tropical soils where green manure were used as soil mansagement practice (JIN et al., 2019; YAO et al., 2019; RODRIGUES et al., 2020; SOUZA et al., 2021).

The use of green manure may reduce the costs related to plant production by reducing the use of mineral fertilizers and in turns promoting the soil physical-chemical properties (FERNANDEZ ET AL., 2020, ZHOU et al., 2020). Some Fabaceae plants have been recommended for tropical soil trought their fast growth and high biomass production, such as the species *Crotalaria juncea* and *C. spectabilis* (MEENA & LAL, 2018). Thus, knowing the benefits that the green manure practice can provide to the soil ecosystem, we must consider it as a soil fertility promoter into tropical soils (STABILE et al., 2020). In this context, we hypothesized that in tropical soils cover crops with high growth rate and high shoot and root biomass production may improve soil fertility and soil C stock by their biomass incorporation and decomposition. We start from this assumption, based on the studies carried out by Souza et al. (2018), Melo et al. (2019), Forstall-Sosa et al. (2020), Barbosa et al. (2021), and Nascimento et al. (2021a) in a long-term field experiment using green manure in the Tropics. These studies have reported the use of Fabaceae plants with positive results on biomass production, soil organic carbon, soil biota, gas exchange, plant nutrition, soil organisms, and soil quality.

It hard to apply the green manure management practice in Tropical ecosystems because two main factors: i) the lack of information about this management practice into the North-eastern Brasil; and ii) the idea that the long dry periods over the year must be a barrier for the correct use of this practice. There are evidence showing that the green manure practice may increase the soil organic matter, nutrient cycling, plant growth, and soil quality (GAO et al., 2018; MELO et al., 2019a; FORSTALL-SOSA et al., 2020). To evaluate these processes in Tropical ecosystem, we analyzed the shoot and root biomass production to estimate the above-, and belowground growth rate, and total biomass production (ZHANG et al., 2019, KHAN et al., 2020). Besides that, we evaluated the available P; exchangeable Ca; exchangeable K, and soil carbon pool (ADEKIYA et al., 2019). According to the multivariate soil quality index proposed by Nascimento et al. (2021b), these soil chemical properties can provide the best results about the benefits of using cover crops as green manure in a tropical sandy soil. Previous studies have showed that in a long-term field experiment on a Regosol, the use of legume cover crops was an alternative to enhance soil chemical properties after 6 years of its cultivation and incorporation into soil profile (SOUZA, Giliane, et al., 2018; MELO et al., 2019a; FORSTALL-SOSA et al., 2020; NASCIMENTO et al., 2021a). In this experiment, our aim was to evaluate the effect of cover crops used as green manure under: i) soil chemical properties (e.g., Ca^{2+}, P, K^{+}, and SOC pools); ii) the above- and belowground growth rate; and iii) total biomass production. To accomplish this aim, we combined: a) soil samplings; b) Predictive models for determine above- and belowground growth rate (SUJA et al., 2017); and c) total biomass by quantification of above- and belowground biomass (LASISI et al., 2018).

2. Material and methods

The experiment was carried out in a 6-year field experiment that used cover crops (plant species from Fabaceae and Poaceae) as green manure at the Experimental Station “Chã-de-Jardim”, Agricultural Science Center, Federal University of Paraíba, located in Areia, Paraiba, Brazil (06° 58′ 12″ S, 35° 42′ 15″ W, altitude 619 m.a.s.l.) from July to December 2019. The climate type in the experimental area is the Savanna Tropical type, with average annual precipitation and air temperature of 1,330 mm and +22.5°C, respectively (SILVA et al., 2019; NASCIMENTO et al., 2021a). Climate data, monthly rainfall, and mean air temperature for Areia, Paraiba, Brazil (July to December 2019) (Fig 1), were obtained online: http://www.inmet.gov.br. The soil was classified as a Regosol with a sandy texture (WRB, 2006).

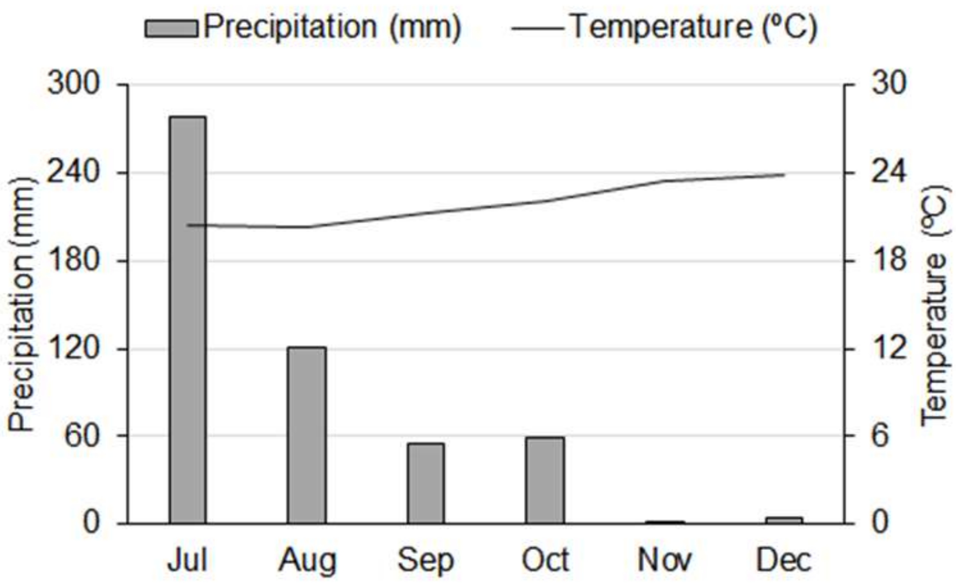

Figure 1. Monthly precipitation (mm, grey bars) and temperature (ºC, black line) data from the experimental area, Areia, Paraiba, Brazil (July to December 2019). Data were obtained online: http://www.inmet.gov.br.

The area was initially planted in 2014 (the current dataset is from the end of the 6-year field experiment) using the same experimental design. During the years we have aimed to study all aspects related to the cover crops on agronomic performance (SOUZA, Giliane, et al., 2018), biomass production, plant nutrition (MELO et al. 2019a), transpiratory rate, arbuscular mycorrhizal fungi (MELO et al., 2019b; BARBOSA et al., 2021), soil biota (FORSTALL-SOSA et al., 2020), and soil quality (NASCIMENTO et al., 2021b). In each studied year, all the cover crops were grown at a distance of 0.50 × 0.50 m, and they were distributed into two main groups: Fabaceae (8 plant species) and Poaceae (2 plant species). For more details on soil preparation, use of fertilizers, liming, doses, and method of application, see Souza et al. (2018), Forstall-Sosa et al. (2020), and Nascimento et al. (2021a). The field experiment was organized in a randomized block design, with five blocks, and ten treatments: *Brachiaria decumbens* Stapf., *Canavalia ensiformis* (L.) DC, *Crotalaria juncea* L., *Crotalaria ochroleuca* G. Don, *Crotalaria spectabilis* Roth, *Lablab purpureus* (L.) Sweet, *Mucuna pruriens* (L.) DC, *Neonotonia wightii* (Wight & Arn.) JA Lackey, *Pennisetum glaucum* L., and *Stilozobium aterrimum* Piper e Tracy. All cover crops were cultivated in the same plots (6 × 4 m) during 6 consecutive years, following a monocropping system (Table 1). All the plant species were seeding in eight lines, with a seeding rate of 400 seeds m^{-2} and 2 cm of deep.

Table 1. Studied plant species (eight Fabaceae species and only two Poaceae species) used as green manure and their main characteristics during the field experiment.

Cover crops	**Family**	**Flowering (days)**	**Plant density (plants plot^{-1})**
Brachiaria decumbens	Poaceae	180	480
Canavalia ensiformis	Fabaceae	70	480
Crotalaria juncea	Fabaceae	55	240

Crotalaria ochroleuca	Fabaceae	55	240
Crotalaria spectabilis	Fabaceae	76	240
Dolichos lablab	Fabaceae	90	480
Mucuna pruriens	Fabaceae	124	240
Neonotonia wightii	Fabaceae	75	480
Pennisetum glaucum	Poaceae	66	480
Stilozobium aterrimum	Fabaceae	124	480

To evaluate the aboveground and belowground biomass production, we selected and marked ten plants with homogeneous traits (e.g., height, number of leaves, stem diameter, and without leaves's damage by pests or diseases) per plot during the flowering stage. Next, all marked plants were cuted at 5-cm above the soil surface, packaged in paper bags, and oven-dryed at 65 ºC. We used the shoot dry biomass to estimate the aboveground biomass production (kg ha^{-1}) following the equation described by Forstall-Sosa et al. (2020). The aboveground growth rate was estimated using the following equation: $AGR\ (\%) = \frac{lnABP+1.60944}{ND-1}\ x\ 100$, where AGR, ABP, and ND are the aboveground growth rate (%), the aboveground dry biomass production (kg ha^{-1}), and the number of days to reach the flowering stage, respectively. For belowground biomass production, we collected ten soil monoliths with 0.20 × 0.20 × 0.20 m from the same marked plants following the protocol described by Souza and Santos (2018). Each soil monolith was wrapped using plastic film and transported with minimal disturbance until analysis. During our analysis, the fine roots were sampled by washing the root material in a nylon sieve with 0.5 mm of mesh. The root dry biomass per monolith (g monolith^{-1}) was determined after drying for 48 h at 65 ºC. We used the root dry biomass per monolith to estimate the belowground biomass production following the equation described by Nascimento et al. (2021a). The belowground growth rate was determined using the following equation: $BGR\ (\%) = \frac{lnBBP+2.99573}{ND-1}\ x\ 100$, where BGR, BBP are the the belowground growth rate (%), and the belowground dry biomass production (kg ha^{-1}), respectively.

To start the soil fertility assay, we incorporated all aboveground biomass in each studied plot into soil profile (0-20 cm soil depth) after concluding the shoot and root collection to estimate dry biomass. After 90 days of plant incorporation into soil profile, five soil samples per plot were collected (0-20 cm soil depth) with a soil auger. We analysed the available soil P (e.g., extracted by Mehlich-1 protocol); the exchangeable Ca (e.g., extracted using potassium chloride); the exchangeable K (e.g., extracted by Mehlich-1), and the soil C stock was estimated using the following equation: $SOC_{stock} = SOC_{content} * BD * 0.20$, where SOC_{stock} (t C ha^{-1}), SOCcontent (g kg^{-1}), BD (g cm^{-3}) are the soil organic carbon stock, the soil organic carbon content, and the bulk density, respectively. Methods to characterize available soil P, exchangeable Ca, exchangeable K, and the soil C stock were fully described by Nascimento et al. (2021a) and performed according to Teixeira et al. (2017).

All statistical analysis were run using R, version 3.4.0 (R CORE TEAM, 2018). Before analysis, all variables were tested for normality (e.g., by the Shapiro-Wilk test using the "shapiro.test" function in the "stats" package) and homoscedasticity (e.g., by the Bartlet test using the "bartlett.test" function in the "dplyr" package), and log transformations were applied using the "decostand" function in the "vegan" package to meet both required criteria. To compare the effects of the studied cover crops on soil fertility and soil C stock, we used the "kruskal.test" function in the "stats" package, and the means by each studied treatment were compared by using the Bonferroni's test. Differences in aboveground and belowground growth rate, and soil chemical properties between Fabaceae and Poaceae groups were determined by non-parametric *t* test followed by Monte Carlo test (100 replicates).

3. Results

We found significative effects of the studied cover crops used as green manure on aboveground and belowground growth rate ($\chi^2_{9,486} = 28.38$, $p < 0.001$, and $\chi^2_{9,486} = 83.41$, $p < 0.001$, respectively). The highest values of the aboveground growth rate were found on plots where *C. ensiformis* was cultivated (3.71 ± 0.06 %), while for the belowground growth rate the highest values were found on plots where *N. wightii* was cultivated (15.88 ± 0.27 %). We also found significative differences between Fabacea and Poacea groups on both above- and belowground growth rate ($p < 0.01$, and $p < 0.001$, respectively) by the non-parametric *t* test (Table 2).

Table 2. Aboveground and belowground growth rate by the studied cover crops used as green manure observed in the field experiment during the flowering stage, Areia, Paraiba, Brazil (mean ± SD, *n* = 500).

Cover crops[1]	Aboveground growth rate (%)	Belowground growth rate (%)
B. decumbens	0.08 ± 0.05 e	14.54 ± 0.17 b
C. ensiformis	3.71 ± 0.06 a	12.52 ± 0.28 c
C. juncea	1.21 ± 0.49 c	9.33 ± 0.41 e
C. ochroleuca	1.87 ± 0.80 b	11.09 ± 0.37 d
C. spectabilis	2.30 ± 0.45 b	11.88 ± 0.41 c
D. lablab	0.19 ± 0.12 d	12.76 ± 0.52 c
M. pruriens	0.94 ± 0.07 d	13.17 ± 0.40 c
N. wightii	0.62 ± 0.12 d	15.88 ± 0.27 a
P. glaucum	0.41 ± 0.39 d	10.13 ± 0.44 e
S. a1terrimum	1.11 ± 0.20 c	12.73 ± 0.31 c
χ^2 *value*	28.38***	83.41***
Fabaceae *vs.* Poaceae group[2]	8.13**	23.78***

***; ** Significative differences at $p < 0.001$, and $p < 0.01$, respectively.
[1]Different small letters indicate significative differences among the studied cover crops used as green manure assessed by the Bonferroni's test ($p < 0.05$).
[2]Independent sample *t* test comparing Fabaceae vs. Poaceae group.

We found significative differences among the studied cover crops used as green manure by the Kurskall-Walis test on soil Ca^{2+} ($\chi^2_{9,486} = 13.91$, $p < 0.001$), K^+ ($\chi^2_{9,486} = 13.24$, $p < 0.01$), available P ($\chi^2_{9,486} = 36.82$, $p < 0.001$), and SOC pools ($\chi^2_{9,486} = 21.68$, $p < 0.01$). The highest values of exchangeable Ca^{2+} (2.00 ± 0.70 $cmol_c$ kg^{-1}) were found on plots where *B. decumbens* was cultivated. For the exchangeable K^+, we found the highest values on plots where *P. glaucum* (38.50 ± 8.70 mg kg^{-1}) and *B. decumbens* (37.00 ± 21.50 mg kg^{-1}) were cultivated, respectively. Next, the highest values of available P were found on plots where *C. ensiformis* (13.02 ± 1.07 mg kg^{-1}) were cultivated. Finally, for SOC pools the highest values were found on plots where *M. pruriens* (13.55 ± 1.70 t C ha^{-1}), *D. lablab* (13.17 ± 0.82 t C ha^{-1}) were cultivated. We also found significative differences between Fabacea and Poacea groups on all studied chemical properties by the paired t-test (Table 3).

Table 3. Aboveground and belowground growth rate by the studied cover crops used as green manure observed in the field experiment during the flowering stage, Areia, Paraiba, Brazil (mean ± SD, *n* = 500).

Cover crops[1]	Ca^{2+} ($cmol_c$ kg^{-1})	K^+ (mg kg^{-1})	P (mg kg^{-1})	SOC_{pools} (t C ha^{-1})
B. decumbens	2.00 ± 0.70 a	37.00 ± 21.50 a	7.43 ± 1.36 d	12.42 ± 0.76 b

C. ensiformis	1.80 ± 0.50 b	36.00 ± 12.90 b	13.02 ± 1.07 a	11.64 ± 1.44 c
C. juncea	1.70 ± 0.60 b	28.00 ± 17.50 d	5.70 ± 2.35 c	11.45 ± 1.69 c
C. ochroleuca	1.30 ± 0.10 d	34.70 ± 8.60 b	7.19 ± 2.03 e	12.19 ± 1.01 b
C. spectabilis	1.50 ± 0.30 c	21.00 ± 10.00 e	11.81 ± 1.77 b	12.57 ± 1.26 b
D. lablab	1.60 ± 0.30 c	34.00 ± 17.30 b	7.76 ± 2.63 d	13.17 ± 0.82 a
M. pruriens	1.20 ± 0.10 d	32.50 ± 6.30 c	4.77 ± 0.84 d	13.55 ± 1.70 a
N. wightii	1.60 ± 0.30 c	27.50 ± 11.30 d	6.79 ± 2.32 d	12.82 ± 1.14 b
P. glaucum	1.50 ± 0.20 c	38.50 ± 8.70 a	5.88 ± 1.51 e	12.07 ± 1.49 b
S. a1terrimum	1.40 ± 0.10 d	34.10 ± 10.50 b	9.50 ± 1.86 c	11.42 ± 1.34 c
χ^2 *value*	13.91**	13.24**	36.82***	21.68**
Fabaceae *vs.* Poaceae group[2]	9.45***	9.11***	9.57***	10.56***

***; ** Significative differences at $p < 0.001$, and $p < 0.01$, respectively.

[1]Different small letters indicate significative differences among the studied cover crops used as green manure by the Bonferroni's test ($p < 0.05$).

[2]Independent sample *t* test comparing Fabaceae vs. Poaceae group.

3. Discussion

Our results showed the importance of considering cover crops used as green manure for inproving soil chemical properties, and soil organic carbon stocks by the incorporation into soil profile of their aboveground and belowground biomass. Essentially, we wanted to understand how the consecutive use (e.g., 6 years) of Fabaceae and Poaceae plants as green manure changes the soil Ca^{2+}, K^{+}, available P, and soil organic C stocks in a tropical sandy soil. Previous studies have reported these soil chemical properties as the most important variables if we are aiming for high plant production and soil quality (SOUZA, Tancredo, et al., 2018; BARBOSA et al., 2021; NASCIMENTO et al., 2021b). According to the soil quality index proposed by Forstall-Sosa et (2020), these soil variables may affect positively the entire soil food web, thus promoting positive plant-soil feedback by recycling nutrients. The results of this study revealed that long-term cover crops cultivation with green manure significantly increased the contents of exchangeable cations (Ca^{2+} and K^{+}), available P, and SOC pools. We also highlighted the importance of considering plant species with different above- and belowground growth rate. The first one could be used in order to reduce soil erosion, once the plant species cover the soil surface faster than other that present low aboveground growth rate. In our study, the plots where *C. ensiformis* was cultivated showed this phenomenon. On the other hand, the second one could be an interesting way to improve soil porosity, and water and nutrient uptake, once the roots may cover a wide area in a short period as we found on plots where *N. wightii* was cultivated.

Overall, long-term cover crops cultivation with green manure promoted soil improvements after 90 days of their residue incorporation in the soil profile. We also must consider the rhizodeposition hypothesis described by Lucena et al. (2021), which described plant species increasing nutrient cycling and contribute to minimize organic carbon losses into their rhizosphere trough the root exudation process (INAGAKI et al., 2021; HUANG et al., 2020). This condition is relatively important for tropical soils, which in monoculture systems increase organic carbon losses for atmosphere and decrease soil fertility over time (BALASUBRAMANIAN et al., 2020). Based on the hypothesis called "island of fertility" proposed by Souza et al. (2018), Melo et al. (2019a) and Nascimento et al. (2021a), the green manure practive can reduce 69% of the overall costs with organic fertilizers, due to its high capacity of promote ecosystem services, increasing the availability of nutrients for plants (Ca^{2+}, K^{+}, and P) and serving as source of organic material for soil protection (SOC stocks). Our initial hypothesis that leguminous species can promote soil fertility, and thus higher above- and belowground growth rate was supported, except for the exchangeable Ca^{2+} and K^{+} content that was promoted by Poaceae plants.

However, it is important to highlight that green manure species have distinct agronomic traits and nutritional requirements and, for this reason, they exert different effects about the availability of nutrients in the soil profile (HANSEN et al., 2021; FONTANA et al., 2021).

The data highlighted the positive effect of Fabaceae cover crops to the above- and belowground growth rate (e.g., *C. ensiformis*, and *N. wightii*, respectively). A positive effect of Fabaceae plant species on the aboveground growth rate (ASSIS et al., 2019, GLICK et al., 2021) as well as for belowground growth rate (AMEDE et al., 2021) has been frequently found. The aboveground trait is an important mechanism to increase aboveground branching, and a survival strategy for the dry season (SILVA et al., 2020). It also promotes soil cover thus reducing soil erosion. The use of fast-growing plant species in dry season ensures greater efficiency in the use of water and, consequently greater accumulation of carbon, providing a biomass production (MENDES et al., 2017). The highest values for above- and belowground growth rate on plots where *C. ensiformis* and *N. wightii* were cultivated, respectively agree with precious works (NASCIMENTO et al., 2021a; MELO et al., 2019a). Our results supported the Souza et al. (2018) hypothesis that plant species with high growth rate may be more beneficial than plant species with low growth rate as cover crops because their biomass production was supported for both Poaceae and Fabaceae. According to our results, *C. ensiformis* can be established in tropical ecosystems, in dry seasons because they covered the soil in less time and protects the soil surface against the water erosion (SOLIS et al., 2019).

Our findings showed that incorporation of *B. decumbens* and *P. glaucum* improve the Ca^{2+}, and K^{+}, respectively. While the availability P was highest on plots where *C. ensiformis* was cultivated. These results may be related with the higher capacity of nutrients accumulation in their biomass. Poaceae plant in our study may be considered as interesting ways to recover both exchangeable Ca and K on soil surface. These plant species can uptake these macronutrients and to return them back to soil through nutrient cycling. On the other hand, *C. ensiformis* through its root activity can release P that was associated with some soil minerals (MELO et al., 2019a). Previous studies showed the intensification of positive plant-soil feedback in long-term field areas managed with green manures, where essential nutrients were returned to crops by nutrient cycling, and root uptake (ZHONG et al., 2018; KHAN et al., 2020; ABERA, 2021; NASCIMENTO et al., 2021a). Our results emphasized the importance to consider the Fabaceae (e.g., *M. pruriens*, and *D. lablab*) as potential promoters of SOC pools in tropical ecosystems (ZHANG et al., 2019). Previous studies done by Souza et al. (2018), Yao et al. (2019) showed that Fabaceae species may improve the SOC pools (MAUAD et al., 2019; FORSTALL-SOSA et al., 2020; WATTHIER et al., 2020).

Soil organic matter in tropical ecosystem is an important driver to soil fertility and plant growht (LAW et al., 2019). According to these authors, when the aboverground dry biomass is incorporated into soil profile instead be mecanically removed, it improves soil food web that acts promoting soil organic matter decomposition, nutrient cycling, and energy supply for a wide range of soil organism groups (MELO et al., 2019a; KOOCH & NOGHRE 2020; MASSACCESI et al., 2020). Considering some traits into soil profile (e.g., considering the whole timeline of the field experiment) that we observed in our study, we found positive effects on soil organic carbon (SOUZA, Giliane, et al., 2018; MELO et al., 2019b; BARBOSA et al., 2021) and bulk density (NASCIMENTO et al., 2021a) on plots where plant species of Fabaceae family were cultivated. In our study, the plots where we grew plant species from Fabaceae family, we found a significant high soil porosity, shoot and root dry biomass, soil organic carbon, and bulk density. These results agree with Cao et al. (2020), Eze et al. (2020) and Wu et al. (2020), who reported high soil organic carbon stocks in soil ecosystems with aboveground plant species characterized by fast growth and high biomass production were incorporated into soil profile. Once both C- and N-rich plant residues are incorporated consecutively into soil profile, this practice directly and indirectly promotes soil quality and health (SOUZA et al., 2016) by acting as an organic matter source to build-up a sustainable environment where we can efficiently stock carbon (SOUZA et al., 2017; NG et al., 2018; MELO et al., 2019a).

3. Conclusion

The use of cover crops as green manure practice for 6 consecutive years increased soil chemical properties and soil organic carbon pools in a tropical Regosol. The use of Fabaceae plants (e.g., *C. ensiformis*, *D. lablab*, *M. pruriens*, and *N. wightii*) showed high values of aboveground growth rate, available P, SOC stocks, and belowground growth rate, whereas the use of Poaceae plants (e.g., *B. decumbens* and *P. glaucum*) showed high values of exchangeable Ca and K. Our findings suggest that these plant species have positive effects on soil fertility by two main pathways: (i) a consecutive green manure practice without any input of fertilizers after 6 years changed positively soil fertility (e.g., here promoting soil organic matter, high P fertility, and plant nutrient uptake (Ca^{2+} and K^{+}); and 2) by altering soil fertility both Poaceae and Fabaceae plants used as green manure may create a sustainable cycle into the soil profile thus promoting their own growth (e.g., here reducing soil erosion, and nutrient leaching).

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