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CAN NO-TILL RESTORE SOIL ORGANIC CARBON TO LEVELS UNDER NATURAL VEGETATION IN A SUBTROPICAL AND TROPICAL TYPIC QUARTZIPISAMMENT?

Ademir de Oliveira Ferreira[1*], João Carlos de Moraes Sá[2], Rattan Lal[3], Telmo Jorge Carneiro Amado[4], Thiago Massao Inagaki[5], Clever Briedis[6], Florent Tivet[7]

[1] Adjunct Professor, Department of Agronomy, Federal Rural University of Pernambuco, Av. Dom Manuel Medeiros, Zip Code 52171900 - Recife, PE, Brazil. **Corresponding author.* E-mail: ademir.oliveiraferreira@ufrpe.br; aoferreira1@yahoo.com.br. Phone: +55-81-3320 6231.

[2] Associate Professor, Department of Soil Science and Agricultural Engineering, State University of Ponta Grossa, Av. Carlos Cavalcanti 4748, 84030-900 Ponta Grossa, PR, Brazil. E-mail: jcmsa@uepg.br

[3] Distinguished University Professor, Carbon Management and Sequestration Center (CMASC). The Ohio State University. 2021 Coffey Road, Columbus, OH 43210, USA. E-mail: lal.1@osu.edu

[4] Titular Professor, Department of Soil Science, Federal University of Santa Maria, Santa Maria, Brazil. Email: proftelmoamado@gmail.com

[5] Graduate Student, Technical University of Munich, Chair of Soil Science. Emil-Ramann Str. 2 85354 Freising – Bayern, Germany. Email: thiago811@yahoo.com.br

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[6] Assistant Professor, Department of Soil Science and Agricultural Engineering, State University of Ponta Grossa, Av. Carlos Cavalcanti 4748, 84030-900 Ponta Grossa, PR, Brazil. E-mail: cleverbriedis@yahoo.com.br

[7] Researcher, Centre de Coopération Internationale en Recherche Agronomique pour le Développement, CIRAD, UPR SIA, F-34398 Montpellier, France. Email: florent.tivet@cirad.fr

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Abstract

Sandy soils are widely distributed in Brazil and occur in most states. However, they have serious limitations for agricultural use due to low natural fertility, low water retention capacity, low resilience and high susceptibility to erosion. Management of these soils through a no-till (NT) system following its basic principles (i.e., elimination of plowing, diversification of crop rotation, retention of crop residues, and maintenance of permanent soil cover) is a practice that can restore the soil organic carbon (SOC) stock, and restore productivity and economic viability of these soils. We hypothesized that: i) We can recover the C stock in Typic Quartzipisamment in subtropical and tropical climate at the level of native vegetation; ii) The adoption of NT during the initial *phase*, in conjunction with intensive cropping systems with high plant biomass input is an efficient strategy to recover SOC in Typic Quartzipisamment; and iii) Long-term NT (over 20 years - the maintenance phase), and low/ medium input of plant biomass, is an efficient strategy for SOC recovery in Typic Quartzipisamment. Thus, the present study aimed at assessment of the recovery of SOC stocks in soil profile (0 to 1.0 m depth) in a Typic Quartzipisamment in subtropical and tropical climate, in comparison with the neighboring soil under a

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native vegetation (NV). The sites selected for this study are located in two Brazilian grain producing regions: a) Manoel Viana city - Rio Grande do Sul state (MV - site 1) that represents the subtropical climate condition, and b) Luiz Eduardo Magalhães city – Bahia state (LEM - site 2), which represents the tropical climate. Soil samples were collected from soil profile for 0 to 1.0 m depth. At site 1, the predominant crop rotation over the years was wheat / soybean / oats + forage turnip / soybean. At site 2, the crop rotation includes cultivation in two periods designated as the crop and off-season, and the succession consisted of soybean/brachiaria/cotton/millet/soybean/corn-brachiaria. In both sites, soils under the neighboring NV were also sampled. SOC content was determined by the dry combustion method using an elemental C and N analyzer. Soil C stock was calculated based on the equivalent soil mass. Approximately 31 and 23% of the SOC stock was stored in the surface 0-0.20 m, compared with 69 and 77% in 0.20-1.0 m layer of a Typic Quartzipisamment with high and low/ medium input of crop residues, respectively. The Typic Quartzipisamment with low/ medium input of crop residues fully recovered the stock of C in the surface soil layer (0-0.05 m). The Typic Quartzipisamment with high input of crop residues fully recovered the stock of C in the cultivated (0-0.20 m) and also in deeper soil layers (0-0.40 m). Thus, adoption of NT associated with intensification of cultivation systems and high addition of biomass-C is an effective strategy for C restoration in a Typic Quartzipisamment, while also playing a crucial role in restoring ecosystem productivity, soil quality and environment.

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Key-words: neossols, conservation agriculture, crop rotation, carbon recovery.

LIST OF ABBREVIATIONS

NT - no till; MV - Manoel Viana; LEM - Luiz Eduardo Magalhães; NV - native vegetation; C – carbon; SOC – soil organic carbon; Typic Quartzipisamment - Neossols.

Introduction

Sandy soils occur widely and in almost all states of Brazil. The Neossols (Brazilian Soil Classification, 2010) occupy 14.6% (1.25 M Km^2) of the total land area, of which 42% (0.52 M Km^2) are classified as Typic Quartzipisamment (Soil Taxonomy, 2010) (IBGE, 2001). These soils occur most frequently in the Cerrados region, representing approximately 15% of its total area of this biome and in Pampa region, occupy 63% (0.18 M Km^2) of Rio Grande do Sul State. These soils have serious limitations for agricultural use as an excessively sandy texture, low inherent fertility, high aluminum toxicity, low water retention capacity and high susceptibility to

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erosion (Coelho et al., 2002). Thus, adoption of no-till (NT) system through the principles of conservation agriculture (no plowing, permanent soil cover, by cover crops, residue retention, and the diversification of the crop rotation) has been mentioned (FAO, 2018) as a useful strategy to make these soils agronomically productive and economically viable.

Brazil accounts for ~ 36.8 million hectares (Mha) under NT system (Sá and De Oliveira Ferreira, 2018), that represents ~ 55% of total grain production area. In Southern Brazil ,the pioneers adopted NT system during the early 1970s, however the scaling up occurred during the 1990s. In 1990, the area under NT system was 0.9 M ha, with an annual rate of increase at 0.081 Mha yr^{-1} .In 2000 there was a significant expansion of NT to 14.0 Mha (@1.64 M ha yr^{-1}). The area under NT doubled in 2010 to 30.3 M ha (@1.51 M ha yr^{-1}) and in 2016/17 reached the current area of 36.8 Mha(Sá and De Oliveira Ferreira, 2018). Brazil ranks as the second largest land area A system-based NT cropping (FAO, 2018) is capable of partially or totally restoring soil organic carbon (SOC) content in these sandy soils. Crop rotation is one of the pillars for NT success because of its positive impact on soil quality (De Oliveira Ferreira et al. 2013; De Oliveira Ferreira et al. 2018a; De Oliveira Ferreira et 2018b) and crop productivity (Sá, 1999; De Oliveira Ferreira et al. 2009; Sá et al. 2010; Sá et al. 2014).

These benefits of NT(e.g., improved soil quality, increased productivity, increased SOC stock) are achieved gradually over time. The evolution of NT system is divided into 4 phases (Sá, 2004): 1. *Initial phase* (0 - 5 years); 2. *The transition*

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phase (6 - 10 years); 3. *The consolidation phase* (11 - 20 years) and 4. *The maintenance phase* (> 20 years). In the present study, we have obseved two contrasting phases: a) The *Initial phase* which is theoretically characterized by low accumulation and high decomposition of straw, re-aggregation and rearrangement of structural aggregates, and restoration of fauna and microbial biomass in the soil and b) *The maintenance phase* which is theoretically characterized by a high accumulation of plant residues and SOC, stabilization of soil bulk density and increase of the faunal and soil microbial biomass carbon.

The study was based on three hypotheses: i) We can recover the C stock in Typic Quartzipisamment in subtropical and tropical climate at the level of native vegetation; ii) The adoption of NT during the initial *phase*, in conjunction with intensive cropping systems with high plant biomass input, is an efficient strategy to recover SOC in Typic Quartzipisamment ; and iii) Long-term NT (over 20 years - the maintenance phase), and low/ medium input of plant biomass, is an efficient strategy for SOC recovery in Typic Quartzipisamment. However, studies on SOC recovery in Typic Quartzipisamment under subtropical and tropical climate are still scarce. Therefore, the present study was aimed at the assessment the recovery of SOC stocks in soil profile (0 to 1.0 m depth) in a Typic Quartzipisamment in subtropical and tropical climate, in comparison with the neighboring soil under a native vegetation (NV).

Material and methods

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Two sites under NT system selected for this study are located in two very fragile grain producing regions of Brazil: a) Manoel Viana (MV - site 1), located in the state of Rio Grande do Sul, representing the biome Pampa under subtropical region, and b) Luiz Eduardo Magalhães (LEM - site 2), located in the state Bahia, representing the biome Cerrado under tropical region.

In the MV - site 1 - (29°35'S - 55°28'W) the average altitude was 113 m above sea level. The average minimum and maximum temperatures were 13.4 and 25 °C, respectively, and the annual precipitation was approximately 1662 mm evenly distributed through the year. The soil was classified as Neossol (Brazilian classification), which is equivalent to a Typic Quartzipisamment (Soil Survey Staff, 2010), with 176 g kg^{-1} of clay content (0-0.20 m).

In the LEM - site 2 - (12° 04' S - 45° 42' O) the average altitude was 760 m above sea level. The average minimum and maximum temperatures were 18 and 34 °C, respectively, and the annual precipitation was approximately 1480 mm with a bimodal patter (dry April to September and wet season October to May). In both sites, the soil was classified as Neossol (Brazilian classification) equivalent to a Typic Quartzipisamment (Soil Survey Staff, 2010), with 120 g kg^{-1} of clay (0-0.20 m).

Table 1 presents some general characteristics of these experimental sites, along with a summary of the NT adoption time for the specific crop rotations adopted. According to Koëppen climate classification, the experimental sites fall under subtropical and semi-humid tropical climate. The detailed description of soil texture is given in Table 2. Field and laboratory measurements were made at these two sites to

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assess changes in SOC stocks . Baseline measurements in SOC stocks were made on an adjacent soil under NV.

Land Use History and management of study sites

Cultivation of MV - site 1 and LEM - site 2 (Figure 1) was started during the 1970s, which was the era of mechanized agriculture (conventional tillage)/ livestock. MV - site 1 was converted to a NT system in 1987, and continued until soil sampling 2010. While the LEM - site 2 was converted to a NT system in 2008 and continued until soil sampling 2012. The data in Figure 1 show the land use chronologies of both sites.

Characterization and description of native vegetation

The NV in Manoel Viana (Rio Grande do Sul) was classified as steppes, and grassy woody without gallery forest (IBGE, 2010). The rate of dry mass production (DM) at the warm season of the year ranged from 2 to 3.4 Mg ha^{-1} of DM under native pasture (Pillar et al., 2009). The NV in Luiz Eduardo Magalhães (Bahia) was classified as Cerrado or savannah woodland with an almost closed canopy to dense grassland, with a sparse covering of shrubs and small trees (Tivet et al. 2012).

Carbon stock recovery

The SOC recovery was assessed on the basis of the percentage of stock recovered by the use of long-term NT in comparison with that under NV. The C recovery (%) among NT and NV was estimated by using Equation 1:

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$$\textbf{Carbon recovery}\ (\%) = \frac{\text{SOCNT}\ (\text{Mg ha}^{-1}) \times 100}{\text{SOCNV}\ (\text{Mg ha}^{-1})} \qquad \textit{(Eq. 1)}$$

where, SOC_{NT} and SOC_{NV} refer to SOC stock under NT and NV, respectively.

Crop residues equivalent (CRE)

The minimum amount of dry matter (aerial parts and roots) required to maintain the dynamic equilbrium of the system was calculated by Eq. 2**:**

$$\textbf{CRE = C sequestered x 3.77 x 2.28.} \qquad \textbf{Eq. 2}$$

Where, sequestered C is the annual rate of accumulated C estimated based on the Henin and Dupuis (1945) model, 3.77 is the factor used for the transformation of humidified C in the C input (1/0.265 = 3.77), 2.28 is the factor used for the transformation of the C input in crop residues (100 %/43.8 % = 2.28), and 43.8 % (e.g., 438 g C kg^{-1}) is the C content in the crop residue.

Statistical analyses

The normality was assessed through Shapiro-Wilk test. The differences in SOC concentration and stock were tested through analysis of variance (F-test). Mean values were compared using Tukey’s test at the 5% probability level (Ferreira, 2010).

Results

SOC concentrations and stocks

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In the **MV - site 1** the SOC concentration in the NT ranged from 11.2 (± 1.13) gkg^{-1} in the 0-0.05 m layer to 4.6 (± 1.66) g kg^{-1} in the 0.60-1.0 m layer. The mean average range of SOC under NV was 7.8 (± 1.43) to 4.0 (± 1.66) g kg^{-1} for 0-0.05 and 0.60-1.0 m layers, respectively (Table 3). SOC concentrations were significantly higher under NT compared to those under NV in 0-0.05 m layer. SOC concentrations were statistically equal for both systems in other layers (Table 3).

The mean of SOC stock under NT ranged from 8.5 (± 0.93) Mg ha^{-1} in the 0-0.05 m layer to 22.9 (± 2.5) Mg ha^{-1} in the 0.60-1.0 m layer. In comparison, the mean SOC stock under NV ranged from 5.9 (± 0.99) to 32.4 (± 2.2) Mg ha^{-1} for the 0-0.05 and 0.60-1.0 m layers, respectively (Figure 2a). The accumulated C stock of NT varied on average from 17.8 (± 3.40) Mg ha^{-1} in the 0-0.20 layer to 78.3 (± 4.68) Mg ha^{-1} in the 0-1.0 m layer. Moreover, the range of average variation under NV was 18.3 (± 1.50) to 91.7 (± 5.71) Mg ha^{-1} for 0-0.20 and 0-1.0 m layers, respectively .The SOC stock was significantly higher under NT compared to that under NV at 0-0.05 m depth (Figure 2a), and statistically equal to those at 0-0.20, 0-0.30, 0-0.45 and 0-0.60 m depth (Figure 2b).

In the **LEM - site 2** the average SOC concentration under NT ranged from 6.8 (± 1.01) g kg^{-1} in the 0-0.10 m layer to 3.6 (± 0.58) g kg^{-1} in the 0.40-1.0 m layer. Under NV, the range of average concentration was 5.9 (± 1.04) to 4.1 (± 0.05) g kg^{-1} for the 0-0.10 and 0.40-1.0 m layers, respectively (Table 3). Further, SOC concentrations were significantly higher under NT compared to those under NV in the

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0-0.10 m layer. SOC concentrations were statistically equal for both land uses in other layers (Table 3).

The average SOC stock under NT ranged from 10.5 (± 1.44) Mg ha^{-1} in the 0-0.10 m layer to 32.0 (± 2.14) Mg ha^{-1} in the 0.40-1.0 m layer. Under NV, the average SOC stock ranged from 8.8 (± 1.35) to 35.4 (± 0.48) Mg ha^{-1} for the 0-0.10 and 0.40-1.0 m layers, respectively (Figure 3a). The average accumulated C stock under NT ranged from 20.4 (± 1.93) Mg ha^{-1} in the 0-0.20 layer to 65.5 (± 3.66) Mg ha^{-1} in the 0-1.0 m layer. In the NV, the average accumulated SOC stock ranged from 16.3 (± 2.17) to 66.0 (± 3.43) Mg ha^{-1} for the 0-0.20 and 0-1.0 m layers, respectively (Figure 3b).

The SOC stocks under NT were statistically equal to those under NV in the 0-0.10, 0.10-0.20, 0.20-0.40, 0-0.20, 0-0.40 and 0-1.0 m layers (Figure 3ab).

SOC Stock Recovery

In the **MV - site 1**, the recovery of SOC stock under NT compared to NV as the baseline was 144, 74, 85, 99, 91 and 71% for 0-0.05, 0.05-0.20, 0.20-0.30, 0.30-0.40, 0.40-0.60 and 0.60-1.0 m depth, respectively. The percentage recovery of SOC stock for NT (23 years) was 97, 94 and 85% for the 0-0.20, 0-0.40 and 0-1.0 m layers, respectively (Figure 4). In addition, changes in land use and adoption of conservation agriculture affect the SOC stocks differently according the thickness of layer (Figure 2b). For example, the average SOC stock in the 0-0.30 m layer

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decreased from 33.1 Mg ha^{-1}under NV to 30.3 Mg ha^{-1} under NT, and from 91.7 Mg ha^{-1} to 78.3. Mg ha^{-1} in the 0-1.0 m layer.

In the **LEM - site 2,** in comparison with the SOC stock under NV, the percentage recovery for NT was 119, 132, 92 and 90% for 0-0.10, 0.10-0.20, 0.20-0.40 and 0.40-1.0 m layers, respectively. The percentage recovery of SOC stock under NT was 125, 109 and 99% for the 0-0.20, 0-0.40 and 0-1.0 m layers, respectively (Figure 4).

Discussion

Recovery of C stock in Typic Quartzipisamment under Long-term NT (maintenance phase) with low/ medium input of plant biomass

Long-term adoption of a conservation system fully recovered the SOC stock in the surface 0-0.05 m layer of the Typic Quartzipisamment in subtropical climate (site 1) in comparison to that under NV. The complete recovery is probably because these soils have higher SOC decomposition rates under conventional tillage (Bayer et al. 2011). As the low clay content and frequent soil disturbance decrease the physical mechanism of C protection. Other hand, the shallow layer is where the crop residues are input, the root system had higher concentration in this layer, and when associate with minimal soil disturbance there is an enhancement in soil aggregation and physical C protection that is the main mechanism of protection. The SOC accumulated in other deep layers under NT were lower than that under NV (Figure

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4). Probably, this result is associate to deeper root system of NV and can also be explained by better soil structure and physical-hydric attributes of long-term of NV without disturbance (Figure 1). Previously, the cropland site was under conventional tillage for 17 years followed by 23 years of NT. Management under NT was characterized for the use of crop sequence of wheat/ soybean/ oats + forage turnip/ soybean with high intensity of soybean, along with a low/ medium input of biomass-C of 3.2 Mg ha^{-1} yr^{-1} (7.2 Mg ha^{-1} $year^{-1}$).

The main reason was due to the low amount of biomass-C added through residues of summer crop (higher frequency of soybean) and winter species during the 23-yr of NT and the near-absence of legumes as a winter cover crop. De Oliveira Ferreira et al. (2012) reported for this region that the minimum amount of biomass C-input to maintain the steady-state was 3.2 Mg C ha^{-1} yr^{-1} (7.3 Mg ha^{-1} $year^{-1}$ of plant biomass). However, we must reach values above the minimum amount of crop residues required to achieve a positive carbon balance, resulting in greater system stability. In this study, for example, adding 25% more crop residues would amount to 9.2 Mg ha^{-1} $year^{-1}$ of plant biomass, 50% more would have 11.0 Mg ha^{-1} $year^{-1}$ and 75% more would have 12.8 Mg ha^{-1} $year^{-1}$ of plant biomass. In the last two cases we would really achieve the benefits of long-term NT (*the maintenance phase)* which is characterized by a high accumulation of plant residues and SOC, stabilization of soil bulk density and increased faunal and soil microbial biomass carbon, in addition to greater soil water retention (Sá, 2004).

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The results of the present study reflect the trend in South Brazil of higher soybean frequency and lower use of corn throughout the years (De Oliveira Ferreira et al. 2016). Similar results were reported by Amado et al. (2006), Bayer et al. (2011), Campos et al. (2011) and De Oliveira Ferreira et al. (2012) who also observed that SOC stock are depleted more when corn cultivation is less in relation to soybean in the rotation cycle. These researchers also observed that SOC accumulation potential is enhanced when corn is grown in association with leguminous cover crops. Recently, De Oliveira Ferreira et al. (2018a) that SOC recovery was lower (58.3%) in a sandy clay Oxisol than that in a clay loam Oxisol (73.1%) with a higher frequency of maize in the rotation (soybean-maize ratio of ≈1:1) cycle. Using a short term study involving soybean-based cropping systems, Hok et al. (2015) observed a high rate (7.29 to 7.32 Mg C ha^{-1} $year^{-1}$) of SOC sequestration because of a diverse cropping system (millet/ soybean + *stylosanthes guianensis* and millet/ maize + *brachiaria ruziziensis*) in which the biomass-C inputs accrued the highest level of SOC and soil quality. In this case, the low C input of soybean was compensate by high input of Millet and Brachiaria and Stylosanthes that had biological N fixation resulting in more balanced C and N input (Amado et al., 2006).

Recovery of C stock in Typic Quartzipisamment under adoption of NT (Initial phase) with high input of plant biomass

Adoption of NT system fully recovered the SOC stock in surface (0-0.20 m) and deeper (0-040 m) layers of the Typic Quartzipisamment (site 2) in relation to that

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under NV (Figure 4). These results, also supported by the land use history of the site (Figure 1), prove the importance of crop intensification and diversification with *soybean/ brachiaria/ cotton/ millet/ soybean/ corn-brachiaria* in the quality and storage of SOC.

Although additional research is warranted, SOC accumulation in the subsoil could be attributed to the dissolved C movement in soil profile (Lorenz & Lal, 2005; Rumpel and Kogel-Knabner, 2011; Tivet et al. 2013; Nicoloso et al., 2018), higher SOC rhizodeposition in the soil profile by deep rooting systems of grains/forage grasses (corn, *B. ruziziensis* and finger millet) and enhancement of vertical distribution through bioturbation (Wilkinson et al., 2009), which influences SOC dynamics (Lavelle et al., 2006). In addition, these species enhance root/arbuscular mycorrhizal association that enhance exudates, increase soil aggregation (Wright & Upadhyaya, 1998; Rillig, 2004), and accentuate the C allocation to the whole root system (Jones et al., 1991).

These results reinforce the importance of the quantity and quality of crop residues input to maintain the dynamic equilibrium and promote C accumulation above equilibrium level of the NT system in fragile sandy soils. In this case, the high recovery of carbon in Typic Quartzipisamment is due to the high amount of biomass-C added (6.3 Mg ha^{-1} yr^{-1}) through residues of summer crop (*soybean/ cotton*) and winter species (*brachiaria/ millet/ corn-brachiaria*) during the 5-yr of NT with high frequency of *brachiaria* as a winter cover crop (Crusciol et al., 2015). Also for this region, Sá et al. (2015) estimated the minimum amount of biomass C-input required

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to maintain the steady-state at 4.15 to Mg C ha^{-1} yr^{-1} (9,46 Mg ha^{-1} year^{-1} of plant biomass). For example, adding 25% more crop residues would be 11.82 Mg ha^{-1} year^{-1}, adding 50% more would be 14.2 Mg ha^{-1} year^{-1} and 75% more would be 16.55 Mg ha^{-1} year^{-1} of plant biomass. In the present study, we added 50% (14.3 Mg ha^{-1} year^{-1}) more crop residues than required to attain the steady-state, and it resulted in greater SOC stock recovery. Results reported by some other recent studies also highlight the importance of crop quality and intensity to the recovery of SOC stock (De Oliveira Ferreira et al., 2016; De Oliveira Ferreira et al., 2018b; Gonçalves et al., 2019).

Results similar to those presented herein were reported by Hok et al. (2015) who also concluded that adoption of agricultural systems with high input (millet/ soybean + *stylosanthes guianensis* and millet/ maize + *Brachiaria ruziziensis*) of biowaste is necessary for the maintenance or increase of the SOC stock. Hok and colleagues suggested that bi-annual rotations with maize are the appropriate crop rotation schemes to potentially restore SOC in tropical soils of Cambodia.

Another explanation of the high SOC stock recovery in this site (tropical climate) is the high silt content which ranged from 6.1 to 9.3% in profile (0-1.0 m). Together with clay, silt content is considered as the main determinant of soil C protection capacity (Hassink et al., 1997; Six et al., 2002; Tivet et al., 2013). Furthermore, the present experimental site is located at a higher altitude (760 m) and is associated with annual average rainfall of 1480 mm (Table 1), which may have favored the higher accumulation and recovery of SOC.

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In conclusion, SOC stockin the surface layer (0-0.05 m depth) was fully recovered in both environments of Typic Quartzipisamment compared to that under NV. The Typic Quartzipisamment with high input of crop residues fully recovered the SOCstock in the plough layer (0-0.20 m) and also in sub-soil layers (0-0.40 m). The Typic Quartzipisamment with low/ medium input of crop residues fully recovered the SOC stock in the surface soil layer (0-0.05 m). Future studies should continue to evaluate the SOC recovery in Typic Quartzipisamment in short and long-term NT systems for other sites in diverse global ecoregions. The data presented herein indicate that the strategy of combining short-term NT system with high amount of biomass-C contributes to the recovery of SOC in sandy soils.

Conclusions

The data support the following conclusions:

- Approximately 31 and 23% of the SOC stock was stored in the surface 0-0.20 m, compared with 69 and 77% in 0.20-1.0 m layer of a Typic Quartzipisamment in biome of pampa (subtropical) and cerrado (tropical), respectively.
- The Typic Quartzipisamment with low/ medium input of crop residues fully recovered the stock of C in the surface soil layer (0-0.05 m).
- The Typic Quartzipisamment with high input of crop residues fully recovered the stock of C in the plow layer (0-0.20 m) and also in thicker soil layer (0-0.40 m).

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- Adoption of NT, in conjunction with intensive cultivation systems and high input of plant biomass, is an efficient strategy for SOC recovery in Typic Quartzipisamment decreasing its fragility to soil degradation.

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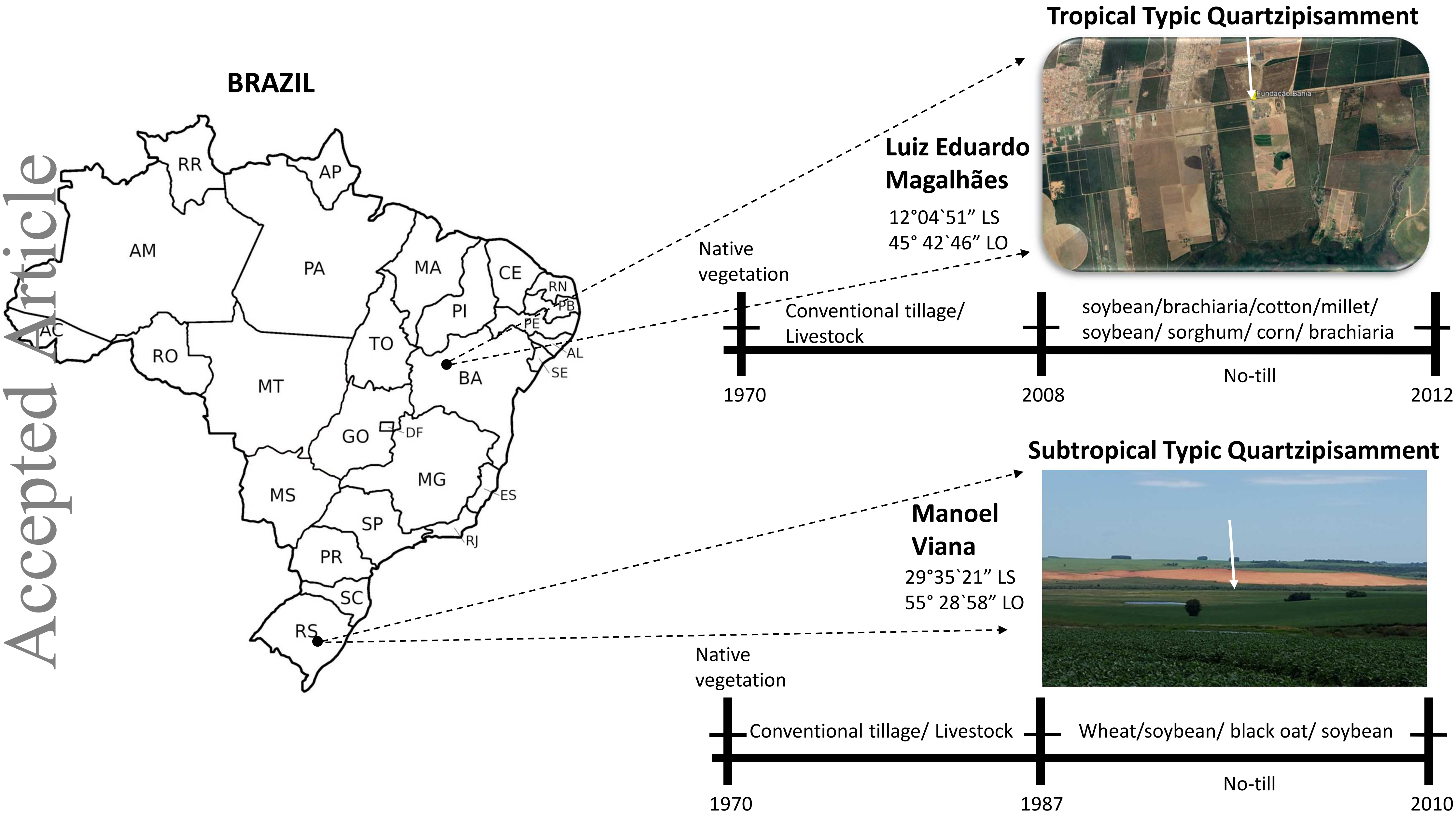

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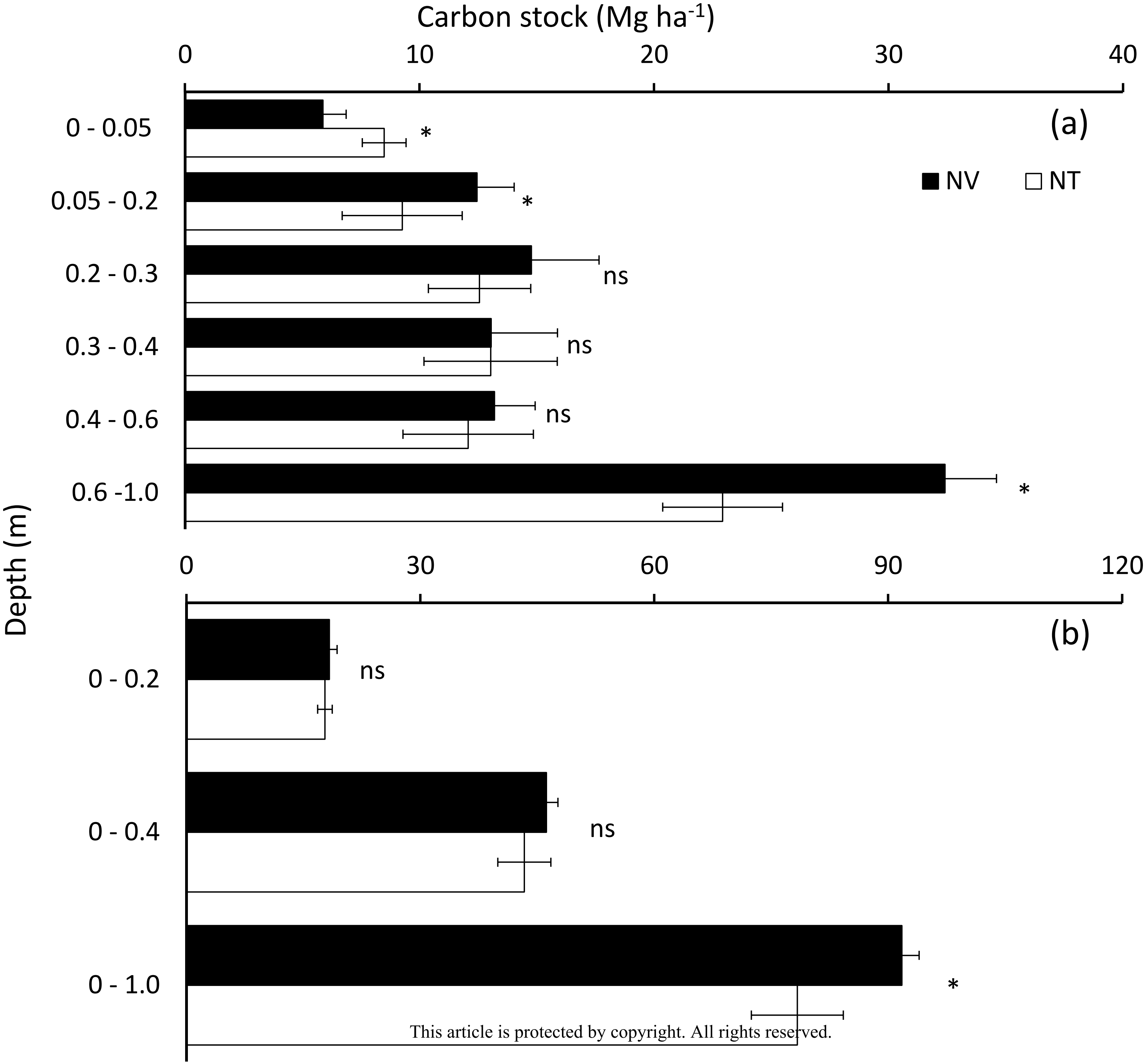

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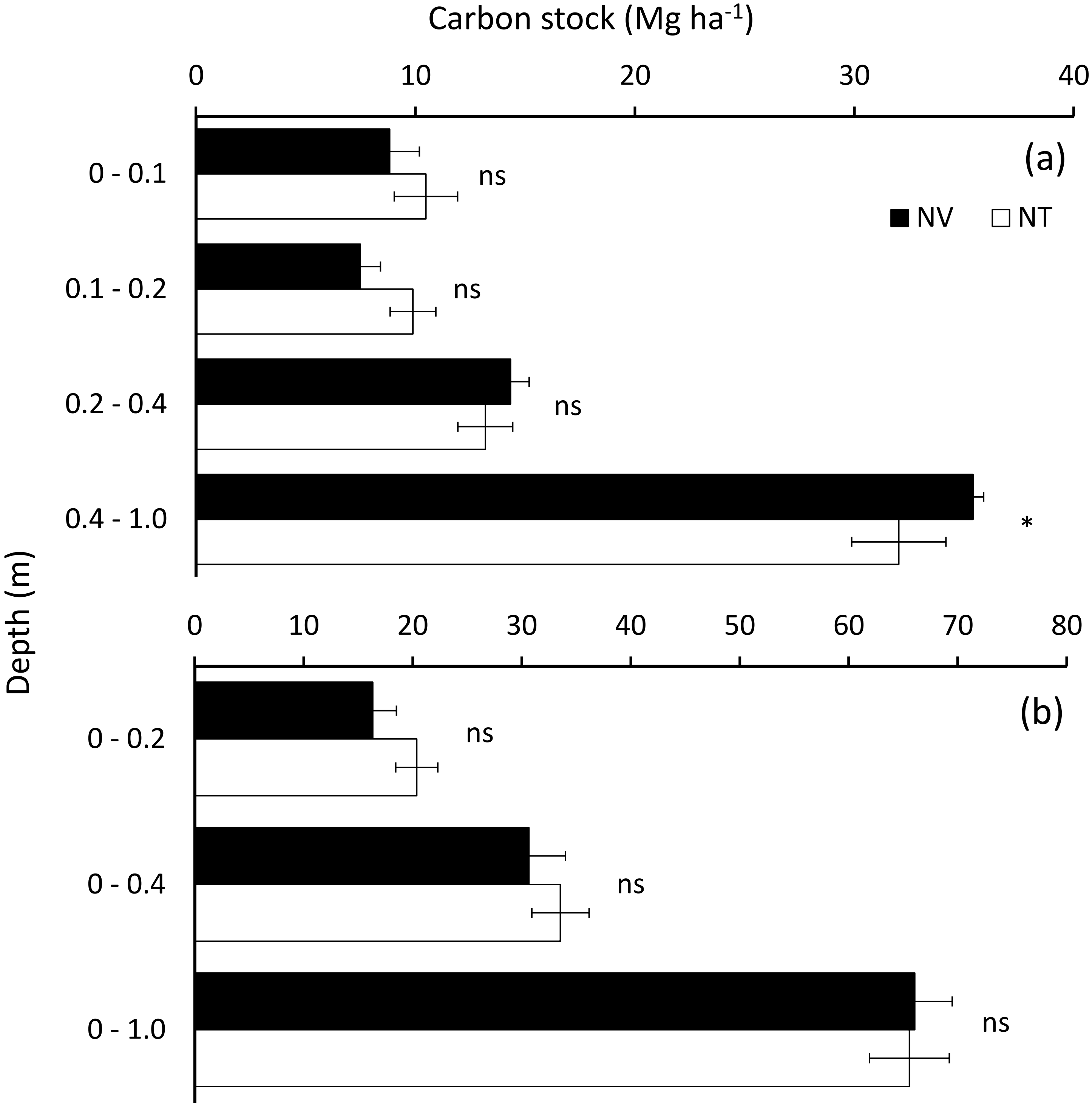

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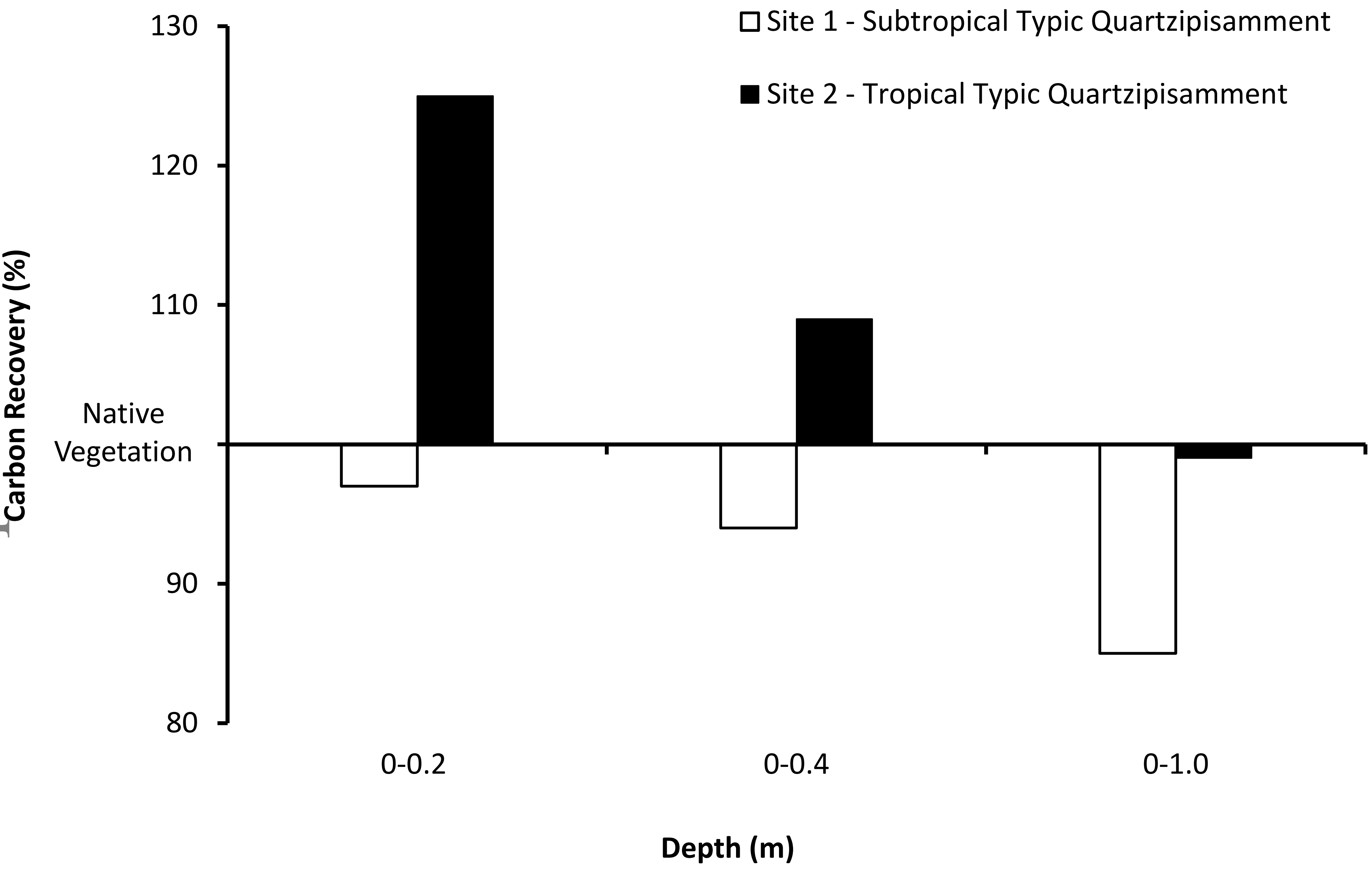

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Table 1. Description of sites: location, soil type, parent material, climate, land use (tillage systems), NT duration and sampling depth.

Description	**Site 1** **Manoel Viana - Rio Grande do Sul state**	**Site 2** **Luiz Eduardo Magalhões - Bahia state**
Geographic coordinates	29°35'S - 55°28'W	12° 04' S - 45° 42' O
Altitude	113 m	760 m
Soil Classification	Typic Quartzipisamment	Typic Quartzipisamment
Parent material	Arenitic-basaltic	Sandstone
Mineralogy - Iron Oxides (g kg^{-1})	18 (extracted by H_2SO_4) ‡	-------
Climate	Cfa (Subtropical)	Aw (Tropical)
Annual average temperature	20.3°C†	22 °C††
Maximum temperature	25°C†	34 °C††
Minimum temperature	13.4°C†	18 °C††
Average annual rainfall (mm)	1662†	1480
Land Use (Crop Systems)	wheat / soybean / oats + forage turnip / soybean	Soybean/Brachiaria/cotton/ millet/Soybean/Corn-Brachiaria
Crop Intensity	low/ medium	High
NT duration	23	5
Addition of plant biomass (Mg ha^{-1} $year^{-1}$)	6-8	14-15
Sampling Depth (m)	0-0.05; 0.05-0.20; 0.20-0.30; 0.30-0.40; 0.40-0.60 e 0.60-1.0	0-0.10; 0.10-0.20; 0.20-0.40 e 0.40-1.0

‡ Brazil (1973); † average from 1976 to 2005. Data source: Rio Grande do Sul Climate Atlas (available at www.cemet.rs.gov.br); †† INMET (2010).

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Table 2. Description of soil texture of two sites.

Sites	Management	Depth m	Sand g kg^{-1}	Clay	Silt
Site 1 Manoel Viana - Rio Grande do Sul state					
	NT	0-0.05	783.06	158.00	58.94
	NT	0.05-0.20	749.58	194.00	56.42
	NT	0.20-0.30	761.98	180.67	57.35
	NT	0.30-0.40	710.52	236.00	53.48
	NT	0.40-0.60	691.92	256.00	52.08
	NT	0.60-1.0	678.90	270.00	51.10
	NV	0-0.05	796.08	144.00	59.92
	NV	0.05-0.20	766.32	176.00	57.68
	NV	0.20-0.30	762.60	180.00	57.40
	NV	0.30-0.40	775.62	166.00	58.38
	NV	0.40-0.60	779.34	162.00	58.66
	NV	0.60-1.0	773.76	168.00	58.24
Site 2 Luiz Eduardo Magalhães – Bahia state					
	NT	0-0.10	817.36	117.33	65.31
	NT	0.10-0.20	803.92	122.67	73.41
	NT	0.20-0.40	794.69	144.00	61.31
	NT	0.40-1.0	734.63	172.00	93.37
	NV	0-0.10	806.93	126.67	66.40
	NV	0.10-0.20	805.10	150.00	44.90
	NV	0.20-0.40	775.20	130.00	94.80
	NV	0.40-1.0	734.07	186.67	79.27

NT = no-tillage system; NV = Native vegetation.

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Table 3. Concentrations of soil organic carbon (g kg^{-1}) at different depths of Quart zarenic soil. Manoel Viana (Rio Grande do Sul state) and Luiz Eduardo Magalhães (Bahia state).

Sites	**Depth (m)**	**Management**	
		NV†	**NT††**
Site 1 Manoel Viana - Rio Grande do Sul state	0-0.05	7.80 b $^{\pm 1,43}$	11.22 a $^{\pm 1,13}$
	0.05-0.20	6.76 a $^{\pm 2,00}$	5.67 a $^{\pm 1,64}$
	0.20-0.30	5.56 a $^{\pm 2,45}$	5.17 a $^{\pm 1,04}$
	0.30-0.40	4.91 a $^{\pm 2,49}$	6.00 a $^{\pm 1,66}$
	0.40-0.60	4.29 a $^{\pm 1,70}$	5.06 a $^{\pm 1,27}$
	0.60-1.0	4.00 a $^{\pm 1,66}$	4.67 a $^{\pm 1,39}$
Site 2 Luiz Eduardo Magalhães – Bahia state			
	0-0.10	5.92 b $^{\pm 1,04}$	6.80 a $^{\pm 1,01}$
	0.10-0.20	5.14 a $^{\pm 0.75}$	5.87 a $^{\pm 0,64}$
	0.20-0.40	4.77 a $^{\pm 0,33}$	4.34 a $^{\pm 0,41}$
	0.40-1.0	4.13 a $^{\pm 0,05}$	3.61 a $^{\pm 0,58}$

† NV = Native Vegetation; †† NT = No-till system.

Means followed by equal letters, lowercase lines, do not differ from each other by Tukey's test at 5% significance. (Comparison between management systems (NV x NT) at the same depth).

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