

Review

Soil Carbon Stocks and Greenhouse Gas Mitigation of Agriculture in the Brazilian Cerrado—A Review

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Abstract: New agricultural practices and land-use intensification in the Cerrado biome have affected the soil carbon stocks. A major part of the native vegetation of the Brazilian Cerrado, a tropical savanna-like ecoregion, has been replaced by crops, which has caused changes in the soil carbon (C) stocks. To ensure the sustainability of this intensified agricultural production, actions have been taken to increase soil C stocks and mitigate greenhouse gas emissions. In the last two decades, new agricultural practices have been adopted in the Cerrado region, and their impact on C stocks needs to be better understood. This subject has been addressed in a systematic review of the existing data in the literature, consisting of 63 articles from the Scopus database. Our review showed that the replacement of Cerrado vegetation by crop species decreased the original soil C stocks (depth 0–30 cm) by 73%, with a peak loss of 61.14 Mg ha^{−1}. However, when analyzing the 0–100 cm layer, 52.4% of the C stock data were higher under cultivated areas than in native Cerrado soils, with a peak gain of 93.6 Mg ha^{−1}. The agricultural practices implemented in the Brazilian Cerrado make low-carbon agriculture in this biome possible.

Keywords: agricultural management; agricultural practices; Brazilian Cerrado; greenhouse gas emissions; organic matter; soil organic carbon



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1. Introduction

The Brazilian Cerrado biome, a vast tropical savanna ecoregion in eastern Brazil, covers an area of 204 million hectares. Approximately 111 million hectares (46%) of the native vegetation is still intact. Pastures occupy 25.13% of the soil in the Cerrado (49,874,051 ha) [1], and annual and perennial crops account for about 12.85% of the area (25,510,455 ha) [2]. This biome is currently the main agricultural frontier of the country. Cerrado soils are mostly well drained and highly weathered, with a predominance of kaolinite clays [3] of low chemical reactivity and with limited carbon (C) [4]. It is imperative to preserve the soil quality of this important biome, which feeds a substantial part of the Brazilian and world population. Several products from the Cerrado are exported to various countries, e.g., soybean, maize, cotton, and cattle. In addition, the headwaters of the three rivers of São Francisco, Prata, and Araguaia/Tocantins, which form the main hydrographic basins in Latin America, lie in the Cerrado [5].

One of the key aspects for the evaluation of soil carbon stocks is the organic matter content, because a large part of the organic matter in the soil is constituted by organic carbon [6]. The preservation of or increase in C in soils is a challenge for Brazilian agriculture,

particularly in the Cerrado, since the climatic conditions in this region favor rapid C losses in the soil. This factor not only reduces the soil fertility, but also affects the emission of greenhouse gases (GHG) into the atmosphere [7].

Several studies have already evaluated the C stocks in soils influenced by distinct agricultural practices applied in the Cerrado [8–11]. A recent review [12] observed a tendency of increases in annual C stock rates in Cerrado soils when climate-smart agriculture practices were adopted, consisting of soil fertilization with organic amendments, no-tillage cultivation, and crop–livestock or crop–livestock–forestry systems.

However, there is still no consensus in the literature about which of the agricultural practices contribute to increasing the soil C stocks in the Brazilian Cerrado. In many areas under systems of conservation agriculture, e.g., no-tillage with cover crops, the soil C stocks are lower than in adjacent areas under native Cerrado vegetation [8,13]; the same is true for areas under integrated cultivation systems [14,15]. On the other hand, studies have reported gains in soil C stocks after the introduction of agricultural practices, whereby the soil C stocks were higher than those under native Cerrado without anthropic interference [9,16,17].

In this review, we proposed an investigation of published papers in the literature, covering all agricultural practices used currently in the Brazilian Cerrado, to identify how agriculture has affected the C stocks of these soils and how it can affect GHG emissions into the atmosphere. The potential of C sequestration by soils is highly influenced by the initial soil C content [18]. Thus, this review took the values of the original C stocks in the soil into consideration, i.e., before the introduction of any agricultural practice, in comparison with the C stocks of the cultivated areas.

At the beginning of the agricultural occupation of the Cerrado, the most used system was conventional cultivation, where the soil is ploughed, involving an intensive use of plow and harrow. Later, the no-tillage and integrated systems with crops, livestock, and forestry were introduced [19,20]. The data of this review represent these different agricultural practices.

Most studies have shown that C stocks in cultivated areas are lower than those found in native Cerrado soils (area with native vegetation, adjacent to the experimental sites). Nevertheless, when soil C stocks are assessed at greater depths (0–100 cm layer), 52.4% of the data from agricultural soils have higher values than in areas of the Cerrado without anthropogenic interference. This shows that it is possible to practice agriculture on the Cerrado soils that contribute to soil C sequestration.

The questions of this review were: (1) Is it possible to have low-C agriculture on Brazilian Cerrado soils? (2) Can agriculture in the Cerrado increase soil C sequestration and, consequently, mitigate GHG emissions? (3) Does the sampling depth of C stocks interfere with the results? (4) Do the agricultural practices applied in the Brazilian Cerrado still need to be improved?

2. Results and Discussion

Figure 1 shows the geographic distribution of the studies across the Brazilian Cerrado. The studies were carried out in the different microregions of the Brazilian Cerrado and are therefore representative of the regionally used agricultural practices.

The selected studies deal with the different agricultural practices used in the Cerrado, namely, no-tillage systems, conventional tillage, monoculture, silvopastoral, integrated crop–livestock, and integrated crop–livestock–forest.

The articles selected for this review include several plant species currently cultivated in the soils of the Brazilian Cerrado (Table 1). The Cerrado vegetation sub-types considered in this review were Cerrado *sensu stricto* (shrubland, savanna-like vegetation with trees) and Cerradão (forest type savanna, closed canopy forest).

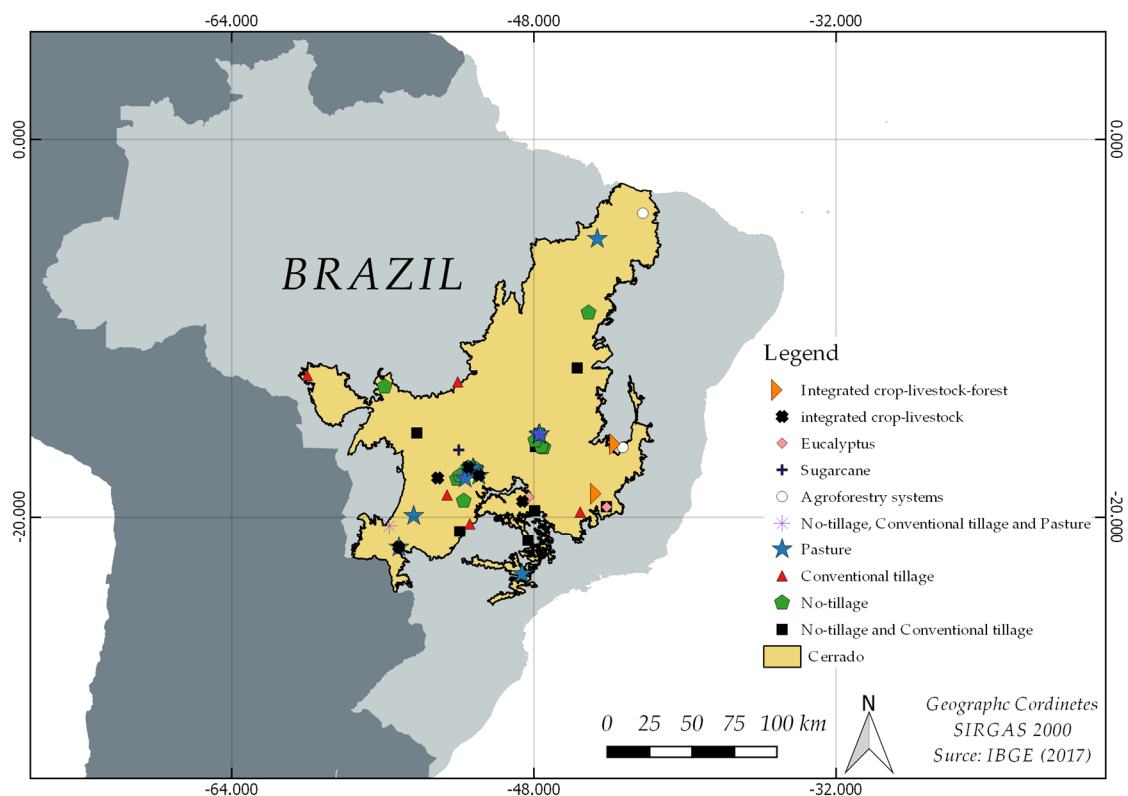


Figure 1. Distribution of locations of experimental studies analyzed in this review, in the Brazilian Cerrado.

Table 1. Cultivated species found in the database obtained for the Cerrado with disponible soil carbon stock data.

Scientific Name	Common Name
Crops	
<i>Glycine max</i>	Soybean
<i>Zea mays</i>	Maize
<i>Sorghum bicolor</i>	Sorghum
<i>Oryza sativa</i>	Rice
<i>Phaseolus vulgaris</i>	Common bean
<i>Solanum lycopersicum</i>	Tomato
<i>Gossypium hirsutum</i>	Cotton
<i>Jatropha</i> spp.	Jatropha
<i>Saccharum officinarum</i>	Sugarcane
Cover crops	
<i>Brassica rapa</i>	Turnip
<i>Gliricidia sepium</i>	Gliricidia
<i>Crotalaria</i> sp	Crotalaria
<i>Cajanus cajan</i>	Pigeon pea
<i>Canavalia ensiformis</i>	Pork bean
<i>Pennisetum glaucum</i>	Millet
Pastures	
<i>Brachiaria decumbens</i>	Brachiaria grass
<i>Brachiaria brizantha</i>	Palisade grass
<i>Panicum maximum</i> cv. Mombaça	Mombaça grass
<i>Panicum maximum</i> cv. Tanzânia	Tanzania grass
<i>Cynodon</i> spp.	Bermuda grass

Table 1. Cont.

Scientific Name	Common Name
<i>Cenchrus ciliaris</i>	Buffalo grass
<i>Cenchrus echinatus</i>	Burr grass
<i>Paspalum atratum</i>	Pojuca Grass
Forestry	
<i>Hevea brasiliensis</i>	Rubber tree
<i>Eucalyptus urophylla</i>	Eucalyptus urophylla
<i>Eucalyptus grandis</i>	Rose gum
<i>Pinus caribaea hondurensis</i>	Pinus
<i>Acrocomia aculeata</i>	Coconut palm

Most of the soil C stock data compiled in this review (185 of 283, or 65.37%) indicated that replacing the Cerrado vegetation with cultivated species reduced soil C stocks when compared with the initial soil C stocks, before the conversion to agriculture. On the other hand, 34.62% (98 of 283) of the soil C data indicated gains in the soil C stocks, i.e., it is possible to maintain the agricultural production on Cerrado soils and yet increase the soil C stocks. Depending on the agricultural practices, after the conversion of native Cerrado to agriculture, the soil can function a source or sink of atmospheric C [21]. Even under conservation managements, such as no-tillage or livestock–forestry integration, the original soil C stocks can be reduced [8,14,15].

Some studies in this review described agricultural practices by which the soil organic C stocks in Cerrado soil were increased by up to 93.6 Mg ha^{−1} [10]. However, other studies reported losses, which reached a maximum of 84.53 Mg ha^{−1} of C lost from the soil [8].

In agriculture, the applied practices affect the natural equilibrium of the soil and vegetation system. This is a consequence of soil tillage, fertilization, and the introduction of new plant species and pesticide application [22]. There is no way of practicing agriculture without any interference. The objective of this review is the identification of agricultural practices that cause the least possible impact, or which could even improve C stocks in the soils of the Brazilian Cerrado. The data of this review were grouped into the following layers: 0–30; 0–40; 0–60; and 0–100 cm. (Figures 2–5).

2.1. Variation in the Soil Carbon Stocks at the 0–30 cm Depth

For the 0–30 cm layer, 82 items of data from the studies in the articles of soil carbon stocks were analyzed (Figure 2). Of these, 26.8% (22 of 82) indicated increases after the implementation of agricultural practices, i.e., native Cerrado replacement by species of agricultural interest increased the soil C stocks. In addition, gains above 10 Mg ha^{−1} were recorded in five data items of soil C stocks [23,24]. Two of them were obtained under no-tillage cultivation and the other two under more than 20-year-old pastures.

Nevertheless, losses of soil C stocks were also recorded in the 0–30 cm layer. Of the 82 data items of soil C stocks analyzed, 60 (73%) indicated a reduction in soil stocks compared to those in soils under native Cerrado (Figure 2). The highest reduction was 61.14 Mg ha^{−1}, recorded in an Oxisol under Integrated Crop Livestock (ICL) cultivated with maize+brachiaria–cotton/soybean [14]. Rotations that include cotton can result in soil C losses due to the stalk management carried out in the areas with a tractor that moves the surface soil layer to control pests and diseases [21].

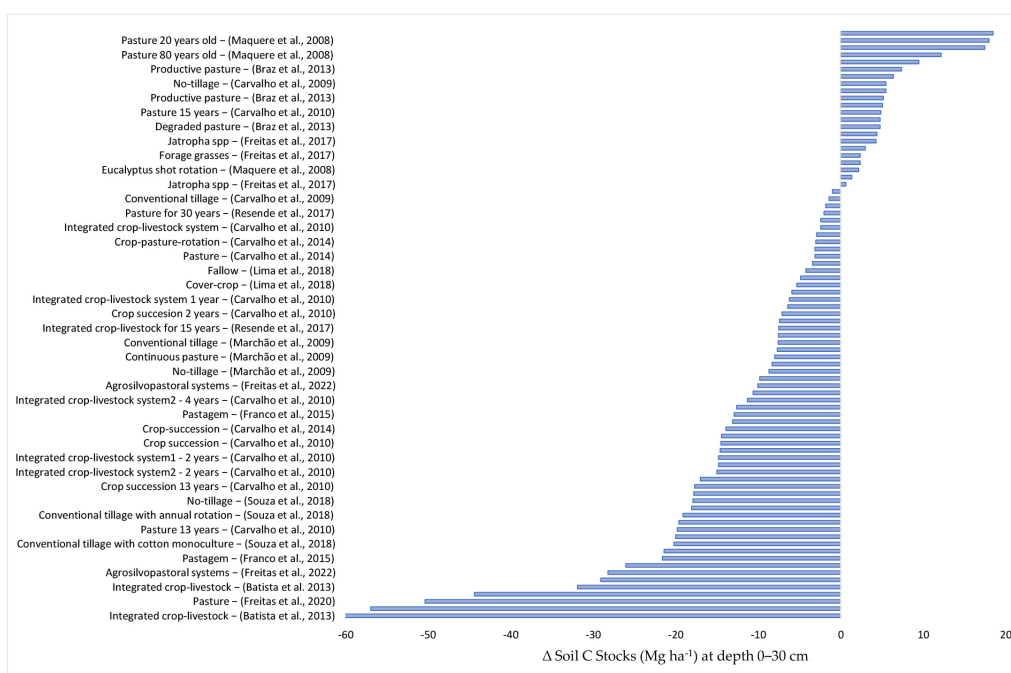


Figure 2. Soil carbon stock losses and gains (Mg ha^{-1}), in response to different agricultural practices, in the 0–30 cm layer compared with the original C stocks in soil under Cerrado vegetation. The works cited are: (Batista et al., 2013) [14], (Freitas et al., 2020) [15], (Carneiro et al., 2013) [16], (Miranda et al., 2016) [17], (Rosinger et al., 2023) [18], (Costa et al., 2006) [19], (Silva et al., 2020) [20], (Carvalho et al., 2010) [21], (Dignac et al., 2017) [22], (Carvalho et al., 2009) [23], (Maquere et al., 2008) [24], (Freitas et al., 2022) [25], (Franco et al., 2015) [26], (Souza et al., 2018) [27], (Ferreira et al., 2016) [28], (Carvalho et al., 2014) [29], (Cruvinel et al., 2011) [30], (Marchão et al., 2009) [31], (Lima et al., 2018) [32], (Resende et al., 2017) [33], (Braz et al., 2013) [34], (Freitas et al., 2017) [35], (Carvalho et al., 2009) [23].

In the 0–30 cm layer, eight data items of soil C stock indicated losses above 25 Mg ha^{-1} [15,16,21,26]. Of these, three were determined in soils under integrated crop-livestock (ICL) (61.14 Mg ha^{-1} , 31.89 Mg ha^{-1} , 29.07 Mg ha^{-1}), three in pasture soils (56.96 Mg ha^{-1} , 50.38 Mg ha^{-1} , 26.06 Mg ha^{-1}), and two in soils under integrated crop-livestock-forestry (ICLF) (44.30 Mg ha^{-1} and 28.2 Mg ha^{-1}). In general, the introduction of pastures, ICL, and ICLF increased the C stocks in the soil. Yet, when planting is carried out in areas with low C stocks, it takes a longer time until the increases in C stocks in these soils become perceptible [15].

2.2. Variation in the Soil Carbon Stocks at the 0–40 cm Depth

Figure 3 lists 74 soil C stock data items of the 0–40 cm layer. Of these, 25 (33.7%) showed an increase in soil C stocks concerning the stocks recorded in the soil under Cerrado vegetation. Seven data items indicated gains above 10 Mg ha^{-1} [11,36–38]. Five of these represent soil under no-tillage cultivation and two soils under agroforestry. The highest gain in soil C stock was 59.63 Mg ha^{-1} , in an Oxisol under agroforestry [11]. The diversification of plant species is one of the aspects that significantly contribute to increase soil C stocks [39]. This is not only due to the quantity, but, mainly, to the quality of these plant residues added to the soil with different C/N and lignin/N ratios [40], as is also the case in agroforestry systems [41].

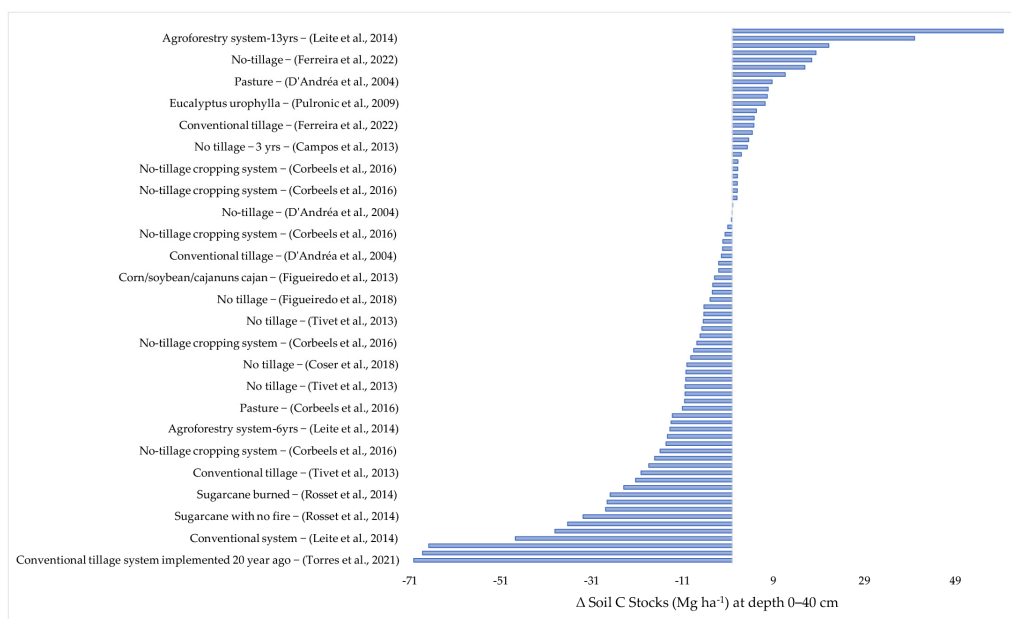


Figure 3. Soil carbon stock losses and gains (Mg ha⁻¹), in response to different agricultural practices, in the 0–40 cm layer compared with the original C stocks in soil under Cerrado vegetation. The works cited are: (Rocha et al., 2014) [11], (Torres et al., 2021) [13], (Ferreira et al., 2022) [42], (Campos et al., 2013) [36], (Leite et al., 2014) [37], (Rosset et al., 2014) [38], (Torres et al., 2019) [43], (Coser et al., 2018) [40], (Corbeels et al., 2016) [41], (Tivet et al., 2013) [44], (Figueiredo et al., 2018) [45], (Figueiredo et al., 2013) [46], (Loss et al., 2012) [47], (Loss et al., 2013) [48], (D'Andréa et al., 2004) [49], (Vicentini et al., 2019) [50], (Pultronik et al., 2009) [51].

In the 0–40 cm layer, 49 (66.2%) of the data items indicated a reduction in the soil C stocks in relation to the native Cerrado areas. Ten data items of soil C stocks showed losses above 25 Mg ha⁻¹, two of which represented crops under conventional tillage; four referred to crops under no-tillage and the other four were sugarcane monoculture [13,37,38,43]. The highest C losses were 70.13 Mg ha⁻¹, recorded in an Oxisol cultivated for 20 years with maize/soybean/common bean/sorghum under conventional tillage [13].

2.3. Variation in the Soil Carbon Stocks at the 0–60 cm Depth

Figure 4 contains 10 data items of soil C stocks recorded in the 0–60 cm layer. Of these, three showed gains in the soil C stock compared to the native Cerrado [52,53]. Two of the data items referred to soils under no-tillage crops (soybean/*Brachiaria ruziziensis*/soybean and soybean/*B. ruziziensis*), and the gains were 5.2 Mg ha⁻¹ and 4.4 Mg ha⁻¹, respectively. The other C stock data were determined in soil under *Eucalyptus camaldulensis*, with a gain of 3.01 Mg ha⁻¹. On the other hand, seven data items recorded decreases in soil C stocks, three of which exceeded reductions of 25 Mg ha⁻¹ [54]. The highest loss in soil C stocks (50.1 Mg ha⁻¹) was recorded in soil growing *Braquiaria brizantha* under conventional management [54], which shows that soil tillage accelerates organic matter decomposition and that a large part of the C is oxidized and returns to the atmosphere as CO₂, reducing the capacity of the soil to accumulate/stock soil C.

2.4. Variation in the Soil Carbon Stocks at the 0–100 cm Depth

Figure 5 shows 63 data items of soil C stocks recorded in the 0–100 cm layer. Of these, 33 (52.4%) indicate higher soil C stocks under agriculture than in Cerrado soils. The gains ranged from 1.3 Mg ha⁻¹ to 93.6 Mg ha⁻¹. This wide variation was due to differences in the systems, which included degraded to well-managed pastures. Twenty data items represented gains above 10 Mg ha⁻¹ [10,17,23,34,51,55]. Of these, 14 were determined in Oxisol under pasture, three in soils under crop–livestock–forestry integration, two in no-

tillage conditions, and one in soil under *Eucalyptus urophylla*. The gains in soil C stock were highest in Oxisol under *Urochloa decumbens* cv Basilisk and *Brachiaria brizantha* [10,34]. This can be explained by the high capacity of pastures to produce shoot and mainly root [56], and the positive effect of pasture management, by which a crop residue cover is left on the soil surface. Even in degraded areas, the biomass production by *Brachiaria* is significant [21]. Some *Brachiaria* species can adapt well to the soils of the Brazilian Cerrado, producing large quantities of the shoot and mainly root biomass and are efficient in storing C in the soil profile [56,57].

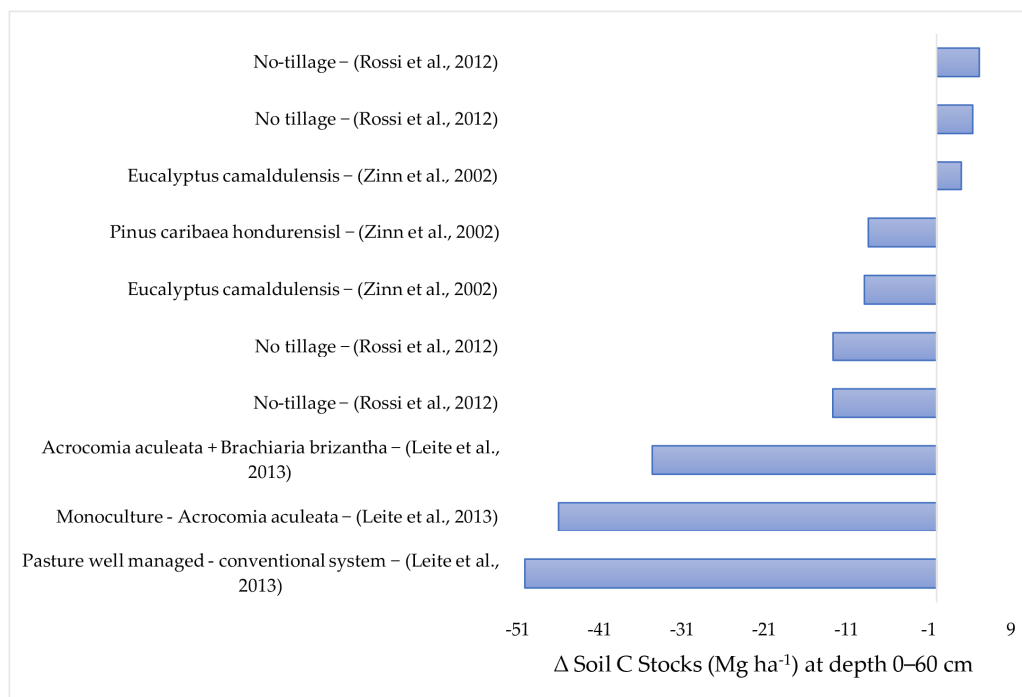


Figure 4. Soil carbon stock losses and gains (Mg ha^{-1}), in response to different agricultural practices, in the 0–60 cm layer compared with the original C stocks in soil under Cerrado vegetation. The works cited are: (Zinn et al., 2002) [52], (Rossi et al., 2012) [53], (Leite et al., 2013) [54].

Carbon losses were also recorded in the 0–100 cm layer. Thirty data items of soil C stocks indicated losses against those under native Cerrado. In 17 cases, the soil C stock data indicated losses above 25.0 Mg ha^{-1} [8,27,28,44,58]. Of these, nine were determined in soils under no-tillage cultivation and eight under conventional tillage. The highest losses (84.53 Mg ha^{-1}) were recorded in soil with different cover crops under no-tillage cultivation [8].

To increase the soil C stocks, the agricultural practices must be adapted to local conditions and must have the capacity to increase biomass production and, consequently, the input of C into the soil. In [59], Rumpel et al. highlight that keeping the soil covered, as well as effective nutrient management, are effective agricultural practices to recover and increase carbon stocks in the soil. Simultaneously, they must prevent this C from being released into the atmosphere or transferred to other reservoirs at harvest [22]. In this sense, agricultural practices that favor the physical, physical–biochemical, and physical–chemical protection of organic carbon must be adopted in production systems. Good results were observed [60], with carbon accumulation distributed along the soil profile (0–100 cm) with manure application.

The choice of plant species for cultivation is decisive for this purpose, since plants represent the link between C in the atmosphere and the C stored in the soil [61]. The diversification of plant species in agricultural systems with a grass–legume species mixture is recommended as a climate-smart farming practice [12,62]. Grasses can remove large

amounts of C from the atmosphere, as they produce high biomass quantities [59]. Legumes will contribute to the nutrition of these plants, which can intensify biomass production without fertilizer application. To increase C stocks in Cerrado soils, [8,63] species such as *Urochloa ruziziensis* and *Canavalia brasiliensis* are recommended as cover crops due to the low C/N ratio, high hemicellulose, and low lignin contents.

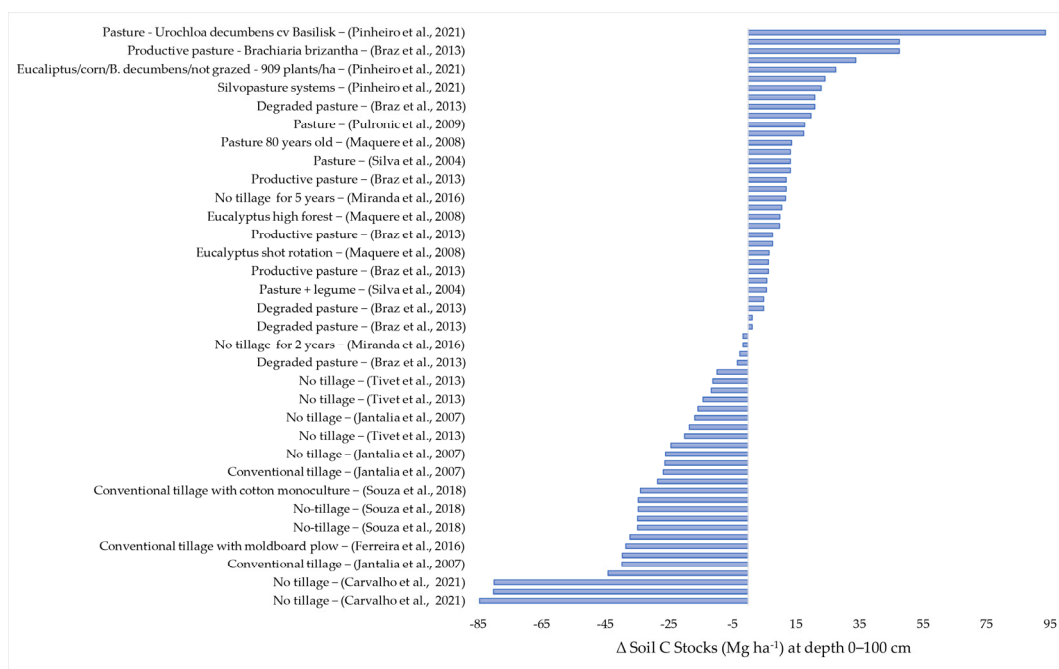


Figure 5. Soil carbon stock losses and gains (Mg ha^{-1}), in response to different agricultural practices, in the 0–100 cm layer compared with the original C stocks in soil under Cerrado vegetation. The works cited are: (Carvalho et al., 2021) [8], (Pinheiro et al., 2021) [10], (Miranda et al., 2016) [17], (Maquere et al., 2008) [24], (Souza et al., 2018) [27], (Ferreira et al., 2016) [28], (Braz et al., 2013) [34], (Tivet et al., 2013) [44], (Pultronic et al., 2009) [51], (Silva et al., 2004) [55], (Jantalia et al., 2007) [58].

The no-tillage system, without soil preparation, will contribute to a reduction in organic matter oxidation, with a consequent increase in soil C stocks. Conversely, the effect of the no-tillage approach may be low if the plants are not able to capture CO_2 from the atmosphere [57]. Therefore, the choice of a diverse range of crop species for the production system is essential for higher soil C stocks. Gerke J [64] highlights that crop rotation with a mix of grasses and legumes, and species with great potential for biomass production associated with no tillage or minimum tillage is of fundamental importance in maintaining an increase in the soil organic carbon content.

The increase in soil C stocks in the Brazilian Cerrado depends on the species included in the cropping systems, and not only on not tilling the soil [61]. When species with a high C/N ratio are included, as in the case of grasses, it is more likely that C will be accumulated in the soils of this region. No-tillage systems with rapid plant decomposition do not contribute to C sequestration in soils in the Cerrado [31,57]. The introduction of legume species in pastures may favor an increase in soil C [65,66] as the nitrogen source can favor biomass production.

In the soil layers, we also observed that the effect of agricultural practices on the soil C stocks in the Brazilian Cerrado was more consistent when analyzing the 0–100 cm layer. Data from surface layers alone may not reflect the real changes that occurred as a result of agricultural practices. The effects of agricultural practices on soil C stocks may be imperceptible when only a depth of 0–30 cm is analyzed [17]. This can mainly be explained by the contribution of the root system of different plant species to increase soil C [17,61]. The carbon taken by the roots into the deeper layers of the soil has a great contribution

to carbon sequestration, because in these layers, the carbon is protected against microbial attack due to the conditions of low oxygen concentration that reduce the microbial biomass as well as its activity [67].

2.5. Principal Component Analysis (PCA)

In order to study the relation between the edaphoclimatic factors that affect variations in the carbon stocks in each land use, a principal component analysis (PCA) was applied on a pair of matrices with two soil layers. These matrices were composed of 107 and 82 lines (carbon stock data) and 9 columns (categorical and response variables), respectively, for the most relevant soil layers (0–30 and 0–100 cm). Soil type and land use were used as categorical variables and clay content, time after conversion, soil carbon stocks, delta C stocks, mean temperature, and rainfall as response variables.

Table 2 shows the results for the principal component analysis for two depths. For the 0–30 cm layer (Table 2, Figure 6a), the PCA indicates that 57.3% of the original data could be explained by the two main components. For the 0–100 cm layer (Table 2, Figure 6b), the PCA indicates that 59.2% of the original data could be explained by the two main components. It was observed that, in the 0–30 cm layer, the soil C stock and clay content were strongly correlated. These variables showed the higher values of loading at the PC1 axis. At the PC 2 axis, the higher value of loading was related to the delta soil C stock. For the 0–100 cm layer, the soil C stock and the clay content were strongly correlated. These variables showed the higher values of loading at the PC1 axis. At the PC 2 axis, the higher value of loading was related to the delta soil C stock.

Table 2. Summary of principal component analysis (PCA) for the 0–30 and 0–100 cm layers.

	PC1	PC2	PC1	PC2
Depth	0–30 cm		0–100 cm	
Variability (%)	34.1	23.2	37.0	22.2
Cumulative (%)	34.1	57.3	37.0	59.2
Clay	0.85	−0.089	0.864	0.034
Time	−0.513	−0.197	−0.174	0.497
Soil carbon stocks	0.719	−0.277	0.898	0.226
Δ Soil carbon stocks	0.040	0.863	0.04	0.729
Mean temperature	0.51	−0.382	0.606	−0.603
Rainfall	0.531	0.615	−0.519	−0.367

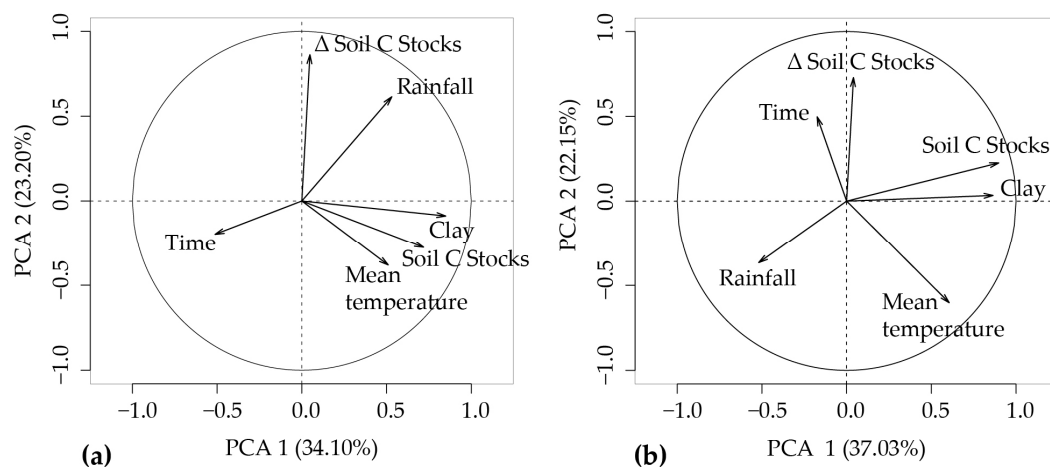


Figure 6. Principal components for (a) 0–30 cm and (b) 0–100 cm layers.

3. Materials and Methods

This systematic review was carried out according to a protocol proposed by [68], based on the PRISMA flowchart. The first step of this review was the definition of the research questions.

The research protocol was based on a combination of keywords. The terms were searched for in the title, abstract, and keywords of published papers. We used the Scopus database to collect the publications.

To answer the research questions, we selected and clustered the keywords as follows: (i) (“integrated crop-livestock” AND “soil carbon stock” AND “cerrado” OR “savanna” AND Brazil), with 215 results; (ii) (“no-tillage” AND “soil carbon stock” AND “cerrado” OR “savanna” AND Brazil), with 216 results; (iii) (“cerrado” AND “carbon stock” AND “soils”), with 99 results; (iv) (“cerrado”, “carbon stock”, “soils” AND “organic matter”), with 51 results; (v) (“soil carbon” OR “soil organic carbon” OR “soil organic matter”) AND (“cerrado” OR “brazilian savanna”) AND (“greenhouse gas”), with 30 results; (vi) (((“organic matter” AND “greenhouse gas”) AND (“cerrado” OR “brazilian savanna”))), with 17 results; (vii) (((“carbon stock” AND “greenhouse gas”) AND (“cerrado” OR “brazilian savanna”))), with 18 results; (viii) (((“organic matter” AND “root pasture”) AND (“cerrado” OR “brazilian savanna”))), with 18 results. Based on the examination of these eight conditions, a total of 664 articles (only complete articles) were found.

After eliminating duplicates, 475 articles remained. The abstracts of these 475 were read to select those in which field experiments were carried out in the Cerrado, with measurements of C stocks in the soil profile. To this end, we used the following exclusion criteria:

Exclusion Criterion 1—Review articles, as we were looking for original soil C stock data;

Exclusion Criterion 2—Carbon modeling papers to estimate soil C stocks;

Exclusion criterion 3—Articles that did not use an area of native Cerrado vegetation adjacent to the experimental sites as a reference for the comparison of C stocks;

Exclusion criterion 4—Articles in which the data were expressed in figures and the exact value of soil C stocks could not be identified.

After applying these four exclusion criteria, 63 articles remained for data extraction. The data were extracted from tables and figures containing the values of C stocks in Mg ha^{-1} , measured in soils under agricultural areas and of the reference area—in this case, Cerrado soil without anthropogenic influence.

A spreadsheet was set up with all of the values of the C stocks of the cultivated and native vegetation areas. Then, the differences between the original C stocks in the soil under native Cerrado and agricultural areas were calculated. These differences were expressed in Mg ha^{-1} of C. Subsequently, the data were grouped according to the soil layers: 0–30, 0–40, 0–60, and 0–100 cm. We did not group the C stock data of layers thinner than 30 cm. Next, the data were organized in ascending order. A graph was created for each layer (see Results and Discussion).

Principal component analysis (PCA) was applied to the database extracted from the articles. The quantitative variables selected were mean temperature ($^{\circ}\text{C}$), average annual rainfall (mm), time since land use change (years), clay content (g kg^{-1}), soil C stocks (Mg ha^{-1}), and Δ C stocks (Mg ha^{-1}), calculated as the difference between the soil C stocks under agricultural areas and those under native Cerrado as reference. The soil sampling layers (0–30 and 0–100 cm) corresponded to the qualitative variable analyzed and were defined as recommended by the Intergovernmental Panel on Climate Change (IPCC) (0–30 cm) and the deepest profile usually sampled (0–100 cm).

Before the PCA, measures of sampling adequacy were calculated by the Kaiser–Meyer–Olkin (KMO) and Bartlett’s sphericity tests ($p < 0.05$). Values of more than 0.5 to 1.0 for KMO are considered acceptable for PCA application [69]. The independence of the variables was checked by Bartlett’s sphericity test. Principal component analysis was performed to group the dataset into new variables that resume the information in principal components (PC).

The analysis also prevented multicollinearity between the original variables. The PC had the objective of explaining as much of the variation in the original variables as possible.

4. Conclusions

The contribution of this study is that it shows that the agricultural practices implemented in the Brazilian Cerrado make low-carbon agriculture in this biome possible. In addition to agricultural production, farming in the Brazilian Cerrado can also contribute to soil carbon sequestration and, consequently, the mitigation of greenhouse gas emissions. We presented some studies with gains in soil carbon stocks after the implementation of agricultural management.

In addition, the effect of the agricultural management on soil carbon stocks in the Brazilian Cerrado was more consistent when the 0–100 cm layer was taken into consideration.

However, the agricultural practices implemented in the Brazilian Cerrado can be further improved to favor and recover the lost soil carbon, and even increase its levels. Although soil C storage capacity is low due to the low clay reactivity, the original soil carbon stocks could not be recovered so far by the agricultural managements applied. For the future, we suggest new research in search of agricultural practices that can increase soil carbon stocks and mitigate GHG in the Brazilian Cerrado, with a special emphasis on plant species diversity in the production systems and cover crops with a high C/N ratio in legume–grass mixtures. The evaluations should take a soil layer of at least 0–100 cm into consideration.

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References

1. LAPIG Atlas Digital Das Pastagens Brasileiras-Laboratório de Processamento de Imagens. Available online: <https://atlasdaspastagens.ufg.br/map> (accessed on 15 May 2023).
2. Mapbiomas, B. COBERTURA E TRANSIÇÕES BIOMA & ESTADOS (COLEÇÃO 7.1)-Dados de Área (Ha) de Cobertura e Uso Da Terra Por Bioma e Estado de 1985 a 2021. Available online: <https://mapbiomas.org/estatisticas> (accessed on 15 May 2023).
3. de Mendes, W.S.; Demattê, J.A.M.; Silvero, N.E.Q.; Rabelo Campos, L. Integration of Multispectral and Hyperspectral Data to Map Magnetic Susceptibility and Soil Attributes at Depth: A Novel Framework. *Geoderma* **2021**, *385*. [CrossRef]
4. Reichenbach, M.; Fiener, P.; Hoyt, A.; Trumbore, S.; Six, J.; Doetterl, S. Soil Carbon Stocks in Stable Tropical Landforms Are Dominated by Geochemical Controls and Not by Land Use. *Glob. Chang. Biol.* **2023**. [CrossRef]
5. Myers, N.; Mittermeier, R.A.; Mittermeier, C.G.; Da Fonseca, G.A.B.; Kent, J. Biodiversity Hotspots for Conservation Priorities. *Nature* **2000**, *403*, 853–858. [CrossRef] [PubMed]
6. Briedis, C.; de Moraes Sá, J.C.; Caires, E.F.; de Fátima Navarro, J.; Inagaki, T.M.; Boer, A.; Neto, C.Q.; de Ferreira, A.O.; Canalli, L.B.; dos Santos, J.B. Soil Organic Matter Pools and Carbon-Protection Mechanisms in Aggregate Classes Influenced by Surface Liming in a No-till System. *Geoderma* **2012**, *170*, 80–88. [CrossRef]

7. Sato, J.H.; de Figueiredo, C.C.; Marchão, R.L.; de Oliveira, A.D.; Vilela, L.; Delvico, F.M.; Alves, B.J.R.; de Carvalho, A.M. Understanding the Relations between Soil Organic Matter Fractions and N₂O Emissions in a Long-Term Integrated Crop–Livestock System. *Eur. J. Soil. Sci.* **2019**, *70*, 1183–1196. [\[CrossRef\]](#)
8. de Carvalho, A.M.; Ribeiro, L.R.P.; Marchão, R.L.; de Oliveira, A.D.; Pulrolnik, K.; de Figueiredo, C.C. Chemical Composition of Cover Crops and Soil Organic Matter Pools in No-Tillage Systems in the Cerrado. *Soil Use Manag.* **2021**, *38*, 940–952. [\[CrossRef\]](#)
9. da Silva Farias, P.G.; da Silva Souza, C.B.; Rosset, J.S.; Ozório, J.M.B.; Panachuki, E.; Schiavo, J.A.; Lima, P.R.; Marra, L.M. Physical Fractions of Organic Matter and Mineralizable Soil Carbon as Quality Indicators in Areas under Different Forms of Use in the Cerrado-Pantanal Ecotone. *Environ. Monit. Assess.* **2022**, *194*. [\[CrossRef\]](#) [\[PubMed\]](#)
10. Pinheiro, F.M.; Nair, P.K.R.; Nair, V.D.; Tonucci, R.G.; Venturin, R.P. Soil Carbon Stock and Stability under Eucalyptus-Based Silvopasture and Other Land-Use Systems in the Cerrado Biodiversity Hotspot. *J. Environ. Manag.* **2021**, *299*. [\[CrossRef\]](#) [\[PubMed\]](#)
11. Rocha, G.P.; Fernandes, L.A.; Cabacinha, C.D.; Lopes, I.D.P.; Ribeiro, J.M.; Frazão, L.A.; Sampaio, R.A. Characterization and Carbon Storage of Agroforestry Systems in Brazilian Savannas of Minas Gerais, Brazil. *Cienc. Rural* **2014**, *44*, 1197–1203. [\[CrossRef\]](#)
12. da Silva Oliveira, D.M.; Tavares, R.L.M.; Loss, A.; Madari, B.E.; Cerri, C.E.P.; Alves, B.J.R.; Pereira, M.G.; Cherubin, M.R. Climate-Smart Agriculture and Soil C Sequestration in Brazilian Cerrado: A Systematic Review. *Rev. Bras. Cienc. Solo* **2023**, *47*. [\[CrossRef\]](#)
13. Torres, J.L.R.; e Silva, V.R.; de Almeida Costa, D.D.; Pereira, M.G.; Assunção, S.A.; Gonzalez, A.P.; Pinto, L.A.D.S.R.; Loss, A. Aggregation and Dynamics of Soil Organic Matter under Different Management Systems in the Brazilian Cerrado. *Soil Res.* **2021**, *59*, 715–726. [\[CrossRef\]](#)
14. Batista, I.; Pereira, M.G.; Correia, M.E.F.; Bieluczyk, W.; Schiavo, J.A.; Rows, J.R.C. Teores e Estoque de Carbono Em Frações Lábéis e Recalcitrantes Da Matéria Orgânica Do Solo Sob Integração Lavoura-Pecuária No Bioma Cerrado. *Semin. Cienc. Agrar.* **2013**, *34*, 3377–3388. [\[CrossRef\]](#)
15. de Freitas, I.C.; Ribeiro, J.M.; Araújo, N.C.A.; Santos, M.V.; Sampaio, R.A.; Fernandes, L.A.; Azevedo, A.M.; Feigl, B.J.; Cerri, C.E.P.; Frazão, L.A. Agrosilvopastoral Systems and Well-Managed Pastures Increase Soil Carbon Stocks in the Brazilian Cerrado. *Rangel. Ecol. Manag.* **2020**, *73*, 776–785. [\[CrossRef\]](#)
16. Carneiro, M.A.C.; de Souza, E.D.; Barbosa, H.P.; de Oliveira Sales, L.E.; Vilela, L.A.F. Attributes Quality Indicators in Cerrado Soils Surrounding the Parque Nacional Das Emas, State of Goiás, Brazil. *Biosci. J.* **2013**, *29*, 1857–1868.
17. Miranda, E.; Carmo, J.; Couto, E.; Camargo, P. Long-Term Changes in Soil Carbon Stocks in the Brazilian Cerrado under Commercial Soybean. *Land Degrad. Dev.* **2016**, *27*, 1586–1594. [\[CrossRef\]](#)
18. Rosinger, C.; Keiblinger, K.; Bieber, M.; Bernardini, L.G.; Huber, S.; Mentler, A.; Sae-Tun, O.; Scharf, B.; Bodner, G. On-Farm Soil Organic Carbon Sequestration Potentials Are Dominated by Site Effects, Not by Management Practices. *Geoderma* **2023**, *433*. [\[CrossRef\]](#)
19. Costa, A.E.; Goedert, W.J.; de Souza, D.M.G.S. Qualidade de Solo Submetido a Sistemas de Cultivo Com Preparo Convencional e Plantio Direto. *Pesqui. Agropecuária Bras.* **2006**, *41*, 1185–1191. [\[CrossRef\]](#)
20. Da Silva, J.R.M.; Ensinas, S.C.; Barbosa, G.F.; Rezende, J.V.O.; Barreta, P.G.V.; Zuffo, A.M. Total Organic Carbon and the Humic Fractions of the Soil Organic Matter in Silvopastoral System | Carbono Orgânico Total Do Solo e Frações Húmicas Da Matéria Orgânica Em Sistema Silvopastoril. *Rev. Bras. Cienc. Agrar.* **2020**, *15*. [\[CrossRef\]](#)
21. Carvalho, J.L.N.; Raucci, G.S.; Cerri, C.E.P.; Bernoux, M.; Feigl, B.J.; Wruck, F.J.; Cerri, C.C. Impact of Pasture, Agriculture and Crop–Livestock Systems on Soil C Stocks in Brazil. *Soil Tillage Res.* **2010**, *110*, 175–186. [\[CrossRef\]](#)
22. Dignac, M.F.; Derrien, D.; Barré, P.; Barot, S.; Céillon, L.; Chenu, C.; Chevallier, T.; Freschet, G.T.; Garnier, P.; Guenet, B.; et al. Increasing Soil Carbon Storage: Mechanisms, Effects of Agricultural Practices and Proxies. A Review. *Agron. Sustain. Dev.* **2017**, *37*. [\[CrossRef\]](#)
23. Carvalho, J.L.N.; Cerri, E.P.; Brigitte, J.F.; de Cássia Piccolo, M.; de Paula Godinho, V.; Herpin, U.; Cerri, C.C. Conversion of Cerrado into Agricultural Land in the South-Western Amazon: Carbon Stocks and Soil Fertility. *Sci. Agric.* **2009**, *66*, 233–241. [\[CrossRef\]](#)
24. Maquere, V.; Laclau, J.P.; Bernoux, M.; Saint-Andre, L.; Gonçalves, J.L.M.; Cerri, C.C.; Piccolo, M.C.; Ranger, J. Influence of Land Use (Savanna, Pasture, Eucalyptus Plantations) on Soil Carbon and Nitrogen Stocks in Brazil. *Eur. J. Soil Sci.* **2008**, *59*, 863–877. [\[CrossRef\]](#)
25. de Freitas, I.C.; Alves, M.A.; Magalhães, J.R.; Dias, R.F.; Albuquerque, C.J.B.; Ferreira, E.A.; Fernandes, L.A.; Pegoraro, R.F.; Frazão, L.A. Soil Carbon and Nitrogen Stocks under Agrosilvopastoral Systems with Different Arrangements in a Transition Area between Cerrado and Caatinga Biomes in Brazil. *Agronomy* **2022**, *12*, 2926. [\[CrossRef\]](#)
26. Franco, A.L.C.; Cherubin, M.R.; Pavinato, P.S.; Cerri, C.E.P.; Six, J.; Davies, C.A.; Cerri, C.C. Soil Carbon, Nitrogen and Phosphorus Changes under Sugarcane Expansion in Brazil. *Sci. Total Environ.* **2015**, *515–516*, 30–38. [\[CrossRef\]](#)
27. Souza, L.H.C.; da Silva Matos, E.; de Souza Magalhães, C.A.; de la Torre, É.R.; Lamas, F.M.; Lal, R. Soil Carbon and Nitrogen Stocks and Physical Properties under No-till and Conventional Tillage Cotton-Based Systems in the Brazilian Cerrado. *Land Degrad. Dev.* **2018**, *29*, 3405–3412. [\[CrossRef\]](#)
28. Ferreira, E.A.B.; da Cunha Bustamante, M.M.; Resck, D.V.S.; de Figueiredo, C.C.; de Siqueira Pinto, A.; Malaquias, J.V. Carbon Stocks in Compartments of Soil Organic Matter 31 Years after Substitution of Native Cerrado Vegetation by Agroecosystems. *Rev. Bras. Cienc. Solo* **2016**, *40*. [\[CrossRef\]](#)

29. Carvalho, J.L.N.; Raucci, G.S.; Frazão, L.A.; Cerri, C.E.P.; Bernoux, M.; Cerri, C.C. Crop-Pasture Rotation: A Strategy to Reduce Soil Greenhouse Gas Emissions in the Brazilian Cerrado. *Agric. Ecosyst. Environ.* **2014**, *183*, 167–175. [\[CrossRef\]](#)
30. Cruvinel, Ê.B.F.; da Bustamante, M.M.C.; Kozovits, A.R.; Zepp, R.G. Soil Emissions of NO, N₂O and CO₂ from Croplands in the Savanna Region of Central Brazil. *Agric. Ecosyst. Environ.* **2011**, *144*, 29–40. [\[CrossRef\]](#)
31. Marchão, R.L.; Becquer, T.; Brunet, D.; Balbino, L.C.; Vilela, L.; Brossard, M. Carbon and Nitrogen Stocks in a Brazilian Clayey Oxisol: 13-Year Effects of Integrated Crop-Livestock Management Systems. *Soil Tillage Res.* **2009**, *103*, 442–450. [\[CrossRef\]](#)
32. De Oliveira Lima, I.M.; Silva, M.F.G.; Ensinas, S.C.; Da Silva, J.R.M.; Filho, W.C.M.; Barbosa, G.F. Green Manure for the Increase of Soil Carbon Stocks in Typic Quartzipisament of Cerrado | Adubos Verdes Para o Incremento Dos Estoques de Carbono Em Neossolo Quartzarênico de Cerrado. *Rev. Bras. Cienc. Agrar.* **2018**, *13*. [\[CrossRef\]](#)
33. Resende, T.M.; Rosolen, V.; Bernoux, M.; Moreira, M.Z.; Conceição, F.T.D.; Govone, J.S. Dynamics of Soil Organic Matter in a Cultivated Chronosequence in the Cerrado (Minas Gerais, Brazil). *Soil Res.* **2017**, *55*, 750–757. [\[CrossRef\]](#)
34. Braz, S.P.; Urquiaga, S.; Alves, B.J.R.; Jantalia, C.P.; Guimarães, A. Paula.; dos Santos, C.A.; dos Santos, S.C.; Machado Pinheiro, Ê.F.; Boddey, R.M. Soil Carbon Stocks under Productive and Degraded Brachiaria Pastures in the Brazilian Cerrado. *Soil Sci. Soc. Am. J.* **2013**, *77*, 914–928. [\[CrossRef\]](#)
35. De Freitas, R.C.A.; Popin, G.V.; Milori, D.M.B.P.; Signor, D.; Drumond, M.A.; Cerri, C.E.P. Soil Organic Matter Quality in *Jatropha* Spp. Plantations in Different Edaphoclimatic Conditions. *Rev. Bras. Cienc. Solo* **2017**, *41*. [\[CrossRef\]](#)
36. Campos, L.P.; Leite, L.F.C.; Maciel, G.A.; Brasil, E.L.; de Freitas Iwata, B. Stocks and Fractions of Organic Carbon in an Oxisol under Different Management Systems. *Pesqui. Agropecu. Bras.* **2013**, *48*, 304–312. [\[CrossRef\]](#)
37. Leite, L.F.C.; de Freitas Iwata, B.; Araújo, A.S.F. Soil Organic Matter Pools in a Tropical Savanna under Agroforestry System in Northeastern Brazil. *Rev. Árvore* **2014**, *38*, 711–723. [\[CrossRef\]](#)
38. Rosset, J.S.; Schiavo, J.A.; Atanázio, R.A.R. Chemical Attributes, Total Organic Carbon Stock and Humified of Organic Matter Soil Submitted to Different Systems of sugarcane Management. *Semin. Cienc. Agrar.* **2014**, *35*, 2351–2366. [\[CrossRef\]](#)
39. Denny, D.M.T.; Cerri, C.E.P.; Cherubin, M.R.; Burnquist, H.L. Carbon Farming: Nature-Based Solutions in Brazil. *Green Low-Carbon Econ.* **2023**, *x*, 1–9. [\[CrossRef\]](#)
40. Coser, T.R.; de Figueiredo, C.C.; Jovanovic, B.; Moreira, T.N.; Leite, G.G.; Cabral Filho, S.L.S.; Kato, E.; Malaquias, J.V.; Marchão, R.L. Short-Term Buildup of Carbon from a Low-Productivity Pastureland to an Agrisilviculture System in the Brazilian Savannah. *Agric. Syst.* **2018**, *166*, 184–195. [\[CrossRef\]](#)
41. Corbeels, M.; Marchão, R.L.; Neto, M.S.; Ferreira, E.G.; Madari, B.E.; Scopel, E.; Brito, O.R. Evidence of Limited Carbon Sequestration in Soils under No-Tillage Systems in the Cerrado of Brazil. *Sci. Rep.* **2016**, *6*. [\[CrossRef\]](#)
42. de Barcellos Ferreira, A.C.; Bogiani, J.C.; Borin, A.L.D.C.; Perina, F.J.; Ferreira, G.B.; da Silva, M.A.S.; de Almeida Machado, P.L.O. Organic Carbon Stock Changes and Crop Yield in a Tropical Sandy Soil under Rainfed Grains-Cotton Farming Systems in Bahia, Brazil. *Pesqui. Agropecu. Trop.* **2022**, *52*. [\[CrossRef\]](#)
43. Torres, J.L.R.; Júnior, J.M.; Júnior, J.S.; Vieira, D.D.S.; Souza, Z.M.; Assis, R.; Lemes, E.M. Soil Physical Attributes and Organic Matter Accumulation under No-Tillage Systems in the Cerrado. *Soil Res.* **2019**, *57*, 712–718. [\[CrossRef\]](#)
44. Tivet, F.; De Moraes Sá, J.C.; Lal, R.; Borszowski, P.R.; Briedis, C.; dos Santos, J.B.; Sá, M.F.M.; da Cruz Hartman, D.; Eurich, G.; Farias, A.; et al. Soil Organic Carbon Fraction Losses upon Continuous Plow-Based Tillage and Its Restoration by Diverse Biomass-C Inputs under No-till in Sub-Tropical and Tropical Regions of Brazil. *Geoderma* **2013**, *209–210*, 214–225. [\[CrossRef\]](#)
45. de Figueiredo, C.C.; de Oliveira, A.D.; dos Santos, I.L.; Ferreira, E.A.B.; Malaquias, J.V.; de Sá, M.A.C.; de Carvalho, A.M.; dos Santos, J.D.D.G. Relationships between Soil Organic Matter Pools and Nitrous Oxide Emissions of Agroecosystems in the Brazilian Cerrado. *Sci. Total Environ.* **2018**, *618*, 1572–1582. [\[CrossRef\]](#) [\[PubMed\]](#)
46. Figueiredo, C.C.; Resck, D.V.S.; Carneiro, M.A.C.; Ramos, M.L.G.; Sá, J.C.M. Stratification Ratio of Organic Matter Pools Influenced by Management Systems in a Weathered Oxisol from a Tropical Agro-Ecoregion in Brazil. *Soil Res.* **2013**, *51*, 133–141. [\[CrossRef\]](#)
47. Loss, A.; Pereira, M.G.; Perin, A.; Coutinho, F.S.; Dos Anjos, L.H.C. Particulate Organic Matter in Soil under Different Management Systems in the Brazilian Cerrado. *Soil Res.* **2012**, *50*, 685–693. [\[CrossRef\]](#)
48. Loss, A.; Pereira, M.G.; Perin, A.; Beutler, S.J.; Anjos, L.H.C. Oxidizable Carbon and Humic Substances in Rotation Systems with Brachiaria/Livestock and Pearl Millet/No Livestock in the Brazilian Cerrado. *Span. J. Agric. Res.* **2013**, *11*, 217–231. [\[CrossRef\]](#)
49. d'Andréa, A.F.; Silva, M.L.N.; Curi, N.; Guilherme, L.R.G. Carbon and Nitrogen Storage, and Inorganic Nitrogen Forms in a Soil under Different Management Systems. *Pesqui. Agropecu. Bras.* **2004**, *39*, 179–186. [\[CrossRef\]](#)
50. Vicentini, M.E.; Pinotti, C.R.; Hirai, W.Y.; de Moraes, M.L.T.; Montanari, R.; Filho, M.C.M.T.; Milori, D.M.B.P.; Júnior, N.L.S.; Panosso, A.R. CO₂ Emission and Its Relation to Soil Temperature, Moisture, and O₂ Absorption in the Reforested Areas of Cerrado Biome, Central Brazil. *Plant Soil* **2019**, *444*, 193–211. [\[CrossRef\]](#)
51. Pulrolnik, K.; de Barros, N.F.; Silva, I.R.; Novais, R.F.; Brandani, C.B. Carbon and Nitrogen Pools in Soil Organic Matter under Eucalypt, Pasture and Savanna Vegetation in Brazil. *Rev. Bras. Cienc. Solo* **2009**, *33*, 1125–1136. [\[CrossRef\]](#)
52. Zinn, Y.L.; Resck, D.V.; da Silva, J.E. Soil Organic Carbon as Affected by Afforestation with Eucalyptus and Pinus in the Cerrado Region of Brazil. *For. Ecol. Manag.* **2002**, *166*, 285–294. [\[CrossRef\]](#)
53. Rossi, C.Q.; Pereira, M.G.; Giacomio, S.G.; Betta, M.; Polidoro, J.C. Organic Fractions and Soil Organic Carbon Management Index in an Oxisol under Soybean Cultivation in the Cerrado Region of Goiás, Brazil. *Rev. Bras. Cienc. Agrar.* **2012**, *7*, 233–241. [\[CrossRef\]](#)

54. Leite, L.F.C.; de Arruda, F.P.; Costa, C.D.N.; Ferreira, J.D.S.; Holanda Neto, M.R. Chemical Quality of Soil and Dynamics of Carbon under Monoculture and Intercropping of Acrocomia Palm and Pasture. *Rev. Bras. Eng. Agrícola Ambient.* **2013**, *17*, 1257–1263. [\[CrossRef\]](#)
55. da Silva, J.E.; Resck, D.V.S.; Corazza, E.J.; Vivaldi, L. Carbon Storage in Clayey Oxisol Cultivated Pastures in the “Cerrado” Region, Brazil. *Agric. Ecosyst. Environ.* **2004**, *103*, 357–363. [\[CrossRef\]](#)
56. Ayarza, M.; Rao, I.; Vilela, L.; Lascano, C.; Vera-Infanzón, R. Soil Carbon Accumulation in Crop-Livestock Systems in Soil Savannas of South America: A Review. *Adv. Agron.* **2022**, *173*, 163–226.
57. de Sant-Anna, S.A.C.; Jantalia, C.P.; Sá, J.M.; Vilela, L.; Marchão, R.L.; Alves, B.J.R.; Urquiaga, S.; Boddey, R.M. Changes in Soil Organic Carbon during 22 Years of Pastures, Cropping or Integrated Crop/Livestock Systems in the Brazilian Cerrado. *Nutr. Cycl. Agroecosyst.* **2017**, *108*, 101–120. [\[CrossRef\]](#)
58. Jantalia, C.P.; Resck, D.V.S.; Alves, B.J.R.; Zotarelli, L.; Urquiaga, S.; Boddey, R.M. Tillage Effect on C Stocks of a Clayey Oxisol under a Soybean-Based Crop Rotation in the Brazilian Cerrado Region. *Soil Tillage Res.* **2007**, *95*, 97–109. [\[CrossRef\]](#)
59. Rumpel, C.; Amiraslani, F.; Bossio, D.; Chenu, C.; Cardenas, M.G.; Henry, B.; Espinoza, A.F.; Koutika, L.-S.; Ladha, J.; Madari, B.E.; et al. Studies from Global Regions Indicate Promising Avenues for Maintaining and Increasing Soil Organic Carbon Stocks. *Reg. Environ. Change* **2023**, *23*, 8. [\[CrossRef\]](#)
60. Abrar, M.M.; Xu, M.; Shah, S.A.A.; Aslam, M.W.; Aziz, T.; Mustafa, A.; Ashraf, M.N.; Zhou, B.; Ma, X. Variations in the Profile Distribution and Protection Mechanisms of Organic Carbon under Long-Term Fertilization in a Chinese Mollisol. *Sci. Total Environ.* **2020**, *723*, 138181. [\[CrossRef\]](#)
61. Albuquerque, M.A.; Dieckow, J.; Sordi, A.; Piva, J.T.; Bayer, C.; Molin, R.; Pergher, M.; Ribeiro-Junior, P.J. Carbon and Nitrogen in a Ferralsol under Zero-Tillage Rotations Based on Cover, Cash or Hay Crops. *Soil Use Manag.* **2015**, *31*, 1–9. [\[CrossRef\]](#)
62. Rosolem, C.A.; Li, Y.; Garcia, R.A. Soil Carbon as Affected by Cover Crops under No-till under Tropical Climate. *Soil Use Manag.* **2016**, *32*, 495–503. [\[CrossRef\]](#)
63. Ramos, M.L.G.; da Silva, V.G.; de Carvalho, A.M.; Malaquias, J.V.; de Oliveira, A.D.; de Sousa, T.R.; Silva, S.B. Carbon Fractions in Soil under No-Tillage Corn and Cover Crops in the Brazilian Cerrado. *Pesqui. Agropecu. Bras.* **2020**, *55*. [\[CrossRef\]](#)
64. Gerke, J. The Central Role of Soil Organic Matter in Soil Fertility and Carbon Storage. *Soil Syst.* **2022**, *6*, 33. [\[CrossRef\]](#)
65. Fisher, M.J.; Rao, I.M.; Ayarza, M.A.; Lascano, C.E.; Sanz, J.I.; Thomas, R.J.; Vera, R.R. Carbon Storage by Introduced Deep-Rooted Grasses in the South American Savannas. *Nature* **1994**, *371*, 236–238. [\[CrossRef\]](#)
66. Tarré, R.; Macedo, R.; Cantarutti, R.B.; Rezende, C.D.P.; Pereira, J.M.; Ferreira, E.; Alves, B.J.R.; Urquiaga, S.; Boddey, R.M. The Effect of the Presence of a Forage Legume on Nitrogen and Carbon Levels in Soils under Brachiaria Pastures in the Atlantic Forest Region of the South of Bahia, Brazil. *Plant Soil* **2001**, *234*, 15–26. [\[CrossRef\]](#)
67. Alcántara, V.; Don, A.; Vesterdal, L.; Well, R.; Nieder, R. Stability of Buried Carbon in Deep-Ploughed Forest and Cropland Soils-Implications for Carbon Stocks. *Sci. Rep.* **2017**, *7*, 5511. [\[CrossRef\]](#)
68. Koutsos, T.M.; Meneses, G.C.; Dordas, C.A. An Efficient Framework for Conducting Systematic Literature Reviews in Agricultural Sciences. *Sci. Total Environ.* **2019**, *682*, 106–117. [\[CrossRef\]](#)
69. Hair, J.F. Multivariate Data Analysis: An Overview. In *International Encyclopedia of Statistical Science*; Springer: Berlin/Heidelberg, Germany, 2011; pp. 904–907.

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