CROP SCIENCE

Assessing the carbon stock of cultivated pastures in Rondônia, southwestern Brazilian Amazon

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Abstract: Cattle ranching is the primary land-use of deforested areas in the Brazilian Amazon. Deforestation precedes pasture establishment, implying tremendous amounts of greenhouse gas emissions caused by carbon stock losses. Despite several studies addressing carbon storage in forests, there is a lack of data regarding cultivated pastures. Hence, the estimation of greenhouse gas emissions associated with land-use change becomes uncertain. In this study, we assessed the carbon stock of cultivated pastures located in Rondônia, southwestern Brazilian Amazon. A total of 50 squared plots of 1 m² were randomly allocated in cattle ranching farms covered by Oxisols (Dystrophic Yellow and Dystrophic Red-Yellow Latosols). Carbon fraction ranged from 0.36 for belowground biomass to 0.45 $gC.g^{-1}$ d.m. for aboveground biomass. The average total carbon stock was 5.17 $MgC.ha^{-1}$, with non-significant differences when stratifying data by soil types. Considering data from the III Brazilian Inventory of Anthropogenic Emissions and Removals of Greenhouse Gases, our results suggested that land-use change from primary forests to cultivated pastures resulted in a loss of 192.54 $MgC.ha^{-1}$, which corresponds to a net emission of 705.98 $MgCO_2eq.ha^{-1}$ to the atmosphere. This study provides valuable information to improve the Brazilian Inventory of Anthropogenic Emissions and Removals of Greenhouse Gases.

Key words: climate change, deforestation, land-use change, signal grass.

INTRODUCTION

The Brazilian Amazon rainforest has suffered from tremendous deforestation rates over the last decades (Fearnside 2008, 2017). The deforestation process usually starts with the logging of valuable timber species. Subsequently, other less-valuable and smaller trees are felled. Commonly, law-protected species remain in the landscape, such as the giant Brazilian nut tree (*Bertholletia excelsa* Bonpl.). This process results in the complete conversion of the natural forest to another land use (Cardille & Foley 2003, Guild et al. 2004, Vieira 2019).

The agricultural frontier (so-called "Arc of Deforestation") accounts for a significant portion of deforestation in the Brazilian Amazon, in which anthropic activities promote environmental degradation (Fearnside 2009). Cattle pastures represent 60-80% of deforested areas in the Brazilian Amazon (Barreto et al. 2005, Bowman et al. 2012, Fearnside 2008). The Amazon Deforestation Monitoring Program (PRODES) estimates that ca. 446,019 km² were deforested since 1988 (INPE 2020). However, the deforested area is much higher when considering the previous deforestation (*i.e.*, before 1988).

Cattle pastures reached 200 million ha in 2007 in Brazil (Benett et al. 2008, Bowman et al. 2012), and nearly one-third of it is located in the Amazon – 29% (Zu Ermgassen et al. 2018). In this scenario, the so-called "brachiaria" is the key species. It is estimated that about 80% of cattle pastures are covered by genotypes brachiaria, mainly the *Urochloa brizantha* cv. Marandu (marandu grass) (Cardoso et al. 2015, Silva et al. 2017).

Rondônia is one of the most threatened states in the Brazilian Amazon. PRODES data figures that 26% of Rondônia's territory has lost forest cover (INPE 2020), while 35% (83,500 km²) have been disturbed somehow. Historically, Rondônia faced huge deforestation rates promoted by illegal logging, road construction, and mining (Guild et al. 2004). However, the most critical land-use change vector is the extensive cattle ranching, practiced for decades (Bastos et al. 2015). In the last decade, however, large-scale mechanized agriculture for soybean production has significantly expanded, replacing cattle pastures and forcing forested areas' conversion onto new pastures (Costa et al. 2017).

The replacement of tropical forests by pasture represents a loss of carbon stocked in the vegetation and implies greenhouse gas emissions (GHG) by land-use change and burning woody waste. Thus, accurate information on biomass and carbon stocks is crucial to calculating GHG emissions. National GHG inventories support the United Nations Framework Convention on Climate Change and report national-scale data to the Paris Agreement, to which Brazil is a signatory. The IPCC default value (IPCC 2003) of carbon stock in planted pastures was used in the third Brazilian GHG inventory (MCTI 2014), resulting in uncertainties in the calculation of emissions derived from land-use change, which is the largest accumulated source of GHG emissions

in Brazil since the beginning of its performing in 1990.

Given this scenario, this study aimed to quantify the carbon stock in cultivated pastures accounting for its different biomass components. This study also aimed to subsidize future Brazilian GHG inventories with novel and site-specific data to make it more accurate and reliable.

MATERIALS AND METHODS

This study was conducted in cattle ranching farms located in Itapuã do Oeste and Cujubim – State of Rondônia, southwestern Brazilian Amazon (Figure 1). The predominant grass species is signal grass (*Urochloa brizantha* Hochst ex A.Rich R.Webster), synonymy of *Brachiaria brizantha*.

Soils are classified as Dystrophic Yellow Latosol (LAd) and Dystrophic Red-Yellow Latossol (LVAd), following the Brazilian System of Soil Classification (IBGE-EMBRAPA 2001, Rondônia 2002). These soil types correspond to Oxisols in US Soil Taxonomy (NRCS – United States Department of Agriculture 2010) and present low natural fertility caused by deficiencies of phosphorus, potassium, and calcium (Fortuna 1988). The study area is encompassed by tropical monsoon climate (*Am*), according to Köppen classification (Alvares et al. 2013). The average annual temperature range from 24 to 26°C, and the precipitation from 2,400 to 2,600 mm.year^{-1} (Gama 2002). The original predominant vegetation is Sub-Mountain Open Rainforest (RADAMBRASIL 1978, Silva & Vinha 2002). Further details can found in Sanquetta et al. (2017).

A total of 50 plots with an area of 1 m² (1 m x 1 m) were randomly allocated in ranching farms across the study area. Data collection were performed during the final period of dry-to-wet transition season (November) of 2019 and
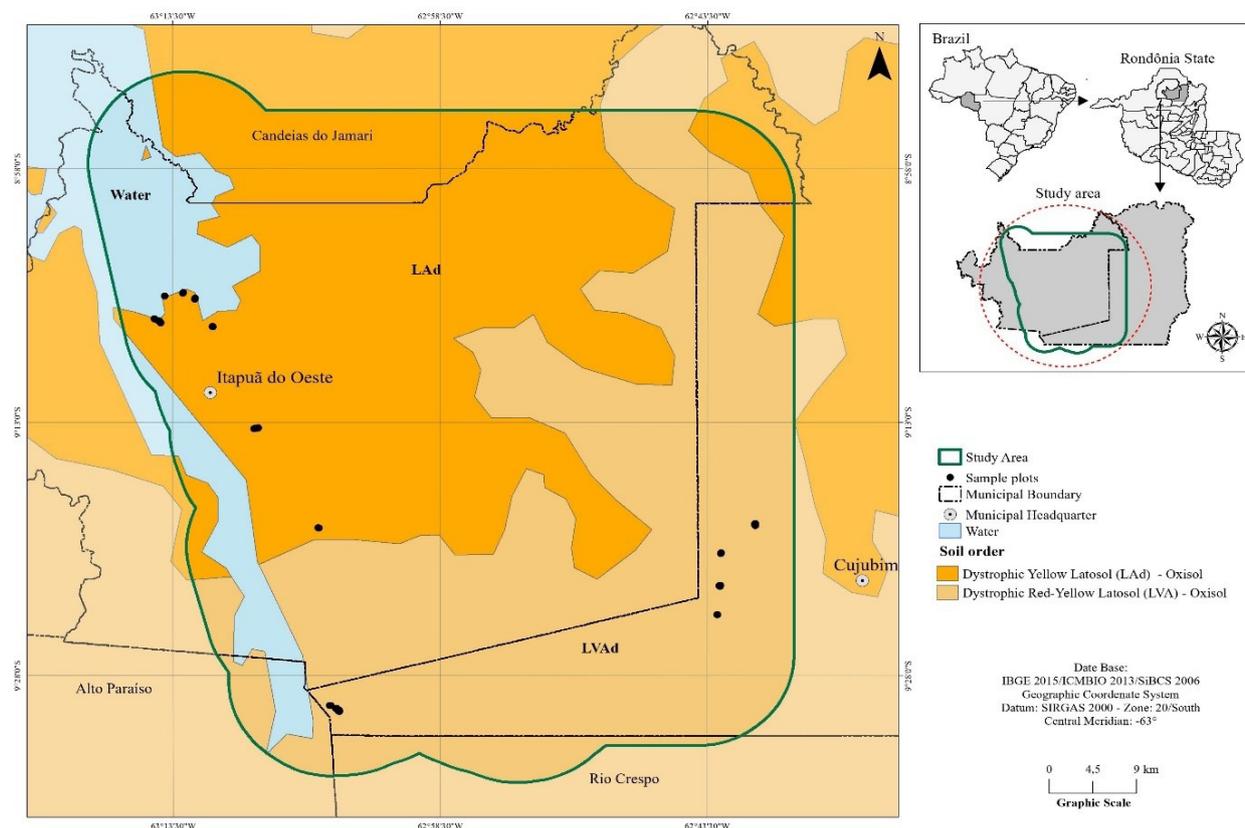
Figure 1. Geographical location and soil characterization of the study area in the State of Rondônia, southwestern Brazilian Amazon.

2020 to avoid the influence of environmental conditions. The sampling strategy encompassed 23 cattle farms in which 25 samples covered each soil type (both LAd and LVAd). Regional cattle ranching consist of pastures (signal grass) established for at least ten years with signal grass and managed by cutting and burning. None has ever been limed or fertilized. The management practices consist of releasing animals (ca. 0.5-1.5 LSU.ha^{-1} – livestock unit per hectare), then conduction to pens, and later grazing (*e.g.*, Bastos, unpublished data).

The aboveground biomass – *AGB* consisted of all living pasture grass (*i.e.*, pseudostems, true stems, nodes, and leaves) within the sample plot, while necromass – *N* consisted of all non-living material, such as dried leaves, stems, and roots. The belowground biomass - *BGB* sampling followed IPCC recommendations, in which all coarse roots (diameter ≥ 2mm) were excavated to 30 cm depth (IPCC 2006, 2019). Every component was weighed using a dynamometer of 10 g precision (fresh weight).

Additionally, samples of 500 g of each component were collected for dry matter and carbon fraction determination. These samples were oven-dried (at 65°C) until they reach constant weight (dry matter). In order to provide a set of conversion factors, we assessed both the Root-to-shoot (*R*) and Dead-live (*DL*) ratios, as defined by the IPCC 2006 Guidelines (IPCC 2006). Finally, each component's carbon stock was assessed by multiplying the dry matter by its carbon fraction. The carbon stock was then converted into CO_2 equivalent ($MgCO_2eq.ha^{-1}$), according to the methodology indicated by the IPCC (Table I).

Every sample was grounded in a Willey-type mill and sifted in a 20-mesh standard. Then, carbon fraction for each grass component (*AGB*, *BGB*, and *N*) was determined by the dry combustion method in a Leco C-144 analyzer, totaling 150 samples.

Biomass and carbon stock partitioning were analyzed considering three components: 1. aboveground biomass (*AGB*); 2. belowground biomass (*BGB*); and 3. necromass (*N*). Descriptive statistical analyses were performed for dry matter, carbon fraction, and carbon stock data. In addition, the Tukey test performed multiple comparisons of carbon stock means for each component and soil type.

RESULTS

Dry matter

The average dry matter was 12.63 Mg.ha^{-1}, in which belowground biomass (*BGB*) presented the greatest partitioning (38%), followed by necromass – *N* (37%). The aboveground biomass (*AGB*) comprised 25% of the total dry matter. All biomass components presented high variability, illustrated by elevated coefficient of variations (*AGB* = 86%; *BGB* = 87%; *N* = 75%).

Table II displays the descriptive statistics for each soil type. Necromass (*N*) presented a similar pattern regardless of soil type, in which the dead-live ratio (*DL*) was 0.57 for LVAd and 0.59 for LAd. In contrast, there was a remarkable difference between the aboveground (*AGB*) and belowground biomass (*BGB*) patterns and partitioning between LAd and LVAd. This difference is evidenced by the root-to-shoot ratio (*R* for LAd = 2.49, *R* for LVAd = 0.96) and the biomass partitioning.

Table I. Term definitions, units, and formulas of biomass components and conversion factors applied to cultivated pastures in the State of Rondônia, southwestern Brazilian Amazon.

Term	Unit	Definition	Formula
Aboveground biomass (*AGB*)*	Mg.ha^{-1}	Dry matter of all living tissues - pseudostems, true stems, nodes and leaves	
Belowground biomass (*BGB*)*		Dry matter of living coarse roots (diameter ≥ 2mm)	
Necromass (*N*)*		Dry matter of non-living materials both above and belowground (*e.g.*, dried leaves, stems, and roots)	
Carbon fraction (*CF*)	gC.g^{-1} d.m.	Grams of C for each gram of dry matter	$CF = \dfrac{m_C}{d.m.}$
Carbon stock (*CS*)	MgC.ha^{-1}	Mega gram of C per hectare	$CS = B \cdot CF$
CO$_2$ equivalent	MgCO$_2$eq.ha^{-1}	Molecular weight ratio of CO$_2$ and C	$CO_2eq = CS \cdot \dfrac{44}{12}$
Root-shoot ratio (*R*)		Ratio between belowground and aboveground biomass	$R = \dfrac{BGB}{AGB}$
Dead-live ratio (*DL*)		Ratio between necromass and living biomass (aboveground + belowground)	$DL = \dfrac{N}{ABG + BGB}$

Where: m_C is mass of C; *d.m.* is the biomass dry matter; Source: IPCC (2006), adapted. * No invasive herbs, secondary vegetation, nor remaining parts of trees were accounted for in this study.

Table II. Descriptive statistics of the dry matter from cultivated pastures in the State of Rondônia, southwestern Brazilian Amazon.

Dry matter (Mg.ha⁻¹)	LAd				LVAd				Total			
	AGB	BGB	N	Total	AGB	BGB	N	Total	AGB	BGB	N	Total
Mean	2.37	5.90	4.89	13.15	3.94	3.77	4.40	12.10	3.15	4.83	4.64	12.63
SD	3.09	5.07	3.76	10.88	2.02	2.90	3.24	7.43	2.70	4.22	3.48	9.24
Minimum	0.27	0.69	0.91	2.36	1.03	0.63	0.81	2.74	0.27	0.63	0.81	2.36
Maximum	11.05	18.25	18.21	47.51	10.05	12.13	12.16	33.39	11.05	18.25	18.21	47.51
CV%	130%	86%	77%	83%	51%	77%	74%	61%	86%	87%	75%	73%
Partitioning%	18%	45%	37%		33%	31%	36%		25%	38%	37%	
R	2.49				0.96				1.53			
DL	0.59				0.57				0.58			
n	25				25				50			

Where: LAd is Dystrophic Yellow Latosol; LVAd is Dystrophic Red-Yellow Latosol; *AGB* is aboveground biomass; *BGB* is belowground biomass; *N* is necromass; *SD* is standard deviation; *CV%* is coefficient of variation; *R* is the root-to-shoot ratio; *DL* is the dead-live ratio; and *n* is the number of plots.

Carbon fraction

Carbon fractions (*CF*) ranged from 0.36 (*SD* = 0.05 gC.g⁻¹ d.m., and CV% = 13.3%) for *BGB* to 0.45 gC.g⁻¹ d.m. for *AGB* (*SD* = 0.01 gC.g⁻¹ d.m., and CV% = 0.3%). The mean carbon fraction of *N* was 0.44 gC.g⁻¹ d.m. (*SD* = 0.01 gC.g⁻¹ d.m., and CV% = 2.1%). Lower mean and higher variability for belowground carbon fraction may be attributed to the fact that this component is in closer contact with soil.

Carbon stock

The mean total carbon stock was 5.17 MgC.ha⁻¹ (*SD* =3.81 MgC.ha⁻¹, and CV% = 74%), ranging from 1.04 to 19.57 MgC.ha⁻¹. The aboveground biomass accounted for 27% of the total carbon stock, while *BGB* and *N* represented 33% and 39%, respectively (Table III). Figure 2 displays the distribution of the carbon stock, in which non-normal data was observed (*p*-value ≤ 0.0001). Log-transformation (with base 10), however, led to data normality, as indicated by Shapiro-Wilk test. All carbon stock distributions were

positive-skewed, indicating the lack of normality. In these cases, log-transformation (with base 10) led to data normality.

The partitioning analysis indicated that necromass – *N* accounted for ca. 40% of the total carbon stock, regardless of soil type. Carbon stock partitioning differed for *ABG* and *BGB* when contrasting soil types. Samples collected on Dystrophic Yellow Latosols (LAd) presented lower *AGB* (20%) when compared to those collected on Dystrophic Red-Yellow Latosols (LVAd) – 35%. Consequently, *BGB* also differed, in which LAd samples presented higher partitioning (40%) when compared to LVAd samples (27%). However, non-significant differences were noticed among the carbon stock of different signal grass components (Figure III). Similarly, the Student´s *t*-test indicated non-significant difference between the total carbon stock in both LAd and LVAd.

The total carbon storage (*AGB* + *BGB* + *N*) is equivalent to 18.96 MgCO₂eq.ha⁻¹, which corresponds to the gross removal of CO₂ by signal grass pastures in the study region, excluding the

Table III. Descriptive statistics of the carbon stock from cultivated pastures in the State of Rondônia, southwestern Brazilian Amazon.

Carbon stock (MgC.ha⁻¹)	LAd				LVAd				Total			
	AGB	*BGB*	*N*	Total	*AGB*	*BGB*	*N*	Total	*AGB*	*BGB*	*N*	Total
Mean	1.06a	2.13a	2.11a	5.31 [ns]	1.76a	1.35a	1.93a	5.03 [ns]	1.41a	1.73a	2.03a	5.17
SD	1.38	1.86	1.65	4.48	0.90	1.02	1.41	3.08	1.21	1.52	1.54	3.81
Minimum	0.12	0.25	0.41	1.04	0.46	0.27	0.36	1.20	0.12	0.25	0.36	1.04
Maximum	4.94	6.65	7.98	19.57	4.50	4.42	5.33	13.90	4.94	6.65	7.98	19.57
CV%	130%	87%	78%	84%	51%	76%	73%	61%	86%	88%	76%	74%
Partitioning%	20%	40%	40%		35%	27%	38%		27%	33%	39%	
n	25				25				50			

Where: LAd is Dystrophic Yellow Latosol; LVAd is Dystrophic Red-Yellow Latosol; *AGB* is aboveground biomass; *BGB* is belowground biomass; *N* is necromass; *SD* is the standard deviation; *CV%* is the coefficient of variation; a is the mean group by the Tukey test at 0.05; subscript [ns] indicates non-significant difference by the Student's *t*-test; and *n* is the number of plots.

soil carbon stock. This value can be considered as the baseline scenario for most cattle ranching farms in the Amazon region since our data inspected the most cultivated pasture in this region, with typical management practices.

DISCUSSION

Cattle ranching activity in Brazil has always been related to forest degradation and deforestation (Cerri et al. 2009). Approximately 60-80% of deforested areas in the Brazilian Amazon are encompassed by cattle ranching pastures (Barreto et al. 2005, Bowman et al. 2012, Fearnside 2008), which places this activity as the most pervasive land-use in the region (Carvalho et al. 2020). Cattle ranching in the Brazilian Amazon is most extensive, characterized by the lack of mechanization and management practices, such as fertilizing. This combination results in low productivity (Escada et al. 2005). Under this scenario, burning is commonly used to improve pasture yield in the first years (Alfaia et al. 2004, Fearnside et al. 2001). However, burning and livestock overgrazing decreases soil fertility over time (Barbosa & Fearnside 1996, Neves Jr et al.

2013). This fact, combined with the low natural fertility of Oxisols, results in degraded pastures.

Degraded pastures are usually abandoned as cattle ranching becomes unviable. This process promotes secondary forests' natural regeneration (Barbosa & Fearnside 2003, Cardille & Foley 2003, Foley et al. 2007, Strassburg et al. 2014). Hence, the land-use change process starts with the displacement of new cattle ranching to areas still covered by primary forests (Barona et al. 2010, Buschbacher et al. 1988). The III Brazilian GHG inventory suggested that the Brazilian Amazon's primary forests account for 197.71 MgC.ha⁻¹ (MCTI 2016). Our results indicated that cultivated pastures account for 5.17 MgC.ha⁻¹, which indicates that the land-use change from primary forest to cultivated pastures results in a loss of 192.54 MgC.ha⁻¹. This value corresponds to a net emission of 705.98 $MgCO_2eq.ha^{-1}$ to the atmosphere. Most of this loss occurs in the first years after deforestation, in which the merchantable timber is harvested, and the remaining biomass is simply left-over or burned before pasture implantation. When roots are not removed, their decomposition leads to slow and continuous GHG emissions by decomposition.
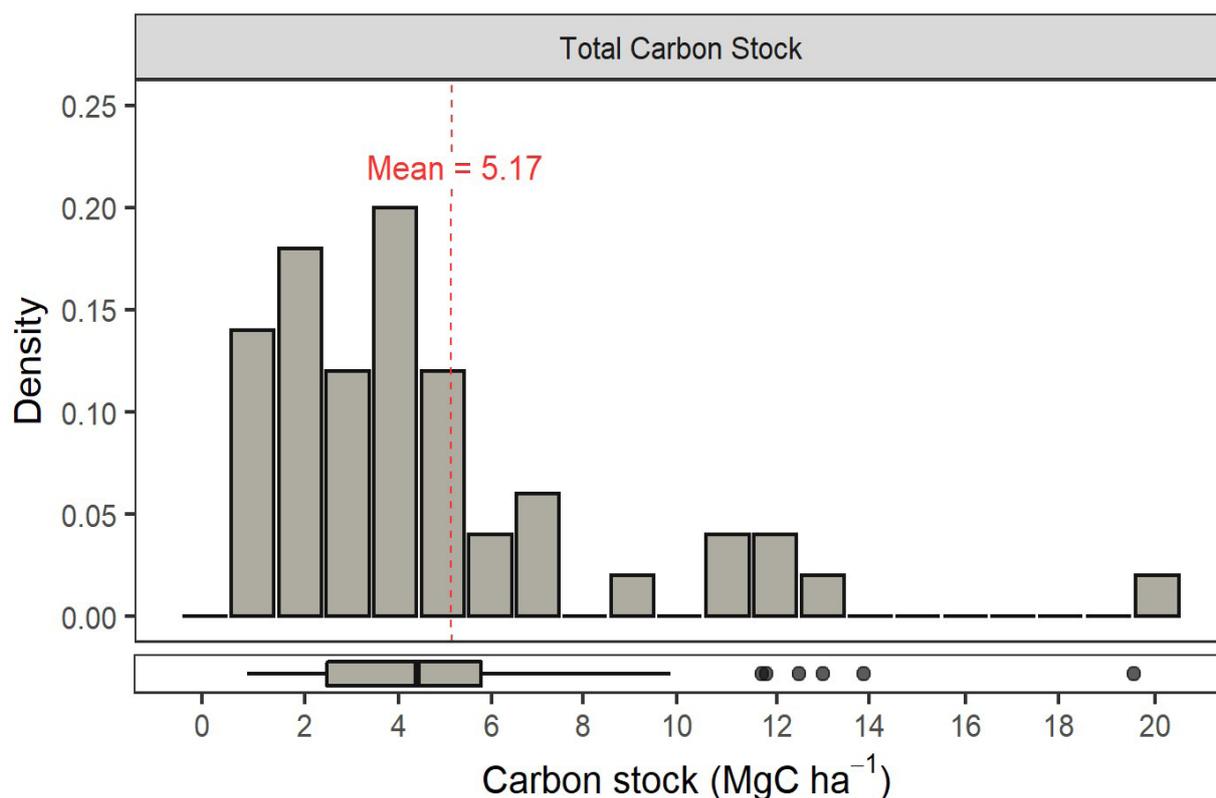
Figure 2. Carbon stock distribution of cultivated pastures in the State of Rondônia, southwestern Brazilian Amazon.

In this sense, the proper management of soils and pastures is vital to increase grass yield and avoid the land-use change process. There is, however, a lack of studies addressing the impact of management practices, such as fertilization, irrigation, and crop rotation, on the carbon stock of cultivated pastures. Most related studies addressed the carbon stock on soils covered by pastures. The influence of land use on soil carbon storage is stressed by literature (Medeiros et al. 2017).

Large-scale studies, such as the III Brazilian GHG inventory, use default values provided by the Intergovernmental Panel on Climate Change – IPCC (2006). Mean biomass and carbon fraction for grasslands are available on IPCC reports (DM for grassland present on Tropical – moist and wet climate zone = 16.1 Mg.ha^{-1}, and CF = 0.40 gC.g^{-1} d.m). Hence, the IPCC default values suggest a carbon stock of 6.44 MgC.ha^{-1} ($CS=DM.CF$). In a scenario where 50% of cultivated pasture in the Brazilian Amazon is covered by signal grass, these values would be employed for ca. 39 million ha (Cardoso et al. 2015, INPE 2017, Silva et al. 2017, Sanquetta et al. 2020). The difference in calculations using IPCC defaults and site-specific values would be tremendous (181.61 M MgCO$_2$eq) only due to small differences in carbon fraction and dry matter values.

Similarly, the root-to-shoot ratio (R) found in this study (R = 1.53) was lower than the IPCC default (R = 1.60). This fact can be attributed to poor management practices in small farms within the study region. In addition, our results indicated an influence of soil type on biomass partitioning and the root-to-shoot ratio. Nonetheless, using a unique carbon fraction value is not recommended when considering
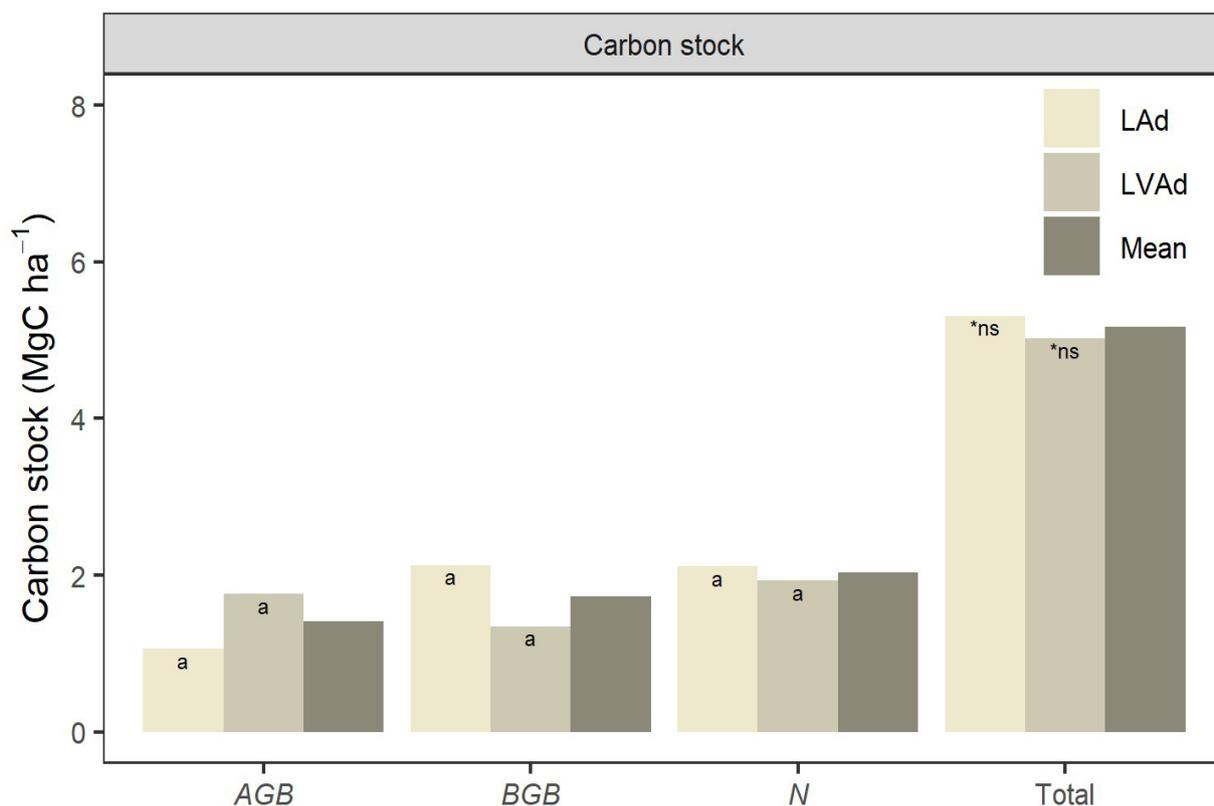
Figure 3. Carbon stock distribution of cultivated pastures for each soil type and biomass component.

different plant tissues or biomass components. Our results reinforced the high variability of carbon fractions among different biomass components. Studies assessing the carbon stock of grassland litter found values ranging from 0.05 to 0.50 $gC.g^{-1}$ d.m (Naeth et al. 1991, Kauffman et al. 1998, IPCC 2006). However, there is no information available regarding to the carbon fraction of different grass components, such as AGB, BGB, and N. When addressing the total carbon stock of signal grass, the weighted mean can be used by multiplying the total biomass (0.4138 $gC.g^{-1}$ d.m.).

Despite the limitations of our data in terms of extensity and coverage, our findings provide insightful information regarding the carbon stock of cultivated pastures in the southwestern Brazilian Amazon, which can help for improve the Brazilian GHG Inventory and the National Communication report delivered to the United Nations Framework Convention on Climate Change - UNFCCC. This study also brings site-specific carbon fractions, root-to-shoot, and dead-live ratios in two of the region's most common soil types. Despite non-significant differences, future studies are needed to confirm the reliability of carbon stocks found in this study and compare data from different regions and soil types.

CONCLUSIONS

Signal grass presented a higher amount of carbon in necromass, indicating poor condition regarding management practices.

Carbon stock values were compatible with IPCC default for grasslands in the tropics. However, the values reported in this study are

site and species-specific for *U. brizantha* in the Amazon region and should be used accordingly.

The replacement of mature Tropical forests by cultivated pastures reduces the carbon stock and promotes huge carbon dioxide emissions to the atmosphere.

Acknowledgments

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CRS: Conceptualization, Writing - original draft, Project administration; ASB: Conceptualization, Resources, Project administration; MNIS: Formal analysis, Writing – review and editing; IMB: Database, Methodology, Writing – review and editing; APDC: Writing - original draft; AQ: Methodology, Database; LFPUA: Methodology, Database.