

Hunter MO*, Pinto AS, dos Santos CO, dos Santos MP, de Macedo IN, de Lima GSA, Neto MBR, Vieira DLM, Ferreira Jr LG (2026) **Zero-Deforestation Land Use Scenarios in the Brazilian Cerrado: Pasture Intensification for Agriculture, Livestock and Regeneration.** *Regional Environmental Change* *maria.hunter@ufg.br Remote Sensing and GIS Lab (LAPIG), Federal University of Goiás (UFG), Goiânia-GO, 74001-970, Brazil

ESM_1 Validation of Soybean Parameters in the Brazilian Cerrado

To simulate carbon stocks and dynamics in soybean cultivation areas in the Cerrado, we used the CENTURY model, version 4.5. The data used to validate the model were obtained from literature reviews and partner researchers (Madari et al. *in review*).

Methods

Literature review – Data collection and analysis

To obtain reference values for C stocks and soil physicochemical properties (0-20 cm) in the Cerrado biome (IBGE 2024), a systematic literature search was conducted excluding gray literature. For further details of the literature review, please refer to the complete documentation available in dos Santos et al. 2026.

For each study, we recorded geographic information (latitude and longitude), land use and cover history, year of conversion, type of cultivation (conventional or no-till), cultivation duration (age), year of sampling, soil class, soil texture (sand, silt, and clay), soil bulk density, soil water pH, soil carbon stock in the 0-20 cm layer, and biomass and/or carbon data in different plant compartments (aboveground biomass, grains, and roots). For articles that only contained biomass data, the carbon content was estimated using a conversion factor of 0.5 (IPCC 2006). When location was not provided, the coordinates of the municipal seat were used to identify the closest weather station for climate data collection. For articles lacking previous land use history, a visual inspection of historical imagery was conducted using the Visual Inspection Tool (Lapig-UFG 2025). If the article did not report soil carbon stock but included carbon content and soil density data, the stock was calculated according to equation 1 (Fernandes and Fernandes 2008):

$$\text{SOC} = (\text{C} \cdot \rho \cdot d)/10 \quad \text{Equation (1)}$$

where:

SOC = organic C stock at a specific depth (Mg ha⁻¹)

C = total organic C content at the sampled depth (g kg⁻¹)

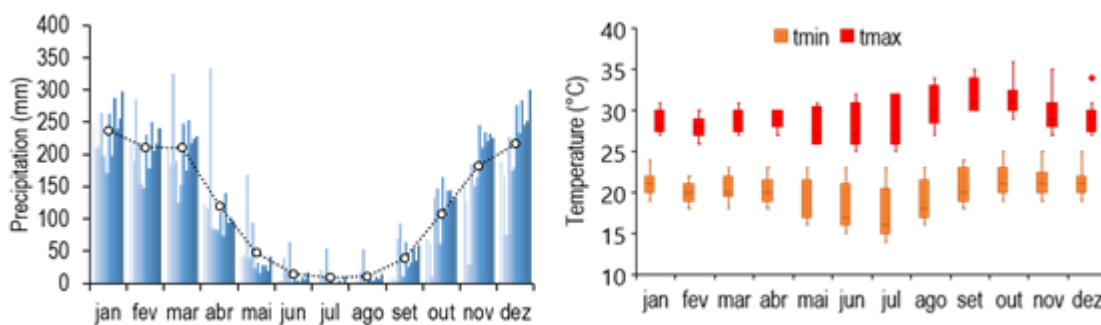
ρ = bulk soil density at the sampled depth (kg dm⁻³)

d = thickness of the considered layer (cm)

CENTURY model validation

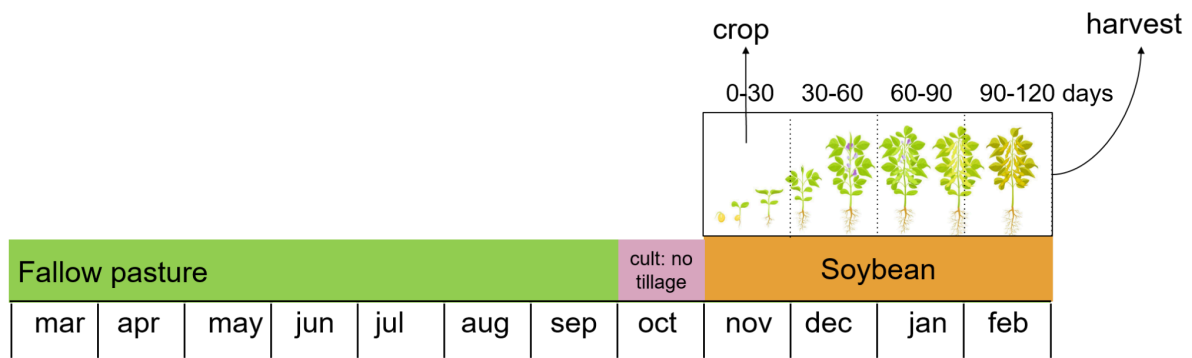
Model developer-provided default parameters (crop.100 file, SYBN code) (Metherel et al. 1993) were applied after conversion of parameters from version 4.0 of the model to version 4.5 (Santos et al. 2026).

The period (months) of soybean cultivation used in the simulations took into consideration the climate variation throughout the year at reference locations (ESM_1.1), the average period required for the plant's full development from planting to grain harvest, and the period referenced in field studies (between the months of October and March, e.g., Davi et al. 2022, Neto et al. 2018).



ESM 1.1 Variation in (a) precipitation and (b) temperature at the sites used to validate the model in soybean cultivation areas in the Cerrado

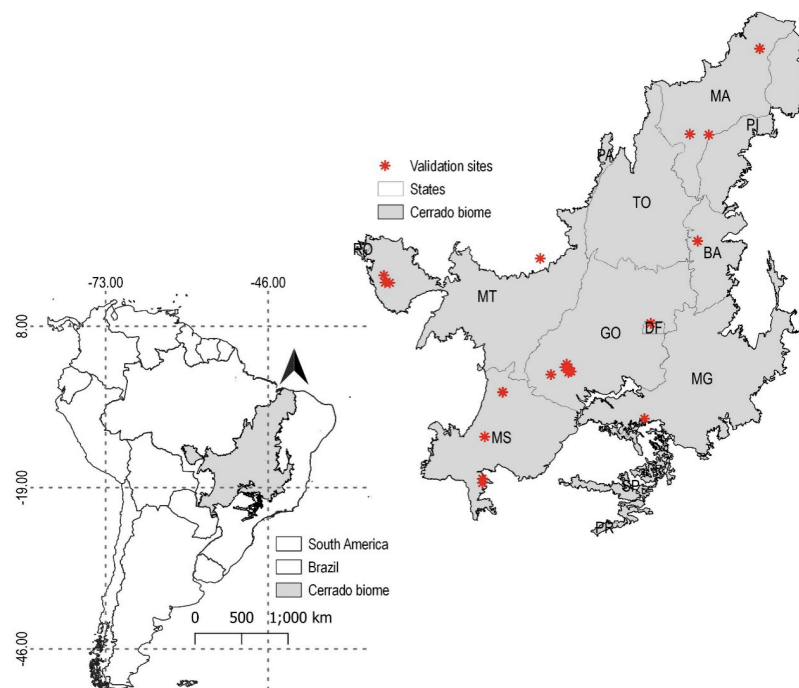
The type of cultivation (conventional tillage or no-till) was simulated according to the information provided by the authors in their description of the land use history for each site together with average fertilization levels (Automatic__medium_nutrient_concentrations). Between cultivation cycles, we simulated spontaneous herbaceous vegetation without grazing to maintain soil cover. Specifically, using the parameters described in Santos et al. (2022) for moderate-vigor pasture without grazing (ESM_1.2).



ESM 1.2 Schematic representation of land cover and management applied to model soybean cultivation in the Cerrado region.

Statistical analysis

The model's accuracy in simulating carbon stocks in soybean areas was evaluated by means of the coefficient of determination (r^2) and the model's mean error (M). To assess the model's estimation of carbon stocks in biomass and grains, we considered relative differences between simulated and measured C stocks within the range of $\pm 25\%$ to be acceptable (Parton et al. 1993).



ESM 1.3 Location of the study area and distribution of validation sites in soybean cultivation areas within the Cerrado biome using the CENTURY model

Results

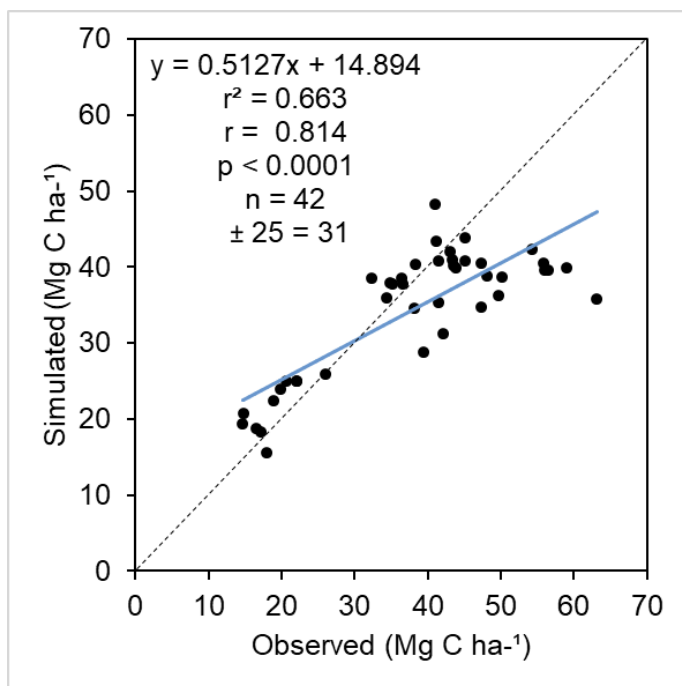
In total, data from 42 sites were found that are well distributed throughout the biome (ESM 1.3). The location, soil characteristics, land use history and original reference of all 42 sites are included in Table 1. The average simulated C stock in the soybean areas for the 42 sites was 34.4 ± 8.4 (mean $\pm$ sd) MgC ha⁻¹, similar to the value found in the literature 37.2 ± 13.3 . The model's coefficient of efficiency (COE) was 0.67, and the correlation between observed and simulated values (r) was significant (0.81; $p \leq 0.0001$) as shown in ESM 1.4. The comparison of carbon within aboveground biomass, roots and grains was conducted using values from 5 sites and are shown in Table 2.

Table 1. Location, soil characteristics (0–20 cm), and history of land use and cover at the sites used in the CENTURY model validation for soybean cultivation in the Brazilian Cerrado.

UF	Municipality	Lat	Long	Soil class (SiBCS)	Cultivation	Sand	Silt	Clay	Ds	pH	C	NV removal	Start	Sample	Time	Reference
						%			g cm ⁻³		Mg ha ⁻¹				yr	
MA	Buriti	-3.9	-43.1	Yellow Latosol	conventional	79.1	5.7	14.9	1.3	5.3	14.7	1997	2001	2004	3	Azevedo et al. 2007
MA	Buriti	-3.9	-43.1	Yellow Latosol	no-till	81.6	5.8	12.2	1.4	5.3	17.9	1997	2001	2004	3	Azevedo et al. 2007
MA	Buriti	-3.9	-43.1	Yellow Latosol	na	81.4	6.9	12.2	1.4	5.4	17.2	1997	2001	2004	3	Azevedo et al. 2007
MA	Buriti	-3.9	-43.1	Yellow Latosol	na	81.5	6.1	13.2	1.3	5.2	16.6	1997	2001	2004	3	Azevedo et al. 2007
MS	Costa Rica	-18.5	-54.0	na	conventional	20.0	20.0	60.0	1.3	5.2	54.3	1983	1993	1999	6	Bayer et al. 2004
MS	Costa Rica	-18.5	-54.0	na	no-till	20.0	20.0	60.0	1.2	5.4	56.1	1983	1993	1999	6	Bayer et al. 2004
MS	Costa Rica	-18.5	-54.0	na	no-till	20.0	20.0	60.0	1.2	5.4	56.5	1983	1993	1999	6	Bayer et al. 2004
MS	Costa Rica	-18.5	-54.0	na	no-till	20.0	20.0	60.0	1.2	5.0	55.9	1983	1993	1999	6	Bayer et al. 2004
MS	Costa Rica	-18.5	-54.0	na	no-till	20.0	20.0	60.0	1.2	5.2	59.0	1983	1993	1999	6	Bayer et al. 2004
BA	Luís Eduardo Magalhães	-12.1	-45.7	Quartzarenic Neosol	no-till	77.5	7.5	15.0	1.7	6.2	20.7	na	2012	2017	6	Bogiani et al. 2020
BA	Luís Eduardo Magalhães	-12.1	-45.7	Quartzarenic Neosol	no-till	77.5	7.5	15.0	1.7	6.2	22.0	na	2012	2017	6	Bogiani et al. 2020
BA	Luís Eduardo Magalhães	-12.1	-45.7	Quartzarenic Neosol	no-till	77.5	7.5	15.0	1.7	6.2	22.1	na	2012	2017	6	Bogiani et al. 2020

MT	Querência	-12.8	-52.4	Latosol	no-till	31.0	15.5	53.5	1.8	5.9	50.2	1983	2003	2013	10	Bonini et al. 2018
GO	Rio Verde	-17.8	-51.9	Latosol	no-till	37.4	6.4	56.2	1.1	5.5	47.3	na	1990	2002	12	Corbeels et al. 2006
GO	Rio Verde	-17.7	-51.2	Latosol	conventional	32.5	5.8	61.7	1.1	5.6	38.2	1977	1979	2003	24	Corbeels et al. 2016
GO	Montividiu	-17.5	-51.3	Latosol	no-till	35.2	4.0	60.8	1.2	5.8	43.5	1991	1992	2003	11	Corbeels et al. 2016
GO	Rio Verde/Montividiu	-17.6	-51.1	Latosol	no-till	44.8	3.2	52.0	1.2	5.9	35.2	1990	1992	2003	11	Corbeels et al. 2016
GO	Rio Verde/Montividiu	-17.6	-51.1	Latosol	no-till	37.9	3.2	58.9	1.2	5.8	38.3	1990	1992	2003	11	Corbeels et al. 2016
GO	Rio Verde/Montividiu	-17.7	-51.1	Latosol	no-till	29.4	5.2	65.4	1.2	5.9	45.2	1983	1986	2003	17	Corbeels et al. 2016
GO	Rio Verde/Montividiu	-17.5	-51.2	Latosol	no-till	26.7	5.2	68.1	1.0	5.6	43.4	1981	1985	2003	18	Corbeels et al. 2016
GO	Rio Verde/Montividiu	-17.5	-51.3	Latosol	no-till	28.1	6.9	65.0	1.1	5.5	43.8	1977	1985	2003	18	Corbeels et al. 2016
GO	Rio Verde/Montividiu	-17.3	-51.3	Latosol	no-till	30.6	5.2	64.2	1.1	5.9	48.1	1977	1984	2003	19	Corbeels et al. 2016
MS	Campo Grande	-20.4	-54.7	Latosol	conventional	51.0	13.0	36.0	1.2	5.5	39.5	1973	1993	2004	11	Dieckow et al. 2009
MS	Dourados	-22.4	-54.8	Latosol	conventional	10.2	20.8	69.0	1.3	5.5	41.4	1970	1987	2004	17	Dieckow et al. 2009
MS	Campo Grande	-20.4	-54.7	Latosol	no-till	51.0	13.0	36.0	1.2	5.6	42.2	1973	1993	2004	11	Dieckow et al. 2009
MS	Dourados	-22.4	-54.8	Latosol	no-till	10.2	20.8	69.0	1.4	5.6	41.2	1970	1987	2004	17	Dieckow et al. 2009
MS	Dourados	-22.2	-54.8	Latosol	no-till	9.0	17.0	74.0	1.2	5.6	43.1	1975	1995	2005	10	Fernandes and Fernandes 2012
MS	Dourados	-22.2	-54.8	Latosol	na	9.0	17.0	74.0	1.3	5.6	45.2	1975	1995	2005	10	Fernandes and Fernandes 2012
GO	Santo Antônio de Goiás	-16.5	-49.3	Red-Yellow Latosol	conventional	37.0	15.0	48.0	1.4	6.1	47.4	1978	1995	1999	4	Freixo et al. 2002
GO	Santo Antônio de Goiás	-16.5	-49.3	Red-Yellow Latosol	conventional	36.0	15.0	49.0	1.2	5.6	41.5	1978	1995	1999	4	Freixo et al. 2002
GO	Santo Antônio de Goiás	-16.5	-49.3	Red-Yellow Latosol	no-till	40.0	10.0	50.0	1.3	5.8	32.4	1978	1995	1999	4	Freixo et al. 2002
GO	Santo Antônio de Goiás	-16.5	-49.3	Red-Yellow Latosol	no-till	39.0	11.0	50.0	1.2	5.7	36.5	1978	1995	1999	4	Freixo et al. 2002
MA	Balsas	-20.8	-42.9	Red-Yellow Latosol	conventional	17.0	27.6	55.4	1.3	5.5	41.0	1992	1992	1996	4	Leite et al. 2005
PI	Baixa Grande do Ribeiro	-7.6	-45.2	Red-Yellow Latosol	conventional	47.0	10.0	43.0	1.3	5.3	63.1	1993	1994	2005	11	Leite et al. 2010
NA	Campos do Júlio	-13.9	-58.9	na	na	89.2	3.3	7.4	1.6	6.2	14.8	1990	na	2021	na	Madari et al. in review

NA	Sapezal	-13.9	-58.7	na	na	81.5	4.5	14.0	1.6	5.5	19.0	1990	na	2021	na	Madari et al. in review
NA	Campos do Júlio	-13.5	-59.0	na	na	77.2	4.6	18.1	1.6	5.7	19.8	1991	na	2021	na	Madari et al. in review
GO	Rio Verde	-17.3	-51.3	Red Latosol	no-till	30.8	5.3	64.0	1.0	6.1	49.7	na	1977	2003	26	Siqueira Neto et al. 2009
DF	Planaltina	-15.6	-47.7	Red Latosol	conventional	35.7	7.2	57.1	1.0	5.5	34.4	1976	1999	2010	11	Souza Nunes et al. 2011
DF	Planaltina	-15.6	-47.7	Red Latosol	no-till	35.7	7.2	57.1	1.0	5.6	36.6	1976	1999	2010	11	Souza Nunes et al. 2011
DF	Planaltina	-15.6	-47.7	Red Latosol	no-till	35.7	7.2	57.1	1.0	5.6	34.9	1976	1999	2010	11	Souza Nunes et al. 2011
M G	Uberaba	-19.7	-48.0	Red Latosol	no-till	77.0	5.0	18.0	1.2	6.3	26.0	na	2000	2007	7	Pereira et al. 2010



ESM_1.4 Relationship between measured soil C stocks (MgC ha⁻¹) (0–20 cm) in the field and those simulated by the CENTURY model for soybean areas in the Cerrado biome

Table 2. Carbon stocks in aboveground biomass, belowground biomass, and grains (observed and simulated) and model errors.

Compartment	Observed (C Mg ha ⁻¹)	Simulated (C Mg ha ⁻¹)	Error (%)
Biomass ^{2,3}	2.85±0.5	3.3±0.6	15.8
Grain ¹	1.54	1.05±0.07	-31.8
Roots ³	1.21±0.13	1.1±0.1	-9.1

Bogiani et al. 2020¹, Bonini et al. 2018², Leite et al. 2010³

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