Greenhouse gas emissions and carbon sequestration by agroforestry systems in southeastern Brazil

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Agrosilvopastoral and silvopastoral systems can increase carbon sequestration, offset greenhouse gas (GHG) emissions and reduce the carbon footprint generated by animal production. The objective of this study was to estimate GHG emissions, the tree and grass aboveground biomass production and carbon storage in different agrosilvopastoral and silvopastoral systems in southeastern Brazil. The number of trees required to offset these emissions were also estimated. The GHG emissions were calculated based on pre-farm (e.g. agrochemical production, storage, and transportation), and on-farm activities (e.g. fertilization and machinery operation). Aboveground tree grass biomass and carbon storage in all systems was estimated with allometric equations. GHG emissions from the agroforestry systems ranged from 2.81 to 7.98 t CO2e ha−1. Carbon storage in the aboveground trees and grass biomass were 54.6, 11.4, 25.7 and 5.9 t C ha−1, and 3.3, 3.6, 3.8 and 3.3 t C ha−1 for systems 1, 2, 3 and 4, respectively. The number of trees necessary to offset the emissions ranged from 17 to 44 trees ha−1, which was lower than the total planted in the systems. Agroforestry systems sequester CO2 from the atmosphere and can help the GHG emission-reduction policy of the Brazilian government.

The Paris Agreement, adopted in the 21st session of the Conference of the Parties (COP 21) for the United Nations Framework Convention on Climate Change (UNFCCC), aims to maintain the global average temperature below 2 °C of pre-industrial levels1. The signatory countries stipulate their Intended Nationally Determined Contributions (INDCs), which are the main commitments and contributions of that country for the fulfillment of the agreement2,3. The Brazilian INDC proposed to reduce the greenhouse gases (GHG) emission by 37% in 2025, based on 2005 levels1. Agriculture is the main emission source with enteric fermentation being responsible for 90% of CH4 and animal manure on pasture for 33% of N2O emissions in Brazil in 20144. The Brazilian government established a “low-carbon agriculture plan” to promote sustainable practices in agriculture by reducing greenhouse gas (GHG) emissions while maintaining profitability5.

This plan is based on practices such as restoration of degraded pastures, crop-livestock-forest integration, no-till farming, biological nitrogen fixation and forestry and agroforestry systems6. The agroforestry system is a land use management system combining trees and/or woody perennial plants, pasture and livestock benefiting from ecological and economic interactions between its component parts due to production diversification7. Food production8 and carbon sequestration by tree planting9 in these systems can help to reduce deforestation in tropical countries10,11.

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Agrosilvopastoral and silvopastoral systems are agroforestry system types that can reduce and offset GHG emissions from the Brazilian agricultural sector, mainly using cattle and forest integration12–14. These systems lower animal emission levels by improving grass quality, which can reduce 

CH4 emissions from enteric fermentation15 and digestion efficiency16. Furthermore, these systems may mitigate GHG emissions by enhancing carbon sequestration through increasing above and belowground biomass17–19.

The objective of this study was to estimate GHG emissions, tree and grass aboveground biomass and carbon storage in silvopastoral and agrosilvopastoral systems in southeastern Brazil, and the number of trees required to offset these emissions.

Results

GHG emissions. The pre-farm GHG emissions were 0.37, 0.15, 0.12 and 0.10 t CO2e ha−1 in systems 1, 2, 3 and 4, respectively. Nitrogen production was the main emission source for pre-farm activities (Fig. 1). On-farm GHG emissions were 7.61, 4.10, 3.92 and 2.71 t CO2e ha−1 in systems 1, 2, 3 and 4, respectively. Enteric fermentation and manure produced by livestock were the main emission sources for on-farm activity (Fig. 1). Total GHG emissions were 7.98, 4.25, 4.04 and 2.80 t CO2e ha−1, on systems 1, 2, 3 and 4, respectively (Table 1).

Aboveground biomass and carbon storage. The equation m1 was the best to predict aboveground biomass and carbon storage in systems 1, 3 and 4 (Tables 2 and 3). These equations had the highest R2adj and lower RMSE (%) than the m2. In system 2, the equation m1 was rejected due to the incoherence of the values for parameter b21, with negative values (Tables 2 and 3).

A total of 17, 39, 44 and 35 trees ha−1 are necessary to offset all GHG emissions, which is equivalent to 4.0, 10.2, 3.4 and 13.1% of the total numbers of trees in systems 1, 2, 3 and 4, respectively (Table 1).

Discussion

The average annual GHG emissions ranged from 0.93 to 1.60 t CO2e ha−1 yr−1, which may be considered low when compared to other systems20,21, probably due to the use of no-till farming and the adoption of agroforestry systems with reduced machinery use, fuel inputs and CO2 emissions22. No-till farming in these systems may increase organic carbon and nitrogen content in the soil, and the microbial biomass, mitigating GHG emissions23–26. Usual management practices in agroforestry systems, such as no-till farming and optimal fertilization/manure regimes can increase carbon sequestration while reducing GHG emissions27. Such a combination provides additional environmental benefits such as soil erosion reduction and prevention28,29, more efficient water-use30, and improvement in biodiversity31.

The difference in the mean annual aboveground carbon increment (MAI-AGB) on the four systems indicates that the amount of this element sequestered may depend on tree species, age, geographic location, environmental factors, and system management32,33. System 1 presented the largest MAI-AGB (11.19 t ha−1 yr−1) due to its older age and the fertilization carried out to enhance maize production indirectly increasing tree biomass34. System 3 presented the second largest IMA due to its greater plant density (9 × 1 spacing), however competition between systems 2 and 3 may have reduced the IMA due to competition for nutrients and water35.

Table 1. GHG emission, carbon stock, carbon balance, trees to offset, total trees, surplus trees in all systems.

| System | Emission (t CO2e ha−1) | Carbon Stock (t CO2e ha−1) | Balance (t CO2e ha−1) | Trees to offset | Total trees | Surplus Trees |
|--------|------------------------|---------------------------|-----------------------|----------------|-------------|--------------|
| 1      | 7.98                   | 200.14                    | 192.16                | 17             | 424         | 407          |
| 2      | 4.25                   | 41.86                     | 37.61                 | 39             | 388         | 349          |
| 3      | 4.04                   | 94.33                     | 90.29                 | 44             | 1031        | 987          |
| 4      | 2.81                   | 21.78                     | 18.97                 | 35             | 267         | 232          |
plants can negatively affect individual growth\(^{35,36}\) and may increase future mortality\(^{37}\). All systems were important in carbon sequestration and had environmental benefits such as soil fertility and water quality improvement and erosion reduction\(^{18,38–40}\). The estimated MAI-AGB found was higher than the 1.43 t ha\(^{-1}\) yr\(^{-1}\) in a silvopastoral system with 105 trees per hectare (eucalypt and acacia) in Minas Gerais, Brazil\(^{41}\). The MAI-AGB of 7.67 t ha\(^{-1}\) yr\(^{-1}\) of an agrosilvopastoral system with eucalyptus spaced 10 × 4 m and rice in Paracatu, Minas Gerais, Brazil\(^{42}\) was similar to that observed in the system 2 of this research.

The estimated aboveground grass carbon sequestration was similar to the 3.71 kg C ha\(^{-1}\) of an agrosilvopastoral system with eucalypt in Minas Gerais, Brazil\(^{42}\), and the 3.29 kg C ha\(^{-1}\) of a silvopastoral system with 200 pine trees ha\(^{-1}\) in São Paulo, Brazil\(^{43}\). These systems had a similar production due to the wide spacing of the trees.

| System | Model | Parameter | Estimate | SE | \(R^2_{adj}\) (%) | \(E\) (%) | RMSE (%) |
|--------|--------|-----------|----------|----|-----------------|---------|----------|
| 1      | \(m_1\) | \(b_{01}\) | 0.0204   | 0.0371 | 85.409 | −0.549 | 19.588  |
|        | \(b_{11}\) | 1.9908   | 0.6453   |    | 85.409 | −0.549 | 19.588  |
|        | \(b_{21}\) | 1.0264   | 0.8239   |    | 85.409 | −0.549 | 19.588  |
|        | \(m_2\) | \(b_{02}\) | 0.0208   | 0.0313 | 85.407 | −0.551 | 19.589  |
|        | \(b_{12}\) | 1.0035   | 0.1581   |    | 85.407 | −0.551 | 19.589  |
| 2      | \(m_1\) | \(b_{03}\) | 0.1563   | 0.1784 | 90.699 | −0.221 | 16.911  |
|        | \(b_{13}\) | 3.0839   | 1.0899   |    | 90.699 | −0.221 | 16.911  |
|        | \(b_{23}\) | −0.7883  | 1.2929   |    | 90.699 | −0.221 | 16.911  |
|        | \(m_2\) | \(b_{04}\) | 0.0601   | 0.0586 | 88.996 | 0.040  | 18.390  |
|        | \(b_{14}\) | 0.8691   | 0.1163   |    | 88.996 | 0.040  | 18.390  |
| 3      | \(m_1\) | \(b_{05}\) | 0.0737   | 0.1087 | 90.182 | −0.922 | 19.953  |
|        | \(b_{15}\) | 1.8942   | 0.5883   |    | 90.182 | −0.922 | 19.953  |
|        | \(b_{25}\) | 0.6112   | 0.9028   |    | 90.182 | −0.922 | 19.953  |
|        | \(m_2\) | \(b_{06}\) | 0.0534   | 0.0480 | 90.112 | −0.857 | 20.023  |
|        | \(b_{16}\) | 0.8678   | 0.1086   |    | 90.112 | −0.857 | 20.023  |
| 4      | \(m_1\) | \(b_{07}\) | 0.0895   | 0.0659 | 94.741 | −0.769 | 16.781  |
|        | \(b_{17}\) | 1.4018   | 0.6370   |    | 94.741 | −0.769 | 16.781  |
|        | \(b_{27}\) | 1.0429   | 0.8270   |    | 94.741 | −0.769 | 16.781  |
|        | \(m_2\) | \(b_{08}\) | 0.1027   | 0.0543 | 94.706 | −0.857 | 16.836  |
|        | \(b_{18}\) | 0.7960   | 0.0621   |    | 94.706 | −0.857 | 16.836  |

Table 2. Estimated regression coefficients and adjusted standard errors (±SE) coefficient of determination (\(R^2_{adj}\)), model bias (\(E\)), and root mean square error (±RMSE) of aboveground biomass equations.

| System | Model | Parameter | Estimate | SE | \(R^2_{adj}\) (%) | \(E\) (%) | RMSE (%) |
|--------|--------|-----------|----------|----|-----------------|---------|----------|
| 1      | \(m_1\) | \(b_{09}\) | 0.0108   | 0.0197 | 85.439 | −0.541 | 19.550  |
|        | \(b_{19}\) | 1.9977   | 0.6440   |    | 85.439 | −0.541 | 19.550  |
|        | \(b_{29}\) | 1.0153   | 0.8218   |    | 85.439 | −0.541 | 19.550  |
|        | \(m_2\) | \(b_{010}\) | 0.0110   | 0.0165 | 85.439 | −0.542 | 19.550  |
|        | \(b_{110}\) | 1.0031   | 0.1578   |    | 85.439 | −0.542 | 19.550  |
| 2      | \(m_1\) | \(b_{011}\) | 0.0842   | 0.0960 | 90.663 | −0.226 | 16.906  |
|        | \(b_{111}\) | 3.0889   | 1.0900   |    | 90.663 | −0.226 | 16.906  |
|        | \(b_{211}\) | −0.8036  | 1.2927   |    | 90.663 | −0.226 | 16.906  |
|        | \(m_2\) | \(b_{012}\) | 0.0322   | 0.0314 | 88.930 | 0.039  | 18.409  |
|        | \(b_{112}\) | 0.8663   | 0.1162   |    | 88.930 | 0.039  | 18.409  |
| 3      | \(m_1\) | \(b_{013}\) | 0.0382   | 0.0564 | 90.193 | −0.920 | 19.920  |
|        | \(b_{113}\) | 1.8823   | 0.5867   |    | 90.193 | −0.920 | 19.920  |
|        | \(b_{213}\) | 0.6251   | 0.9013   |    | 90.193 | −0.920 | 19.920  |
|        | \(m_2\) | \(b_{014}\) | 0.0282   | 0.0253 | 90.131 | −0.859 | 19.982  |
|        | \(b_{114}\) | 0.8666   | 0.1083   |    | 90.131 | −0.859 | 19.982  |
| 4      | \(m_1\) | \(b_{015}\) | 0.0475   | 0.0344 | 94.868 | −0.736 | 16.536  |
|        | \(b_{115}\) | 1.3937   | 0.6278   |    | 94.868 | −0.736 | 16.536  |
|        | \(b_{215}\) | 1.0498   | 0.8151   |    | 94.868 | −0.736 | 16.536  |
|        | \(m_2\) | \(b_{016}\) | 0.0547   | 0.0285 | 94.831 | −0.827 | 16.596  |
|        | \(b_{116}\) | 0.7950   | 0.0612   |    | 94.831 | −0.827 | 16.596  |

Table 3. Estimated regression coefficients and adjusted standard errors (±SE), adjusted coefficient of determination (\(R^2_{adj}\)), model bias (\(E\)), and root mean square error (±RMSE) of carbon equations.
allowing sufficient radiation transmittance and improving the microclimate for the forage. This shows that agroforestry systems are an alternative to recover degraded pasture land by improving chemical, physical and biological soil conditions and enhancing carbon sequestration.

The number of trees required to offset GHG emissions was lower than that planted in the systems studied, demonstrating their great potential to sequester carbon and to reduce GHG emissions. Agroforestry systems are important for the "Low-Carbon Agriculture Plan" of the Brazilian government to achieve GHG emission-reduction targets. These systems decrease the pressure on forests and improve animal welfare and crop production. Furthermore, the remaining sequestered carbon can be sold in voluntary markets with a higher price for technologies that bring social and environmental benefits including higher farmer income.

The systems had a positive carbon balance and a tree surplus ranging from 232 to 987. The number of trees was higher than necessary to offset GHG emissions in all systems. Therefore, the agroforestry systems can effectively mitigate GHG emissions.

**Methods**

**Study systems.** The study was conducted in silvopastoral and agrosilvopastoral systems in Viçosa, Minas Gerais, Brazil. The climate in this region is humid subtropical with dry winters and hot summers, classified as Cwa (Köppen classification). The average annual temperature and rainfall are 19.4°C and 1,200 mm, respectively. The soil is classified as red-yellow latosol and the topography ranges from strongly undulated to mountainous with an average altitude of 689.7 m.

The agrosilvopastoral systems were composed of maize (Zea mays) and Eucalyptus saligna (system 1), and bean (Phaseolus vulgaris) and E. urophylla x E. grandis (system 2) during the first year, and the crops were replaced by pasture (Brachiaria decumbens) with livestock grazing in the second year (Table 4). The silvopastoral systems (3 and 4) had pasture (Brachiaria decumbens) + E. urophylla x E. grandis (Table 4). No-till farming was used in all systems. Beef cattle were reared in all systems (one animal/ha).

System 1 was fertilized after soil analysis. In December 2007, a posthole digger machine was used and 0.2 kg of N-P-K (06-30-06) applied per tree hole. Additional fertilization of 0.15 kg of N-P-K (20-05-20) pit was undertaken at 60, 120, 300 and 550 days after tree planting. Animal traction was used to apply 500 kg of N-P-K (08-24-12) ha⁻¹ on maize before planting, and another 500 kg of N-P-K (30-00-10) ha⁻¹ 30 days later. The pasture received 100 kg of urea ha⁻¹ year⁻¹.

Systems 2 and 3, implemented in December 2009, received the same treatment as the system 1 for eucalypt planting and weed/leaf-cutter ant control. In system 2, the bean crop received 250 kg of N-P-K (08-28-16) ha⁻¹ and 200 kg urea ha⁻¹ as top-dressing fertilization.

The eucalypt trees in system 4 were planted, in November 2009, using a posthole digger machine with 0.2 kg N-P-K (06-30-06) applied per hole. Additional fertilization with 0.05 kg N-P-K (20-05-20) plant⁻¹, 0.1 kg of N-P-K (20-05-20) plant⁻¹, 0.05 kg of N-P-K (20-05-20) plant⁻¹, 0.15 kg and 0.1 kg KCl plant⁻¹ were undertaken at 60, 120, 300 and 550 days after tree planting, respectively. Weed and leafcutter ants were controlled before, during and after tree planting. The pasture received 100 kg of N-P-K (20-05-20) ha⁻¹ one year after eucalypt planting.

**GHG emissions.** GHG emission calculations per system were based on pre-farm activities, such as production, storage, and transportation of agrochemicals, and on-farm activities such as fertilization and machinery use (Fig. 2). The data were estimated from personal interviews with farmers. They were asked to report on the use of machine fuel, agrochemicals and estimated crop yield.

Pre-farm emissions were calculated using emission factors (Table 5) and the following equation: emAgr = agrochemical *EF*(44/12), EmAgr = annual emissions resulting from production, packaging, storage and distribution of agrochemicals, kg CO₂ year⁻¹; agrochemical = agrochemical applied, kg year⁻¹; EF = emission factor, kg carbon equivalent kg⁻¹; 44/12 = C to CO₂ conversion factor.

![Figure 2. GHG inventory for the agroforestry systems, for pre-farm and on-farm stages.](image)
On-farm emissions were calculated based on the “Guidelines for National Greenhouse Gas Inventories” of the Intergovernmental Panel on Climate Change.

Input emissions from synthetic fertilizers were calculated via two pathways: direct and indirect. The direct emissions refer to mineral fertilizer applications. Direct emissions are the product of the nitrogen applied by the emission factor (0.01) using the 44/28 factor to convert N₂ to N₂O and N₂O global warming potential (298 units of CO₂e). The equation used to estimate direct emissions was: E_DiF = ESN * EF₃ (44/28) * GWP, where E_DiF = direct CO₂e emissions from N inputs to managed soils, kg CO₂ ha⁻¹; ESN = amount of synthetic fertilizer N applied to soils, kg N ha⁻¹; EF₃ = emission factor for N₂O emissions from synthetic fertilizer, kg N₂O-N (kg N⁻¹); GWP = global warming potential.

Indirect emissions result from volatilization, atmospheric deposition of NH₃, NOx, and nitrogen leaching and runoff from the fertilizers. Indirect emissions were calculated using annual amount of fertilizer N applied to soils and the nitrogen fraction lost by volatilization, leaching, and/or runoff. The emission factor was 0.01 for volatilization and 0.0075 for leaching/runoff. The nitrogen fraction lost due to volatilization, leaching/runoff from the fertilizers was fixed as 0.1 and 0.2, respectively. The equation used to estimate indirect on-farm N₂O emissions per system was E_IiF = E_RN * FSN * EF₅ (44/28) * GWP, where E_IiF = indirect CO₂e emissions from N inputs to managed soils, kg CO₂ ha⁻¹; FSN = annual amount of synthetic fertilizer N applied to soils, kg N ha⁻¹; EF₅ = emission factor developed for N₂O emissions from synthetic fertilizer, kg N₂O–N (kg N⁻¹); GWP = global warming potential.

Nitrogen emissions from urea were calculated with the same equations used for the other nitrogen fertilizers. CO₂ emissions were the product of the urea applied to the soil by its emission factor, 0.20. The equation used to estimate on-farm CO₂ emissions was E_FU = M * EF₆, where E_FU = amount of CO₂e produced from additions to managed soils, kg CO₂ ha⁻¹; M = amount of urea applied to soils, kg N ha⁻¹; EF₆ = emission factor for urea, kg C ton of urea⁻¹. CO₂ emissions from agricultural machinery were those generated by fuel consumption during eucalypt planting due to its emission factor (EF₇), 2.327 kg CO₂ t⁻¹. The equation used in each system was E_M = F * EF₇, where E_M = amount of CO₂e produced from fuel consumed, kg CO₂ ha⁻¹; F = fuel consumed, L ha⁻¹; EF₇ = emission factor for applied urea, kg C (L fuel)⁻¹. CH₄ emissions by enteric fermentation from cattle were calculated using the factor of 39 kg CH₄ year⁻¹ animal unit⁻¹. The equation used was: E_M = N * EF₈ * GWP, where EF₈ = emissions from enteric fermentation, kg CO₂ ha⁻¹; N = number of animals, head ha⁻¹; EF₈ = emission factor for enteric fermentation (kg CH₄) head⁻¹; GWP = CH₄ global warming potential. N₂O emissions due to manure deposition were calculated with the same equations as those for nitrogen fertilizer.

### Carbon storage in aboveground biomass

Ten pasture grass samples (1 m²) between tree rows were collected, per season, from June 2012 to October 2013. Their fresh weight was obtained and the fresh:dry weight ratio calculated with 25 g from each sample. These samples were dried at approximately 65°C in an oven until weight stabilization.

The diameter at breast height (DBH), total height, and commercial height (stem height up to 3-cm diameter) of trees per system were measured between July and August 2012. Trees were grouped into DBH classes, and three individuals per class were selected and felled to determine their total volume, biomass and carbon levels in their stem, branches and leaves.

The trees selected were cut at ground level, and the stem diameters measured at 0.3, 0.7, and 1.3 m from their base, and thereafter at every 2 m until the diameter reached 3 cm. The volume of these stem sections was calculated using the Smalian’s formula. The stems per sample were weighed and 2.5 cm thick stem discs were collected at the base, 25, 50, 75, and 100% of the commercial height to calculate the aboveground biomass. An additional stem disc was cut at breast height (1.3 m). The branches and stem discs were dried at 103 ± 2°C until dry weight stabilization was reached. The leaf and branch weights per tree sample were recorded. Fresh leaf and branch samples were weighed in the field, stored in bags and sent to the laboratory to determine their dry/fresh weight ratio. Leaf and branch samples were dried at 65 ± 2°C until dry weight stabilization.

The stem, leaf and branch carbon content was determined with a LECO TruSpec Micro CHN analyzer (LECO Corp., St. Joseph, MI). The carbon stock was obtained by multiplying the aboveground biomass by the carbon content.

### Table 5. Carbon emissions (mean ± SD) for the production, transportation, storage, and transfer of agrochemicals. Values according to a previous study

| Agrochemicals         | Carbon emission (kg C kg substance⁻¹) |
|-----------------------|---------------------------------------|
| Nitrogen fertilizer   | 1.30 ± 0.30                           |
| Phosphorus fertilizer | 0.20 ± 0.06                           |
| Potassium fertilizer  | 0.15 ± 0.06                           |
| Urea                  | 0.16 ± 0.11                           |
| Herbicide             | 6.30 ± 2.70                           |
| Insecticide           | 5.10 ± 3.00                           |
| Fungicide             | 3.90 ± 2.20                           |

*EF*₁ = emission factor for enteric fermentation (kg CH₄) head⁻¹; *EF*₂ = emission factor for enteric fermentation (kg CH₄) head⁻¹; *EF*₃ = emission factor for N₂O emissions from synthetic fertilizer, kg N₂O–N (kg N⁻¹); *EF*₄ = emission factor developed for N₂O emissions from synthetic fertilizer, kg N₂O–N (kg N⁻¹); *EF*₅ = emission factor developed for N₂O emissions from synthetic fertilizer, kg N₂O–N (kg N⁻¹); *EF*₆ = emission factor developed for N₂O emissions from synthetic fertilizer, kg N₂O–N (kg N⁻¹); *EF*₇ = emission factor developed for N₂O emissions from synthetic fertilizer, kg N₂O–N (kg N⁻¹); *EF*₈ = emission factor developed for N₂O emissions from synthetic fertilizer, kg N₂O–N (kg N⁻¹); *EF*₉ = emission factor developed for N₂O emissions from synthetic fertilizer, kg N₂O–N (kg N⁻¹); *GWP* = global warming potential.
Field data was fitted to allometric equations\(^{60,61}\) to estimate the tree aboveground biomass, and carbon (stem + branches + leaves) per system as: \(Y_i = \beta_0 + \beta_1 \text{DBH}^{1.1} + \beta_2 \text{DBH}^2 + \varepsilon_i\), where \(Y_i\) the biomass or carbon stock (kg) of the \(i^{th}\) model; \(\text{DBH}\), the ith value of the dependent variable (volume, biomass and carbon); \(\varepsilon_i\), the random errors.

All statistical analyses were performed with R statistical software\(^{62}\). The best equations were based on the criteria: parameter significance (\(p < 0.05\)) by Wald test; coherence of the sign associated with a specific parameter; goodness of fit statistics: \(R^2_{adj} = 1 - \frac{\left(\sum (y_i - \hat{y}_i)^2\right)}{\left(n \cdot \sum (y_i - \bar{y})^2\right)}\); \(R^2\), \(\text{RMSE}\%\), the relative bias; \(\text{RMSE}\%\), the root square error in percentage; \(n\), the observation number; \(p\), the number of explanatory variables; \(\Sigma\), the mean of dependent variable (volume, biomass and carbon); \(y_i\), the \(i^{th}\) observed value; and \(\hat{y}\), the \(i^{th}\) value of the dependent variable.

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Author Contributions
C.M.M.E.T.; L.A.G.J.; S.N.O.N. and L.R.F. conceived the study, C.M.M.E.T.; L.A.G.J., F.C.N. and S.N.O.N. conducted the experiment, C.M.M.E.T.; C.W.F.; F.C.N. and C.P.B.S. performed analyses, C.M.M.E.T. wrote the first draft of the manuscript, and L.A.G.J.; S.N.O.N.; C.W.F.; C.P.B.S.; J.C.Z. and P.G.L. contributed substantially to write the final version of the manuscript. All authors reviewed the manuscript.

Additional Information
Competing Interests: The authors declare that they have no competing interests.

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