Agriculture, Ecosystems and Environment 254 (2018) 26–34

Contents lists available at ScienceDirect

Agriculture, Ecosystems and Environment

journal homepage: www.elsevier.com/locate/agee

Adaptation of the century model to simulate C and N dynamics of Caatinga dry forest before and after deforestation

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ARTICLE INFO

Keywords:
Tropical dry vegetation
Soil organic matter
Firewood
Semi-arid NE Brazil

ABSTRACT

About half of the original one million km^2 originally covered by the tropical dry forest of northeastern Brazil (known as "Caatinga"), has been deforested and replaced by crops and pastures. The remaining forest is constantly subjected to firewood removal. Besides that, pastures and cropping fields are often abandoned after a few years, allowing regeneration of secondary forest patches. These patterns create a mosaic of land use types and dry forest fragments under different regeneration stages, but there is little information about biogeochemical cycling in this ecosystem. Understanding the impacts of these changes, especially on carbon and nitrogen cycling, is important to define appropriate policies to preserve soils and vegetation and to contribute to reduce emissions and remove carbon from the atmosphere. Generating data about these processes require monitoring of large areas for long periods, and the use of models can be useful to improve the understanding of such systems. In the present study, the Century model was calibrated and validated to simulate the carbon (C) and nitrogen (N) dynamics in areas of caatinga vegetation before deforestation and during regeneration after abandonment. Calibration data were obtained in field plots in Paraiba state and validation data from plots Rio Grande do Norte state, both areas closely monitored for at least a couple of decades. Two types of deforestation practices were evaluated: clear cutting and cutting with stump removal followed by residue burning. The model files were prepared and calibration parameters were adjusted to represent observed values in the calibration site. Afterwards, the adjusted model was used to simulate the dynamics in the validation site, changing only the site soil and climate characteristics. In areas of preserved native vegetation, the validated C stock values of the woody vegetation biomass (21.0 Mg ha^{-1}) were similar to the average values observed in the field (20.2 Mg ha^{-1}). The soil organic carbon stock (SOC) (30 Mg ha^{-1}) and its C:N ratio (11) were also satisfactorily validated by the Century model, indicating that the model can represent very closely the dynamics in areas under preserved forest vegetation. In areas under regeneration after deforestation, the model also represented well the C accumulation in the biomass of the secondary vegetation and the SOC dynamics for the different firewood harvest practices. The model is very sensitive to the type of deforestation, since the removal of the stumps slows down tree growth during regeneration, therefore it must be well detailed in the site management history during model runs. It is also important to create two different crop files for the herbaceous vegetation within the preserved forest or in the open deforested areas, because they comprise different vegetation types. The model was very sensitive to the KLAI variable, which controls the buildup of leaves during the young phase of the trees. After the necessary adaptations, the Century model simulated adequately C and N cycling in areas of Caatinga

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https://doi.org/10.1016/j.agee.2017.11.016
Received 3 May 2017; Received in revised form 14 November 2017; Accepted 19 November 2017
Available online 22 November 2017
0167-8809/

vegetation in the semi-arid region of Brazil. The model will now be a useful tool to better understand ecosystem functioning in this region.

1. Introduction

The native tropical dry forest vegetation of the semi-arid Brazilian Northeastern region, known as "Caatinga", has been under increasing human pressure, mainly due to the removal of firewood and establishment of pastures and agricultural fields. Caatinga originally covered an area of nearly 1 million km^2, but only about half of this area is currently covered by native shrub and woody vegetation (Gariglio et al., 2010; Araújo Filho, 2013). The changes in land cover derive from the relatively high population density ($\sim$25 inhabitant km^{-2}) and from the predominance of small farms, which impose strong pressure on natural resources, mainly on native vegetation. The forest biomass is one of the most important energy sources in this region, with a total harvest of about 10 million m^3 of wood per year (Gariglio et al., 2010). As a result, more than 90% of the forest cover area nowadays represent secondary forest vegetation under regeneration as part of the fallow cycle of slash and burn agriculture and as part of the regrowth cycle of firewood production (Gariglio et al., 2010)

The removal of firewood is commonly followed by forest residue burning for the establishment of agricultural fields or pastures (Sampaio, 1995), which intensifies the impacts on carbon and nutrient cycling in these ecosystems (Moura et al., 2016). Due to the great population demand, firewood extraction is often carried in short cycles, which do not allow vegetation recovery and may adversely affect ecosystem processes. Therefore, it is evident that wood extraction practices need to be better studied and regulated to ensure sustainable exploitation. The determination of the time required between each harvest to allow adequate recovery of vegetation and soil carbon stocks still lacks detailed studies.

In addition to supporting management of firewood harvest, a better understanding of the functioning of the C and N dynamics in these ecosystems will also improve estimates of emissions and removals of greenhouse gases in the region. Caatinga vegetation represents one of the largest remaining areas of tropical dry forest in the world (Miles et al., 2006) and may play an important role in regional and global processes derived from the interactions between the biosphere and atmosphere (Moura et al., 2016). The understanding of these processes is still limited because there is very little available data about soil and vegetation carbon and nutrient stocks and fluxes in Caatinga areas (Moura et al., 2016).

The scarcity of data is hard to be fulfilled since determining the effects of forest cutting activities in ecosystems, mainly about soil compartment, comprises a relatively long period, often on the scale of decades. Therefore, models to simulate biogeochemical cycling may be particularly important tools because they can improve the understanding of these ecosystems and thereby support immediate decisions and help define appropriate and sustainable land use practices (Parton, 1987). Among the various models used to simulate biogeochemical cycling in terrestrial ecosystems, the Century Model has been used in various biomes, soil types and climates (Parton et al., 1988; Metherell et al., 1994).

Some studies have been conducted using Century in Brazil, both in tropical (Cerri et al., 2003; Carvalho et al., 2015) and subtropical ecosystems (Lopes et al., 2008; Tornquist et al., 2009; Bortolon et al., 2011). In most of the studies, the model has demonstrated good ability to simulate the effects of different land use systems and management practices.

However, the Century model has not been adjusted with the necessary details to represent the diversity of environmental conditions, management practices and caatinga vegetation types that occur in the semiarid region of Northeast Brazil. The adaptation of the model may bring benefits not only to studies in this region but also in other tropical dry ecosystems of the world. Therefore, the main aim of this study was to calibrate and validate the Century model to simulate the dynamics of C and N stocks and flows in the soil-plant system in native Caatinga vegetation areas submitted to different cutting practices with and without burning in the semi-arid region of Northeast Brazil.

2. Material and methods

2.1. Century model

The Century model simulates carbon (C), nitrogen (N), phosphorus (P) and sulfur (S) dynamics in plants and soils of natural or cultivated systems, using a monthly time step. In our work, we simulated only C and N dynamics. The key Century inputs represent monthly climate variables, soil physicochemical properties, initial soil C and N levels, and plant information and management data. Plant production can be simulated using sub-models of pasture/crop, forest or savanna systems. Land use change can be represented by changing the type of community of the plant during the model runs; for example, start with forest, change to a cultivation system and then to the regeneration phase of the native vegetation. The residue production is divided into structural and metabolic residues with differing decomposition rates and initial lignin to N ratios. Soil texture and climate variables control the decomposition rate and organic N flows follow the C flows (Parton, 1987).

The Century model version 4.5 was used for the calibration and validation procedures. The model developers (https://www.nrel.colostate.edu/projects/century/) provide pre-established parameters for several biomes and major crops around the world (Parton et al., 1994). The savanna sub-model (TSAVAN) was used to simulate the caatinga vegetation, integrating woody and herbaceous vegetation into

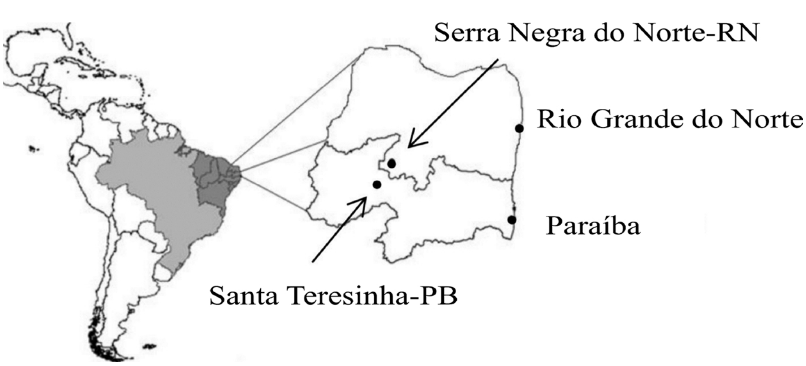

Fig. 1. Location of the areas (indicated by arrows) used for calibration (Santa Teresinha) and validation (Serra Negra do Norte) of the Century model in the present study.