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Simulation of aboveground biomass production under different rainfall scenarios and soil types in the Caatinga Biome, Brazil

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ABSTRACT

Drought years have a negative impact on the livestock production systems of the Brazilian semiarid region because of the strong reduction of forage production on the rangelands. Although drought is recurrent in the Brazilian semiarid, up to the present moment, there are no tools that could help farmers to mitigate the effects of these extreme climate conditions. In this sense, simulation of biochemical cycles using mathematical models could be a helpful tool to understand these processes. The Century model has been largely used to estimate the impact of different environmental variables, management practices, and climate scenarios in the vegetation. The study aims to evaluate the Century model to simulate the dynamics of aboveground biomass production and soil carbon in the Caatinga ecosystem under three different rainfall scenarios: 1) Precipitation 50% below the long-term average; 2) Long-term average rainfall; 3) 50% above the long-term average rainfall. Moreover, two types of soil (sandy and clay) were evaluated in the simulations. Dry years led to 42 and 20% reductions in aboveground biomass production in the shrubby and herbaceous layers, respectively, but there were no significant differences between soil types. Further adjustments in the model are required to simulate herbaceous biomass in the Caatinga ecosystem. At the end of the adaptation phase, we expect that the Century model will generate useful information to fill the lack of knowledge about variability of forage production in the Caatinga, helping in the adaptation to possible climate changes.

Keywords: Century model, forage, semi-arid region

Introduction

Livestock production is an essential economic activity for the semiarid region in NE Brazil. However, during severe drought events, which occur every 10 to 15 years, the livestock herds usually suffer a drastic reduction, caused by death, commercialization, moving of animals for regions with more forage available and/or early slaughter of animals (SAMPAIO, 1995; CARVALHO et al., 2003).

Droughts have a substantial negative impact on the local economy, especially for small breeders with low income, where the animals are the unique source of economic income (MENEZES et al., 2012). The productivity of the rangelands is associated with environmental factors and management practices. Among these factors: type of vegetation, soil fertility and mainly the rainfall control the annual production of forage biomass.

The average annual aboveground biomass production of shrubs and herbaceous in the Caatinga ecosystem varies according to edaphoclimatic conditions and duration of the growing season. Araújo Filho (2013) stated that the Caatinga ecosystem has an average biomass production of 6 Mg ha^{-1} year, which were divided in 2 Mg ha^{-1} of wood and 4 Mg ha^{-1} of leaves, flowers, and fruits. In areas of Caatinga vegetation with a high dominance of shrubs (>90%), the annual biomass consists mainly of shrubs. Stocking rates also influence on biomass production of the rangelands in the Caatinga ecosystem.

Also, the soil and rangeland management, as well as the climate, influence the carbon dynamics of soils and vegetation on rangelands. Projections about climate change reveal that in the future we could have an increase in air temperature and reduction of the precipitation in the northeast region of Brazil (MARENGO et al., 2011; MARENGO e BERNASCONI, 2015; ALTHOFF et al., 2016). In this way, it is important to study how these climate changes could affect the ecosystems on drylands of Brazil. Biochemical simulations models of the plant-soil-atmosphere systems could help to understand the dynamics of these systems.

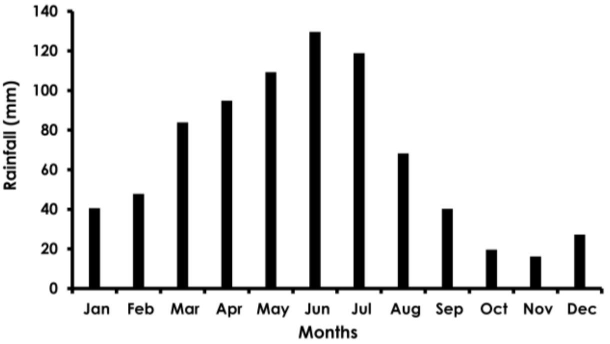
Therefore, the study aimed to adapt the Century model to simulate C-cycles in the shrubland area (Caatinga ecosystem) under two types of soils (clay and sandy) and three different rainfall scenarios (dry, regular and rainy years).

Material and Methods

Study area

The simulations were carried out for the municipality of São João, in the Agreste region of Pernambuco State (8° 52' S; 36° 22' W and an elevation of 705 mamsl). The climate of the zone in the study is As' which it represents a hot and humid climate according to Köppen classification. The rainy season starts in December/January and ends on September. The long-term average annual precipitation is 796 mm (Figure 1). The soil of the area was classified as an Entisol (Embrapa, 2006).

Figure 1 - Long-term average annual precipitation* of the study site.



* The long long-term average was calculated based on monthly precipitation during 1950 to 2002 (52 years).

Use of Century model to estimate the aboveground biomass and C stocks

The use of mathematical models has been suggested as a tool to study the impact of management practices in rangelands, especially on C, Nitrogen (N), Phosphorus (P), and sulfur fluxes in the soil-plant system (WENDGLIN, 2007). Several mathematical models with this purpose have been created, among these, the Century (PARTON et al., 1987). The Century has been widely used in tropical ecosystems (CERRI et al., 2003; CARVALHO et al., 2015); in subtropical ecosystems (BORTOLON et al., 2011; LEITE et al., 2004a, b; LOPES et al., 2008; TORNQUIST et al., 2009), and drylands of Brazil (ALTHOFF et al., 2016). In every ecosystem, the Century showed to be a powerful tool to simulate the effects of land use and management of ecosystems on biogeochemical cycles.

Previously, the Century was calibrated and validated for two sites in the semiarid region of Brazil. The first site was on the "Sertão" region of Paraiba state (06°59'13", 07°00'14"S e 37°18'08", 37°20'38"W) and the second site was on Seridó region of Rio Grande do Norte state (06°35'35"S e 37°14' 19" W). Both sites have the caatinga as dominant vegetation (ALTHOFF, 2018).

To convert the carbon values into forage biomass, we assumed that average C concentration in plant biomass is 45%. We also assumed that 45% of the total biomass was potentially available to be eaten by the animals (leaves, thin stems, and fruits up to 1.5-meter in height) (CHAZDON, 2012). To estimate C allocation of aboveground biomass of shrubs in the Caatinga, we considered that 2-5% of biomass were leaves, 70-80% were thick branches, and 10-20% were thin branches (SAMPAIO e SILVA, 2005).

Firstly, the model was adjusted to simulate the dynamic of biomass production over several centuries, aiming the stabilization of nitrogen and carbon stocks in the ecosystem. Afterwards, the simulation was carried out using the precipitation database previous described which we defined as cycles on the non-disturbed area. Then there were simulated management scenarios with the deforestation of all vegetation in 1989 and regeneration starting in 1990.

Climate database of the study area and simulations of climate scenarios

A file *.WTH (the file format used on Century model) was created including monthly precipitation, maximum and minimal air temperatures of the study area. The long-term monthly precipitation averages were calculated using 63 years (1950-2012) of data obtained from the "Windows precipitation software" (WinPreci) (SILVA, 2015). The interpolations of this software were generated using historical records of precipitation of the Instituto de Tecnologia de Pernambuco (ITEP) and Instituto Nacional de Meteorologia (INMET).

The temperature databased was created using the software Estima-T. The Estima-T was designed to estimate the air temperature for the northeast region of Brazil. The Estima-T determines the coefficients of the quadratic function to maximum, minimal and average air temperatures according to the longitude, latitude, and elevation (CAVALCANTI et al., 2006).

The simulations of the Century model were adjusted to evaluate the biomass production (g C m^{-2}) in function of two types of soil and three precipitation regimes. The types of soil were: 1) soil with sandy texture (87, 9, e 4 % of the sand, silt and clay, respectively), and

2) soil with clay texture (50, 25, e 25 % of the sand, silt, and clay, respectively).

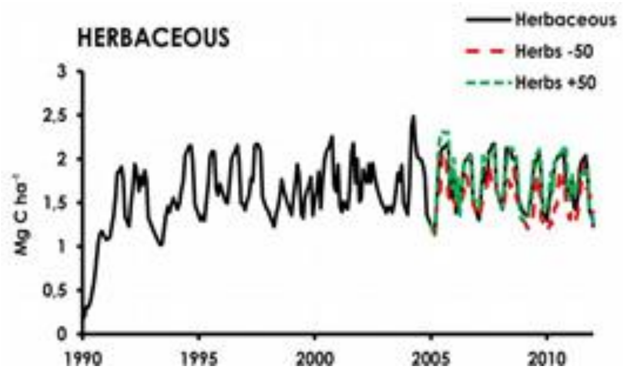
The precipitation regimes simulated were: 1) Precipitation 50% below the long-term average precipitation; 2) Long-term average precipitation; 3) 50% above the long-term average precipitation. The averages were determined using interpolation in the software Winpreci (SILVA, 2015). The model simulated that in some plots all shrub biomass were cut off in 1989 and then the model also simulated the regeneration of the vegetation.

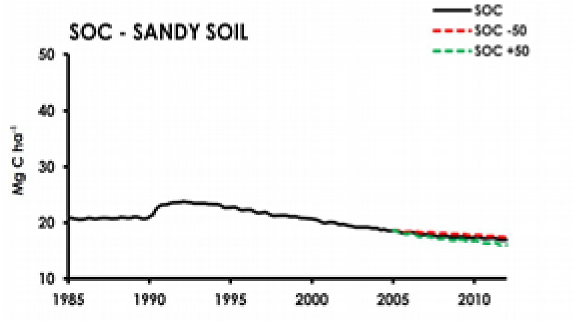
Results and Discussion

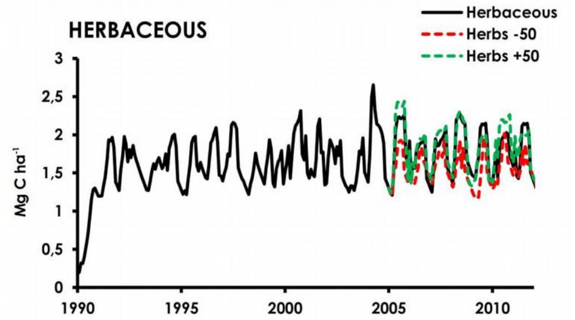
The dynamics of carbon fluxes for the herbaceous layer during the period of the study is shown in figure 2. The annual average herbaceous carbon accumulation for the two types of soil was estimated at 2,1 Mg C ha^{-1}, which represents 4,6 Mg ha^{-1} of dry matter. The simulation showed no differences in herbaceous biomass production between soil types. On the other hand, there were significant differences in biomass production between precipitation scenarios. On dry years there was a reduction of 5% in the dry matter productivity. However, over the years there have been reduction peaks in the biomass production up to 20%, for example, during 2006 and 2010. Overall, these values were lower than we expected, which indicates that the model may need further adjustments to these conditions.

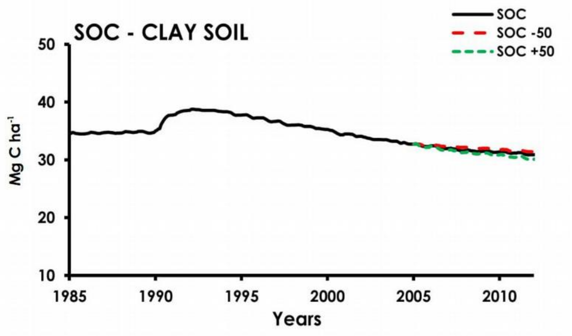
The absence of differences in aboveground biomass between precipitation regimes scenarios could be caused by natural cycles of succession in the caatinga. Most of the Caatinga areas nowadays is mostly in secondary progressive successions. Generally, in situations when non-disturbed Caatinga vegetation is deforested, the herbaceous cover is sparse and with low biodiversity, caused by the extinction of the seed bank of annual plants due to a long time with a predominance of shrub cover in the area.

Figure 2 - Simulations of Herbaceous biomass productivity and COS with two different types of soil and precipitation regimes sceneries*









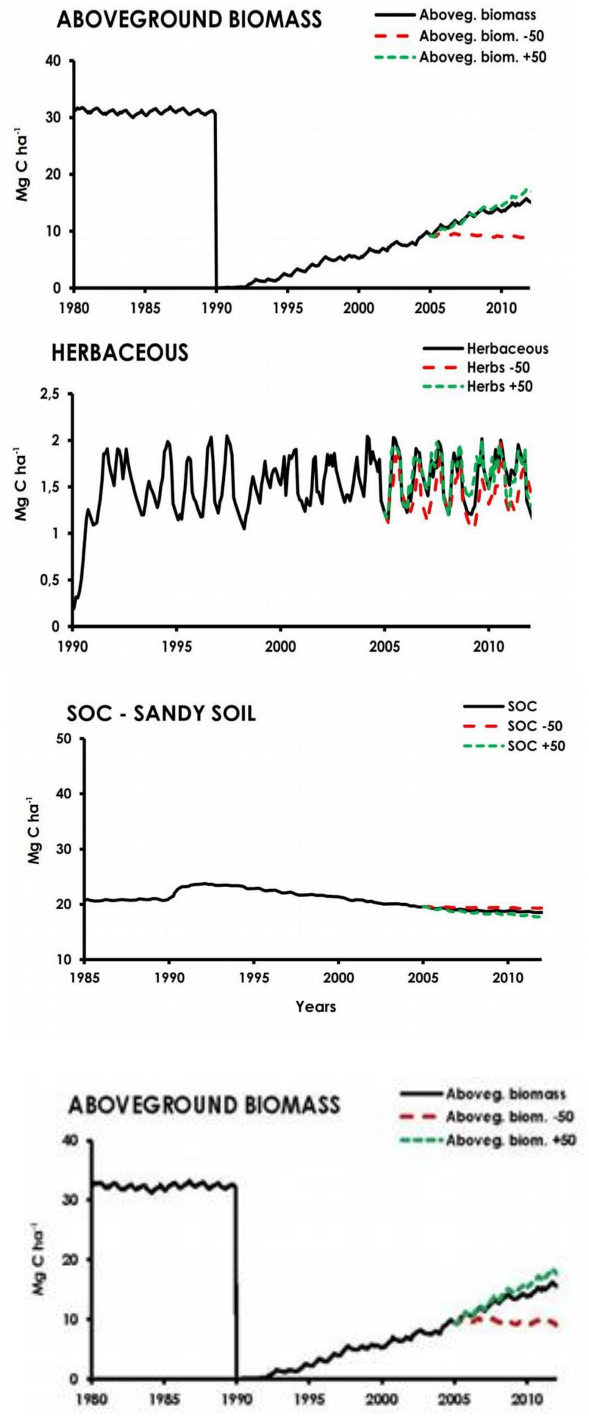
* Precipitation 50% below the long-term average precipitation; 2) Long-term average precipitation; 3) 50% above the long-term average precipitation.

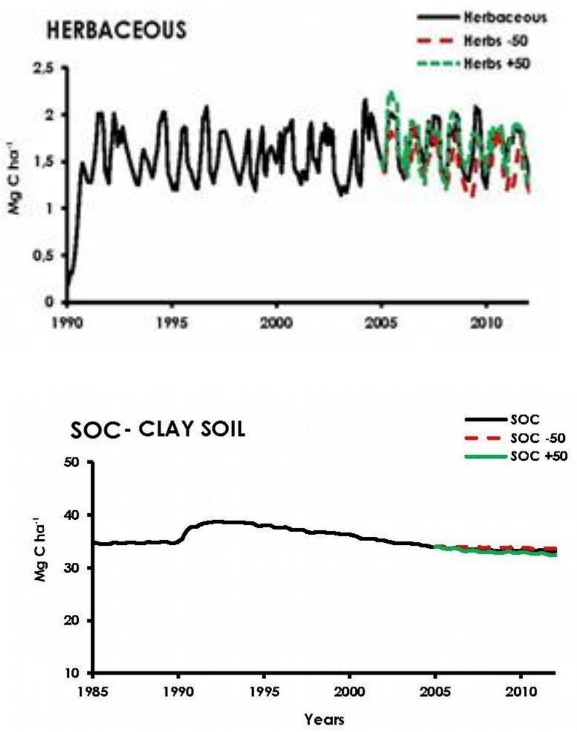
The carbon accumulated in the soil showed differences between soil types. Sandy soil, as expected, accumulated less C than the clayey soil. Soil C stocks were 20 Mg C ha^{-1} under sandy soil and 35 Mg C ha^{-1} under the clayey soil. However, there were no statistical differences in the carbon accumulated in the soil between the precipitation scenarios studied. The C accumulation was highest in the dry years. Wet years exhibited the highest organic matter decomposition, suggesting that an important portion of this carbon was released into the atmosphere.

Aboveground biomass of shrubs in preserved areas (>50 years) was around 70 Mg ha^{-1} with a carbon stock of 30 Mg ha^{-1} (Figure 3). The carbon stock in areas under the process of regeneration of vegetation oscillated between de 9,5 to 14,2 Mg C ha^{-1}, for dry and wet precipitation scenarios, respectively. These values represent a biomass accumulation of 21 and 30,5 Mg ha^{-1}.

If we consider only the biomass of leaves, flowers and fruits production in sites with shrubby-arboreal vegetation, 90% of the total biomass comes from arboreal species, of which 70% is potentially consumed by the animals (280 kg/ha/year). Although the forage biomass in the Caatinga can reach 4.0 t/ha/year during the rainy season a significant proportion are unavailable to be used by the animals. On the other hand, during the dry season, the amount of forage available is low, with the aggravating factor of the drastic reduction in the herbaceous biomass which is the most important for the animal in rangeland systems. CARVALHO FILHO, (1994) reported that on average the herbaceous forage biomass available in the Caatinga is around 400 kg/ha/year.

Figure 3 - Aboveground biomass accumulation and soil organic carbon (SOC) simulations for herbaceous and shrub layers under two soil types and three precipitation scenarios*.





* 1)
Precipitation 50% below the long-term average precipitation; 2) Long-term average precipitation; 3) 50% above the long-term average precipitation.

Biomass production by the shrub layer had a positive correlation with precipitation. Overall, dry years promoted a reduction of 30% in the annual biomass accumulation. The higher reduction in biomass occurred in 2012 (42%) when compared with moderate years. Althoff et al., (2016) obtained similar values under simulations of high temperatures and low precipitation. Under wet years the simulation suggested an increase of 6% in biomass production. The highest value simulated was an increase of 12 % under the last year of analysis (2012). Herbaceous biomass followed the same pattern of shrubs when it was simulated separated from other groups of plants. However, as expected, herbaceous biomass was lower than shrubs biomass, which was probably a result of competition for water and nutrients from the shrub layer. The average value for carbon stock in the herbaceous group was 1,9 Mg C ha^{-1} which represented 4,25 Mg ha^{-1} of dry matter. For the soil organic carbon, the simulations were similar in the three precipitation scenarios, and the two soil types studied.

The simulations with the Century model represented the changes in biomass production of the shrubby layer, especially in dry years. However, the sensibility of the model to catch biomass production changes for the herbaceous layer needs to be more studied and adjusted. Althoff et al., (2016), studied the effect of climate change scenarios and management practices on the Caatinga ecosystem and they concluded that aboveground biomass and the soil organic carbon should decrease in 40 and 13% respectively in the next 100 years. Therefore, climate change scenarios reveal that forest resources, such as wood and forage production of rangelands, could decrease due to more frequent droughts, consequently limiting carbon fluxes in this ecosystem.

Conclusions

Aboveground shrub biomass accumulation simulated by the Century model showed to be sensitive to variations in precipitation. On average, dry years promoted a reduction of 42% in aboveground biomass when compared with years with regular rainfall pattern. However, contrary to the expectations, the herbaceous layer was not very responsive to changes in the precipitation scenarios, which differs from the observed data in the literature. This result indicates the model needs further adjustments in the algorithm and input parameters to simulate the growth of herbaceous species. Soil types (sandy or clayey) did not have a significant effect on simulated biomass production. Soil carbon stocks were higher in clayey soils, but there no effects of rainfall scenarios on soil carbon. This result was already expected due to the short simulation time. Overall, the Century model demonstrated potential to be a useful tool to evaluate the dynamics of forage production in the caatinga ecosystem, but further adaptation and calibration of the model is still necessary.

Acknowledgments

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