Modelling leucaena biomass under rainfed production systems of semiarid regions

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Abstract. The climatic variability of semiarid regions is the main source of uncertainties associated with forage and animal production, indicating a need for tools that accurately estimate forage production in order to construct a forage budgeting plan for livestock. This study simulated the biomass of Leucaena (*Leucaena leucocephala*) using the PHYGROW model in four locations located in Brazilian Semiarid. The work was carried out based on field data collected from 2019 to 2021. After sowing in 2018, leucaena was harvested when it reached 200 cm and to a target residual height of 70 cm. The biomass (fresh matter) was weighed, sampled and dried to obtain the total forage biomass (BFT) of each sample. The BFT was also estimated using the PHYGROW model, with field data being used to parameterize, calibrate and validate the model. The model performance, in turn, was evaluated based on the mean forecast error (BIAS %), root mean square error (RMSE) and Willmott index. Afterwards, a BFT time series was downloaded for each location, with the highest biomass simulated for each year being evaluated in the @Risk regarding their probability distribution. Thereafter, probability calculations of biomass production were performed, based on different levels of warranty in SigmaPlot software (11.0). The model underestimated the BFT collected in two locations and overestimated BFT in the others. The Weibull function was the best one to describe the data. Regarding biomass production under a 95% natural warranty, it was observed that leucaena showed low variation among locations (2240 ± 752 kg of DM ha^{-1} $year^{-1}$). The PHYGROW model accurately predicted the leucaena BFT which, in turn, demonstrated significant adaptation potential to the various soil and climate conditions of Brazilian Semiarid. The use of probability analysis can contribute to forage planning, thus reducing the uncertainties related to climate variability, especially in rainfed production systems of dry areas.

Introduction

The growing demand for food associated with climate issues has put pressure on agroecosystems to be more efficient, with minimal environmental impact (Adesogan et al. 2020). This is even more challenging in a naturally vulnerable environment such as arid and semiarid regions, where the highly variable rainfall patterns make forage and animal production difficult to predict.

To contribute to sustainable animal production in these areas, the use of mechanistic and stochastic modelling can provide an opportunity to predict the forage production in the long term. This enables development of a forage budgeting plan which in turn will insure the maintenance of a stabilized carrying capacity at the farm level, offering producers an alternative for long-term strategic planning.

Taking into account the importance of leucaena (*Leucaena leucocephala*) as a forage resource to low input-based production systems, this study was carried out to simulate the biomass of leucaena using the PHYGROW model in four locations located in Brazilian Semiarid.

Methods

This study used field data from four locations located in Brazilian Semiarid (Table 1).

Before sowing, soil samples were collected to a 20-cm depth to characterize them chemical and physically. Leucaena was sowed in four plots (35 x 12.5 m) per location, with a 1.0 m spacing between plants and 3.0 m between rows. The crop was fertilized at sowing with 100 g of N-P-K mixture (5-25-15) per plant. After the second year from sowing, the biomass was sampled by choosing 10 plants from the 3 central rows in each plot. They were harvested to 70 cm above ground level, each time the plants reached an average height of 200 cm.

Table 1- Locations studied and their climate classification

Location	Climate*	Latitude	Longitude

Carlos Chagas	Aw	-17,683306 S	-40,797694 W
Itapetinga	Aw	-15,261611 S	-40,241000 O
Montes Claros	Aw	-16,662306 S	-43,737694 W
São João	Aw	-8,824000 S	-36,423389 W

*Classification according to Köppen (1936).

Biomass modelling was performing by means of Phytomass Growth (PHYGROW) (STUTH et al. 2003), using its online version named PHYWEB, version 2.0. A field from each location was used to parameterize, calibrate and validate the model. To parameterize the soil components of each site, this component was identified using the soil database for Brazil and chosen based on the chemical and physical characteristics found in the soil analyses of each URT.

Historical rainfall data to feed the model were obtained from the Database of the Climate Prediction Center of the National Oceanic and Atmospheric Administration (NOAA) and temperature from the Global Daily Assimilation System (GDAS) database. Data from the climatological station closest to each URT were also acquired for comparison with the values obtained from NOAA. Weather variables obtained from the seasons included average temperature and precipitation. Solar radiation was estimated from the temperature and latitude of the site, using the procedure described by Samani (2000).

Like soil data, data on forage, such as biomass produced, were entered into the PHYGROW centralized database, which contains a relational table structure for storing parameter data for each of the monitored URTs. Data on the soil parameters included soil depth, apparent density, water retention capacity variables, slope parameters and water flow.

Data from plant parameters for plant community characterization included information about basal area and canopy cover. Specific parameters for studied species such as leaf area index, relative growth rate, rooting depth, plant height and optimal growth and suppression temperatures were also entered in the system through collected data and literature data published in online databases such as EcoCrop (FAO, 1994) and Global Leaf Area Index Database (SCURLOCK et al., 2001).

After calibration, the performance of the model was evaluated using the following statistical parameters: mean forecast error (BIAS%), square root of the mean error (RMSE) and Willmott agreement index (Willmott, 1981; Willmott et al., 1985).

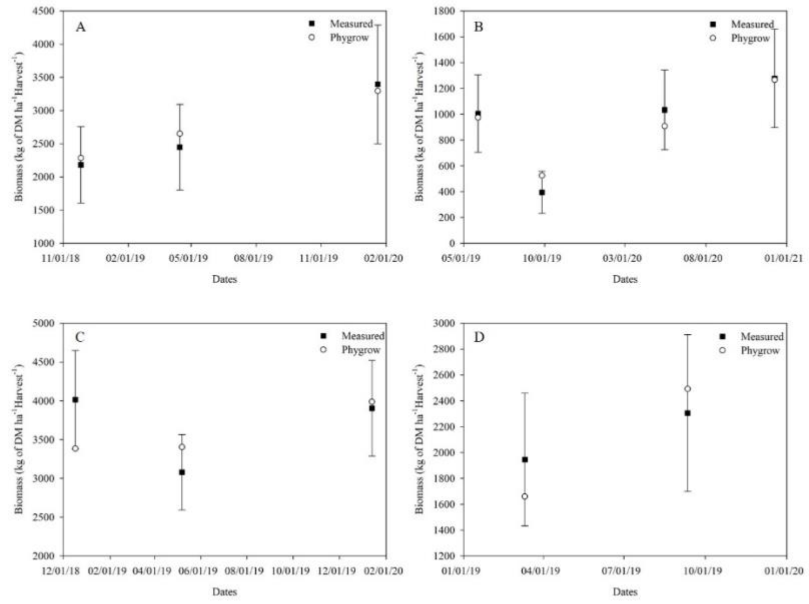
Afterwards, a time series of 840 months (70 years) referring to dry biomass (kg ha^{-1} day^{-1}) was downloaded for each calibrated model. These series were opened in Microsoft Excel software and later selected, for each year, the highest biomass value simulated by the platform. The highest values for each year of the time series analyzed were evaluated in complement @Risk for its probability distribution (adherence test). Subsequently, based on the statistical parameters of the defined probability distribution, 10 synthetic series of 1,000 values each were generated, also in complement @Risk, resulting in a total of 10,000 pseudorandom numbers. Finally, the 10 synthetic series were opened in Microsoft Excel, where probability calculations of biomass production were performed based on different confidence levels. From these guarantee levels, regression calculations were performed between the guarantee levels found and their respective biomasses with the aid of sigmaplot software (11.0).

Results and Discussion

The leucaena biomass was accurately predicted by PHYGROW at the sites studied (Figure 1). Overall, the PHYGROW model slightly overestimated the observed biomass in Carlos Chagas and Montes Claro, with variable response in Itapetinga and São João sites.

The prediction mean error was very small, with values of -2.33; -2.03; -1.02 and +2.59 % to São João, Montes Claros, Itapetinga and Carlos Chagas, respectively. The root mean square error were 746; 406; 511; and 1100 kg DM ha^{-1} to Carlos Chagas, Itapetinga, Montes Claros and São João, respectively, with their corresponding Willmott Index of 0.63; 0.68; 0.56 and 0.45.

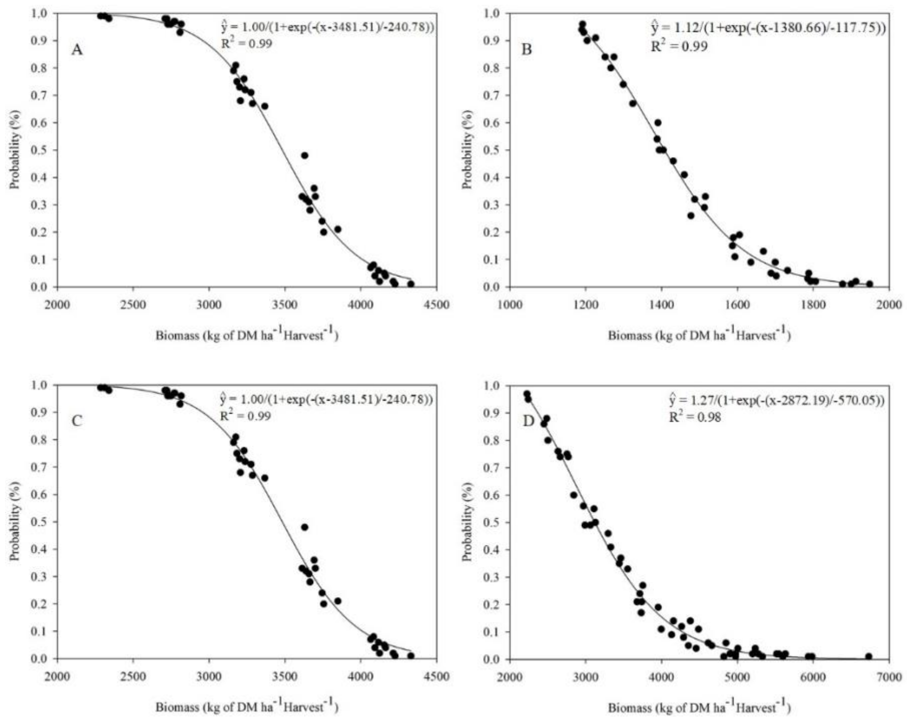
Figure 1 – Leucaena total biomass observed and predicted data at the locations of (A) – Carlos Chagas, (B) – Itapetinga, (C) – Montes Claros e (D) – São João, respectively



The Weibull probability density function fit the historical data series simulated by PHYGROW, with mean values of 3490; 3540; 3510 kg DM ha^{-1} year^{-1} to Carlos Chagas, Itapetinga, Montes Claros and São João, respectively. That function also revealed a discrete negative asymmetry (-0.16) and platykurtic kurtosis (2.79).

After the synthetic series generated by @ Risk, observed estimated biomass was 2800, 1190, 2780, and 2200 kg DM ha^{-1} with a 95% confidence level (Figure 2) to Carlos Chagas, Itapetinga, Montes Claros and São João, respectively.

Figure 2 – Confidence level of Leucaena biomass to the locations of (A) - Carlos Chagas, (B) - Itapetinga, (C) - Montes Claros and (D) - São João, respectively



Overall, the low values of RMSE suggest a good fit between observed and simulated data. Otherwise, the Willmott index denoted a moderate capacity of the PHYGROW model to estimate leucanea biomass. From the density probability function, one suggests the possibility to achieve field values below those estimated by the model. Taking into account the estimated biomass of 2770 kg DM ha^{-1} in Carlos Chagas and considering a value of 50% for efficiency of herbage utilization and a daily dry matter intake of an animal unit of 11.3 kg, we should expect a carrying capacity of 2.96 animal units/ha. This is three to four-fold the reported carrying capacity of Brazilian Semiarid rangeland (Araujo Filho 1992) and stresses the strategic potential to use improved forages to increase the carrying capacity of Brazilian Semiarid farms.

Even with leucaena showing high capacity to produce biomass under water deficit, as related by (Marin et al. 2007), the shallow soils of Brazilian semiarid comprise an extra challenge for this crop to be adopted on a large scale, so that the edaphic characterization at the farm level provides important for optimal allocation of this crop to soils that provide the minimum conditions for its production. In spite of edaphic limitations, the low variation in leucaena biomass (2240 ± 752 kg DM ha^{-1} $year^{-1}$) suggest it tolerates a wide range of edaphic conditions in Brazilian Semiarid.

Conclusions and/or Implications

The PHYGROW model was suitable to predict leucaena biomass in semiarid conditions, showing potential to be used in studies of short and long-term forage budgeting.

Leucaena was adapted to a wide range of conditions in Brazilian Semiarid, with an estimated biomass of 2240 ± 752 DM ha^{-1} $year^{-1}$.

The use of plant growth modeling associated with probability analysis techniques should contribute to forage budgeting, reducing the uncertainty of production in rain fed systems of arid regions.

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