The CROPGRO Perennial Forage Model Simulates Productivity and Re-Growth of Tropical Perennial Grasses

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Abstract
This paper introduces the CROPGRO Perennial Forage model (CROPGRO-PFM) and describes its ability to simulate regrowth dynamics and herbage production of *Brachiaria* and *Panicum* as affected by harvest management and weather. The model simulates regrowth, herbage harvests, percent leaf, and herbage protein of perennial forage grasses and legumes over multiple seasons. It can regrow from zero LAI (after harvest) based on use of carbohydrate and N reserves in storage tissues; however, the amount of residual stubble and residual leaf area index (LAI) are also important for rapid regrowth and productivity. The model is publically available for download from DSSAT.NET.

Introduction
Perennial tropical grass species such as palisadegrass (*Brachiaria*) and guineagrass (*Panicum*) are important pasture grasses worldwide and are affected by management, fertilization, soils, and weather. Crop growth simulation models can be used as tools to evaluate forage production response to management strategies, soils, and weather variation. The CROPGRO Perennial Forage model, released with DSSAT V4.7 software (Hoogenboom et al., 2017), is capable of predicting herbage harvests, herbage protein, and re-growth of perennial forage grasses and legumes over multiple seasons. The model was converted from the annual CROPGRO model (Boote et al., 1998) to a perennial model by Rymph (2004) by adding a storage organ (rhizome, taproot, crown) with carbohydrate and N storage pools that provide the ability for re-growth despite zero LAI caused by harvest, severe drought, or freeze-loss of all leaf tissue. The model includes seasonal dormancy, freeze thresholds, and rules for partitioning to the storage organ. Rules for dormancy, freeze thresholds, partitioning, re-growth, productivity, mobilization of carbohydrate and nitrogen from storage pools to drive re-growth, and re-fill of storage pools are included in "species" and "cultivar" files. This perennial forage version, as released in the DSSAT V4.7, has species/cultivar files for Marandu (*Brachiaria*), Tifton-85 Bermudagrass (*Cynodon*), *Panicum maximum* (Tanzania), and alfalfa (*Medicago sativa*). The model requires a read-in file called "MOW" that specifies the harvest dates, the residual live stubble (kg/ha), associated percent leaf, and a hypothetical "re-set" leaf number on tillers. The model will start from seed or vegetative cutting. The model simulates daily dynamics of soil water, soil C, soil N balance, and growth response to weather, water stress, N deficits, and forage management practices. It uses the DSSAT-CENTURY soil C module (Gijsman et al., 2002) and re-cycles N from senesced litter. Simulated productivity and re-growth dynamics of Marandu, and *Panicum maximum* over multiple seasons are illustrated for Brazilian conditions.

Methods and Study Site
Palisadegrass (*Brachiaria brizantha*) cv. Marandu was grown during April 2011 to April 2013 on a highly fertile Kandiudalfic Eutrudox in a field at the University of Sao Paulo "Luiz de Queiroz" College of Agriculture in Piracicaba, Sao Paulo, Brazil (22°420S, 47°300W; 546 m a.s.l.). Treatments were two harvest frequencies, 28 day and 42 day, at rainfed or irrigated conditions. See Pequeno et al. (2014, 2018) for details of harvest handling, irrigation, weather, and N fertilization (400 kg N/ha per year). Forages were harvested at 10-cm stubble height from two 0.75-m^2 quadrats, and separated into leaf, stem, and dead material. LAI was measured. Living stubble mass and corresponding percent leaf were measured periodically, because stubble mass and percent leaf are required inputs to the MOW file. Herbage yield corresponds to live leaf and stem, while the reported shoot mass is the sum of herbage plus stubble mass. Interpolation of stubble mass was required between sample dates, because stubble mass was not measured on all dates.

Guineagrass (*Panicum maximum)* cv. Tanzania was grown under irrigation at the same soil and site as described above, during December 2002 to April 2004. See Lara et al. (2012) for details on management, irrigation, weather, and N fertilization (250 kg N/ha per year). Forage from three 0.5- by 2.0-m quadrats was clipped at 35-cm height on a 35-day harvest schedule (63-day in winter). Forage mass was separated into leaf, stem, and dead materials. LAI was measured weekly with LI-COR LAI-2000 plant canopy analyzer. The living stubble mass and corresponding percent leaf were measured three times during the study.

The weather, soils, and management information were provided as inputs to the CROPGRO-Perennial Forage model, release version as V4.7 (Hoogenboom et al., 2017), with parameters as calibrated by Pequeno et al. (2014, 2018) and Lara et al. (2012). Model simulations were compared to observed shoot dry matter, leaf dry matter, stem dry matter, percent leaf, and crude protein (Lara et al., 2012; Pequeno et al., 2014).

Results

Simulated shoot growth and herbage production of Marandu:

The CROPGRO-PFM model was able to successfully simulate the shoot growth dynamics of Marandu palisadegrass over two years for the 28-day and 42-day harvest frequencies for rainfed and irrigated conditions (Pequeno et al. 2014). Figure 1A illustrates the simulated shoot mass over time for the 42-day frequency treatment under irrigation. It is important to note that the baseline in the figure is the stubble mass (with a few sample dates showing, along with interpolation), and the sudden drop in the shoot mass corresponds to the herbage harvest (back to the stubble mass left). Figure 1B illustrates the simulated herbage mass for the 42-day frequency under irrigation.

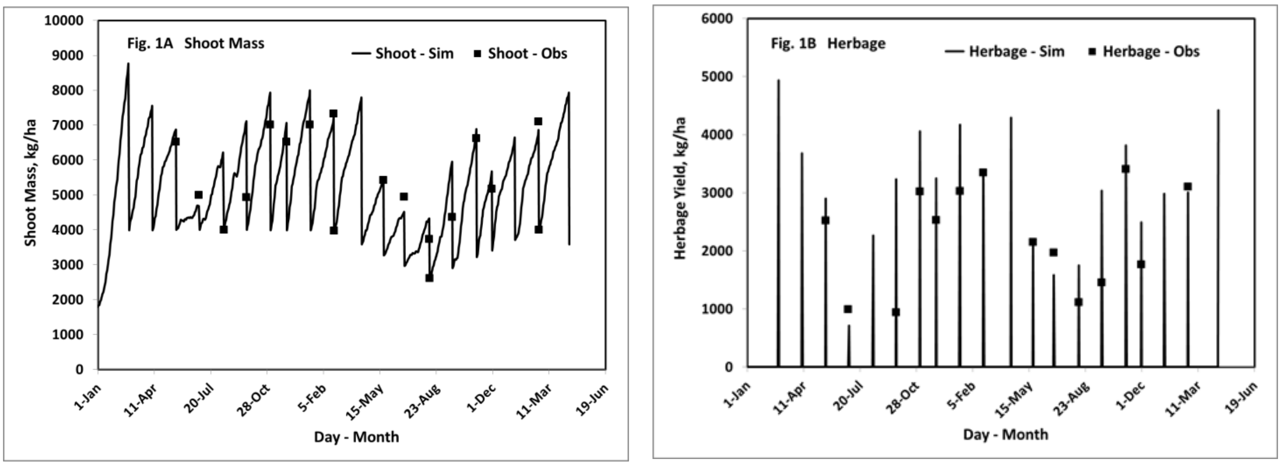

Figure 1. Simulated compared to observed A) shoot mass and B) herbage yield of Marandu palisadegrass for 42-day harvest frequency during 18 cycles over 2 years at Piracicaba, Brazil.

Simulated shoot growth and herbage production of Tanzania: Figure 2A shows the CROPGRO-PFM model simulations of shoot growth dynamics of Tanzania guineagrass over 11 cycles over 1 ½ years under irrigated conditions (Lara et al. 2012). Figure 2B shows the simulated percent leaf (of the total shoot) over time, showing how the percentage leaf drops with each harvest (to baseline percent leaf in stubble), and recovers after each cutting cycle.

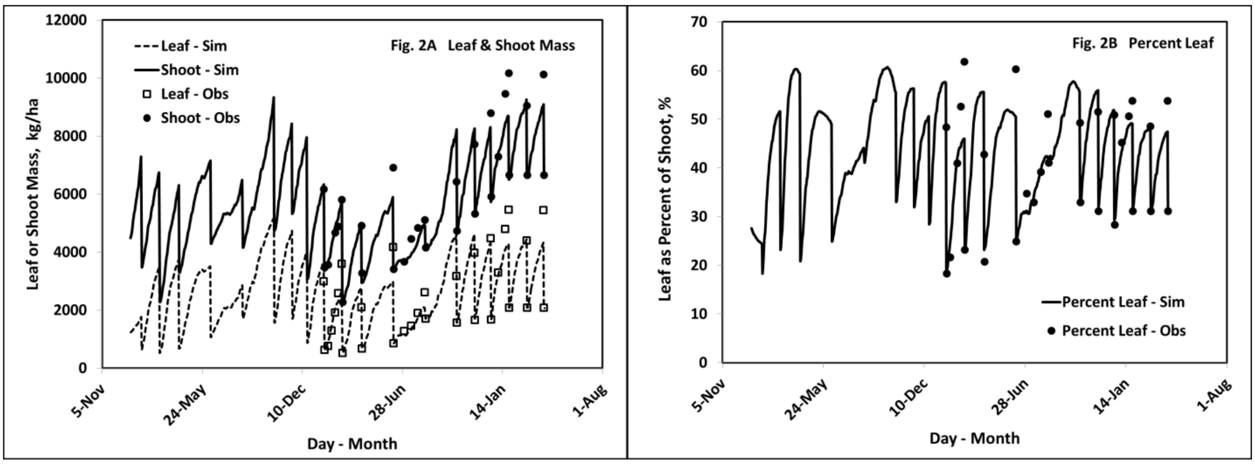

Figure 2. Simulated compared to observed A) leaf and shoot mass and B) leaf as a percentage of shoot for Tanzania guineagrass for 35-day harvest frequency during 11 cycles over 1 1/2 years at Piracicaba, Brazil.

Discussion [Conclusions/Implications]

Simulated shoot growth and herbage production of Marandu: The CROPGRO-PFM model was able to successfully simulate the shoot growth dynamics of Marandu palisadegrass over two years for the 28-day and 42-day harvest frequencies for rainfed and irrigated conditions (Pequeno et al. 2014). Figure 1A illustrates the simulated shoot mass over time for the 42-day harvest frequency under irrigation. The model responds to lower temperature during the winter season, as can be seen in the smaller re-growth increment. During model calibration, these data assisted Pequeno et al. (2014) in setting the base temperature for leaf photosynthesis to 6.2°C. Likewise, the herbage mass (Figure 1B) shows clearly the reduced production during the cooler winter months. The herbage mass (vertical bar in Figure 1B) corresponds to the extent of the drop in the shoot mass in Figure 1A. Pequeno et al. (2014) evaluated the effects of harvest frequency, residual stubble, and percent leaf of the stubble (the latter two affect the LAI after harvest). They found that high frequency harvesting, e.g. every 14-days, reduced annual production, and that the combination of stubble mass and percent leaf of stubble affected residual LAI. The residual LAI for brachiaria should be above 0.7 to 0.8 for good recovery and maximum annual herbage production. Residual LAI less than 0.7 slowed recovery after harvest and reduced annual production.

Simulated shoot growth and percent leaf dynamics of Tanzania: The CROPGRO-PFM model successfully simulated leaf and shoot growth dynamics of Tanzania guineagrass over 11 cycles under irrigated conditions (Figure 2A) (Lara et al. 2012). As expected, the simulated percent leaf (of the total shoot) over time showed that the percentage leaf dropped after each harvest (to baseline percent leaf in stubble), and recovered after each cutting cycle. This is consistent with the knowledge that herbage harvest removes more leaf than stem mass, and that early re-growth (in the model and reality) emphasizes partitioning to leaf rather than stem (this partitioning function response is set in the species file).

Potential use of the CROPGRO Perennial Forage Model: The model can be used to evaluate perennial forage production responses to weather, management, fertility, and irrigation. We have used the model to simulate additional data sets on *Brachiaria* and *Panicum* as well as other perennial forage species including bermudagrass (Pequeno et al., 2014), alfalfa (Malik et al., 2018), and ryegrass (unpublished work) with good success. The model is publically available for download from DSSAT.NET (Hoogenboom et al., 2017).

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