SIMULATING ALFALFA GROWTH DYNAMICS OF FALL DORMANCY CLASSES ACROSS ENVIRONMENTS

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ABSTRACT

The CROPGRO-Alfalfa model, released with DSSAT V4.8 software (available at *dssat.net*), simulates daily growth processes of alfalfa (*Medicago sativa*), including herbage harvests, herbage protein, and re-growth over multiple harvests and multiple seasons. The model includes a storage organ (taproot, crown) with carbohydrate and N storage pools that provide the ability for re-growth despite zero leaf area index caused by complete shoot harvest or freeze-loss of all leaf tissue. Intensive defoliation and aggressive management can cause poor recovery of re-growth. The model includes rules for fall dormancy (FD), freeze thresholds, partitioning as a function of growth stage and daylength, re-fill of storage pools, along with mobilization of carbohydrate and N from storage pools to drive re-growth. Varying these parameters allows genetic variation among cultivars and dormancy classes. The CROPGRO-Alfalfa model has been evaluated with growth and yield data from FD-types 3, 4, 6, and 9 grown in contrasting environments in Arizona, Montana, Canada, and Spain. Daylength is the most important variable affecting the FD simulations, using a critical daylength of 9.8 hr at which allocation to storage taproot is most rapid (and less to shoot) and the opposing critical daylength (14.2 h) at which allocation to storage is least rapid (more to shoot). The relative "strength" of daylength-driven partitioning to storage (RDRMT) varies with FD class, with RDRMT of 0.500, 0.320, and 0.140 for FD 3, 6, and 9, respectively. These features (daylength effect and its strength), along with variation in leaf photosynthesis (per FD) and rate of leaf appearance allow productivity to vary across FD classes 3 (Rugged), 6 (Cisco II), and 9 (CUF 101), as observed in the growth and herbage yield of three FD-class cultivars in Arizona and Montana. Simulated yield response of FD classes is affected by environment (sites differing in daylength-temperature) and cutting management.

Keywords: crop modeling, regrowth, fall dormancy classes, daylength effects

INTRODUCTION

In this paper, we introduce the CROPGRO-Alfalfa model, its capabilities, its sensitivity to weather factors, and give examples of how it simulates daily regrowth and herbage production. Alfalfa is a productive perennial legume forage crop that is important for livestock feed, particularly for dairy animals because of its high protein and high fiber composition. Production practices include three to four harvests in the Midwestern USA, with up to eight or more harvests in warmer winter conditions in Arizona and California. Alfalfa is almost clear-cut at each harvest, leaving very little amounts of residual leaf area to drive regrowth recovery. The regrowth depends on carbohydrate and N reserves from taproot storage tissue to drive new leaf area growth. The speed of regrowth is also dependent on daylength and the cultivar's fall dormancy classification. Shortening daylengths in fall cause increased allocation to taproot reserves and less to shoot growth especially for the lower FD classification (FD 3 or 4), but much

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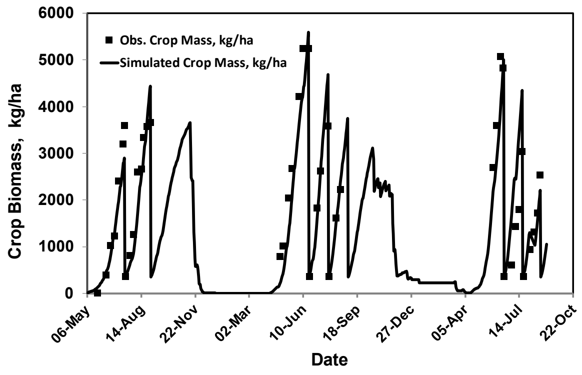
less so for higher FD classes (FD 8 or 9). Weather factors of temperature, solar radiation, rainfall, and daylength influence productivity. We describe how those affect regrowth and herbage production simulated by CROPGRO-Alfalfa.

RESULTS AND DISCUSSION

The CROPGRO-Alfalfa model is part of the Decision Support System for Agrotechnology Transfer (DSSAT) software (Hoogenboom et al., 2021). Its development originated with work by Rymph (2004) who modified the code of the annual CROPGRO model for grain legumes (Boote et al., 1998) to simulate perennial forage crops that regrow after multiple harvests (often harvested to near zero leaf area index (LAI) and over-winter and persist for multiple seasons. This required adding state variables for reserves in storage tissues (such as taproots), along with rules to grow those tissues, to use the reserves for regrowth, and to refill the reserves after cutting harvest. This became the CROPGRO-Perennial-Forage model, which has been adapted for several perennial tropical grasses including *Brachiaria brizantha* (Pedreira et al., 2011), *Panicum maximum* (Lara et al., 2012), and *Cynodon dactylon* (Pequeno et al. 2018). CROPGRO-PFM model was first adapted for alfalfa by Malik et al. (2018) and then evaluated with multiple data sets on FD 3 and FD 4 cultivars in Canada (Figure 1) by Jing et al. (2020). These experimental data were used to solve for cardinal temperature effects on photosynthesis, growth, N-fixation and other processes. The model has since been evaluated against experimental data on multiple FD class cultivars collected in Arizona and Montana (unpublished paper in progress). Simulated results from the sites in Canada, Arizona, and Montana are shown to illustrate how the fall dormancy class effects were calibrated.

Figure 1. CROPGRO-Alfalfa simulation of CFIA (FD4) during 2014, 2015, 2016 at Ottawa, Canada (Jing et al., 2020)



CROPGRO-Alfalfa simulates leaf photosynthesis hourly for sunlit and shaded classes of leaves resulting in hourly canopy assimilation that is integrated to a daily rate. The daily growth dynamics include accumulation of thermal units, leaf appearance rate, partitioning of assimilate to leaf, stem, root, and taproot storage based on vegetative stage. The N dynamics include uptake of inorganic soil N as well as growth of nodules and N-fixation when root N uptake is not sufficient to meet growth demand for N. The soil organic matter dynamics are simulated using the daily CENTURY module which handles residue contributed from senesced roots and surface residue. The soil-crop-water balance operates on a daily step with tipping bucket water balance, with evapotranspiration computed based on Penman-Monteith (FAO-56). If root water uptake is insufficient, the model computes two water-deficit signals, one which reduces canopy assimilation and a more sensitive one that reduces expansive growth sooner than photosynthesis. The model requires Class A weather inputs, soil water-holding traits for soil layers, irrigation and other management inputs. The management inputs include cutting harvest dates, amount of living stubble after harvest, and fraction of leaf. Daily model outputs include LAI, leaf, stem, taproot, root, V-stage, vegetative N concentration, as well as the herbage and herbage crude protein at cutting harvest dates.

Figure 2 illustrates how the CROPGRO-PFM-Alfalfa model simulates LAI for three FD class cultivars in Arizona. Observed LAI was greater for CUF101 (FD9) than Cisco II (FD6) than Rugged (FD3), especially during shorter days of spring/fall. The model was able to capture that response with the modifications of the strength of daylength effect on fall dormancy, along with small differences in photosynthetic rate. Figure 3 illustrates the biomass growth dynamics over time, which like the response of LAI, shows that the model modifications succeeded in capturing the greater biomass accumulation of CUF101 (FD9) compared to Cisco II (FD 6) and Rugged (FD 3).

Figure 4 illustrates the main-stem node number which also differs with FD class (the rate of node appearance set at 0.21, 0.24, and 0.27 per photothermal day for FD 3, 6, and 9). Faster leaf appearance also leads to taller plants for higher FD (data not shown).

Figure 5 shows the model-simulated dynamics of total nonstructural carbohydrate (TNC) reserves in taproot during seven regrowth cycles (where sharp drop of shoot mass reflects herbage harvest) for Cisco II (FD6) in Arizona. While there were no measurements of taproot mass or carbohydrates, the pattern does mimic limited published literature on alfalfa with a 7-14 day depletion of TNC followed by refill of TNC. The taproot and root growth reflect these cycles with slower growth during the 7-14 days after harvest followed by enhanced growth after LAI recovers.

Figure 2 - Simulated (lines) and observed LAI (symbols) for three fall dormancy (FD) alfalfa cultivars grown in Arizona in 2018 (Ottman et al., 2018).

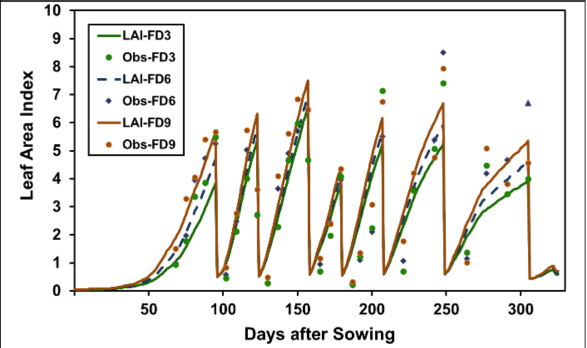


Figure 3 - Simulated (lines) and observed crop biomass (symbols) for three fall dormancy (FD) alfalfa cultivars grown in Arizona in 2018 (Ottman et al., 2018).

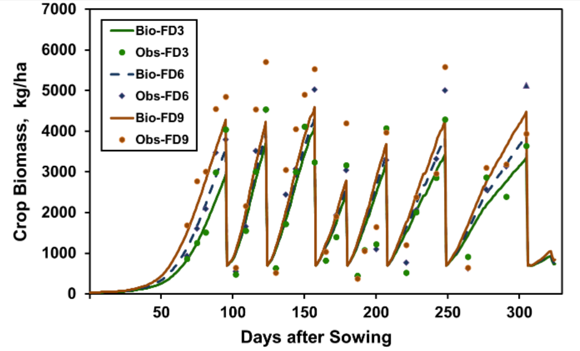


Figure 4 - Simulated (lines) and observed main stem leaf number (symbols) for three fall dormancy (FD) cultivars grown in Arizona in 2018 (Ottman et al., 2018).

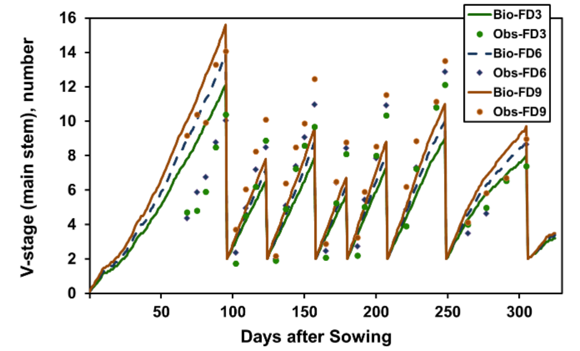


Figure 5 - Simulated taproot, root, and shoot mass, taproot TNC, and shoot mass during 7 harvest cycles of FD6 cultivar in Arizona in 2018 (Ottman et al., 2018).

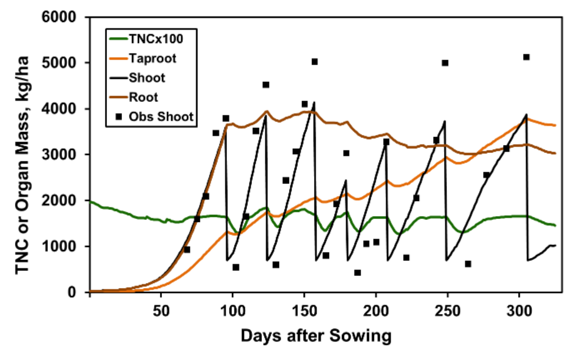
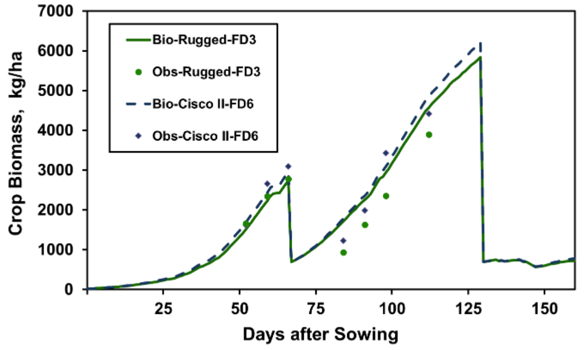


Figure 6 shows biomass growth dynamics over time for two cultivars, Rugged (FD3) and Cisco II (FD6) grown over two harvest cycles in Montana.

The CROPGRO-Alfalfa model is presently available in DSSAT V4.8 (*dssat.net*). The model presently simulates crude protein and percent leaf of herbage. To enhance this as a management tool for alfalfa producers, we hope to add capability for simulating forage quality aspects including digestibility, neutral detergent fiber, acid detergent fiber, relative feed value, and total digestible nutrients.

Figure 6 - Simulated crop biomass of Rugged (FD3) and CIsco II (FD6) during two harvest cycles in 2018 establishment season in Montana (Torrion et al., 2018).



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