Adapting the CROPGRO Model of DSSAT to Simulate the Growth of *Brachiaria decumbens*

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Abstract

We simulated the growth of the perennial tropical forage grass, *Brachiaria decumbens* cv. Basilisk, under a grass-cutting system by using the CROPGRO model released with the Decision Support System for Agrotechnology Transfer (DSSAT version 3.5). To simulate the effect of partial shoot removal, we used the insect pest option to mimic grass being grazed or cut. To calibrate the modified option, we used four sets of Colombian data obtained through the International Network for the Evaluation of Tropical Pastures. We then validated the option against two additional data sets for pasture dry matter (DM) production (cuttings at 3, 6, 9, or 12 weeks) and establishment under drought. For DM production, the simulated results provided a simulation to observed ratio of between 0.96 and 1.01 for one experiment and between 0.82 and 1.00 for the other. However, excluding the data on the first cutting at one site, which was related to pasture establishment during a period of drought when the observed DM production was much lower than the simulated results, provided a closer validation range of 0.98 to 1.01 for this experiment also. Overall, the modified grass option accurately estimated pasture production of cv. Basilisk under different soil and climatic conditions.

INTRODUCTION

Brachiaria decumbens is a widely cultivated forage grass used in cattle production systems in tropical lowlands. It is adapted to different agroecological conditions, ranging from sea level to 2200 m.a.s.l. It tolerates drought, burning, heavy rainfall, intensive grazing, and acid, nutrient-poor soils (Bernal 1994).

Pasture research is relatively expensive because of the multiple factors that affect yield and quality, and the crop's relatively long cycle. The heterogeneity of climatic and edaphic conditions existing in the tropics requires a high number of specific trials, thus notably increasing both, the time taken to make decisions on, and the costs of technology transfer.

The development of analytical models on production systems has considerably reduced both time and costs. The models use equations constructed on the basis of biophysical theory and experimental results and are likewise validated through experimental trials. Once validated, the models permit experimentation and provide support for planning decisions in research, technology transfer, and agricultural development. Furthermore, the models help predict scenarios for land use, explore opportunities for potential but distinct alternatives, identify policies of intervention, and develop support systems for decision making in research and technology transfer (Bouma 1998). A major characteristic of support systems, for decision making in agrotechnology, is their orientation toward meeting the demand for solutions to specific production problems (Stoorvogel 1998). One practical value of simulation models is its utility in situations where carrying out research is physically or economically impossible (Aguilar and Cañas 1992; Quiroz et al. 1996).

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Models help to quickly find answers to such questions as “What would happen to a forage’s yield and quality if more fertilizer were applied, or if climate or soil changed?” (Bouma 1998). Models do not make decisions but help technicians and farmers towards making the right decisions (Stoorvogel 1998).

The Decision Support System for Agrotechnology Transfer (DSSAT) comprises six models for simulating the growth of 16 crops of economic importance. It has demonstrated high reliability under different climates, soil, and management conditions (Jones 1993). With this modeling system, it is possible to:

- Organize and file databases on climate, soils, crops, experiments, and prices;
- Simulate crop production in one or various periods and in sequences;
- Analyze results and graphically present simulations; and
- Evaluate different management practices, specific to one farm or its part (Jones 1993).

The use of the DSSAT for pastures has been restricted to *Paspalum notatum* (bahiagrass). Researchers at the University of Florida incorporated this grass into DSSAT by using the CROPGRO model, which simulates the growth and development of several dicotyledonous plants. Although they modified the values for physiological, phenological, and bromatological parameters to describe the characteristics of the species, its cultivar, and ecotype, they did not alter the model’s structure (Kelly 1995). For those parameters unavailable for bahiagrass, CROPGRO used the original values for soybean.

As well as the model presented here, other models exist for simulating pasture growth, including BLUE GRAMA, CENTURY, GRASMOD, GRASP, GRAZPLAN, and the HURLEY PASTURE models (Hanson et al. 1985; McKeon et al. 1990; Moore et al. 1991; Parton et al. 1993; Thornley and Verberne 1989; Van de Ven 1992). However, none of these models is part of an integrated agricultural simulation model because they do not include the use of different crops nor management options with sufficient sensitivity to the different environmental factors at the plot or farm level. Recently, however, the GRASP and GRAZPLAN models were incorporated into the APSIM model (McCown et al. 1996), which incorporates important elements from the DSSAT models. Nevertheless, its use is less widespread than DSSAT.

This paper describes the methodological process and results of calibrating and validating the CROPGRO model of DSSAT to simulate the criteria for dry matter (DM) production and N content of *Brachiaria decumbens* cv. Basilisk (CIAT 606) under different scenarios for climate, soils, and management.

MATERIAL AND METHODS

The CROPDGRD model is composed of the following input files: (1) plant characteristics, (2) the plant’s ecosystem, (3) trial management, and (4) interfacing file for simulation.

The files on plant characteristics are SPE, CUL, and ECO. The SPE file, also called the species file, contains those parameters that most represent the species physiological behavior over environments. It also contains parameters for photosynthesis, respiration, bromatological composition of each part of the plant, carbon, nitrogen, leaf growth, root parameters, seed and pod growth, phenology, pod loss, behavior and state of the flower in terms of photoperiod and temperature, growth and size of canopy, and internodes.

The CUL file, also called the cultivar file, provides information on photothermal, days, time between planting and flowering, time to first flower, first seed, or first pod, and time to maturity. The file also contains the maximum photosynthetic rate in the leaf and the leaf’s maximum length and specific area. Our study defined the parameters just described for *Brachiaria decumbens* cv. Basilisk (CIAT 606).

The ECO file, that is of the ecotype, requires very similar parameters to those just described for the cultivar, but with reference to the ecotype.

The grows environment is described by the “Soil” and “Climate” files. The “Soil” file provides parameters for the soil’s physical and chemical characteristics, and structure. The “Climate” file contains daily maximum and minimum tempera-tures, solar radiation, and rainfall. The “Time Series file” (“T” file) contains information on the cutting dates (of production and equalization), DM production, and incidence of insect pests. The “Interfacing” file (“X” file) links the files already described and contains information on sowing dates and systems, fertilization, emergence, and treatments.

The existing CROPGRO model was adapted, through calibration and validation, to simulate the dry matter production of *Brachiaria decumbens*, without modifying the model’s structure. Only the input parameters that define a crop species, cultivar, and ecotype were changed.

An extensive literature search was carried out on the necessary physiological, phenological and bromatological information for each of the grass' parameters. Samples of leaves, stems, and roots were taken to analyze their contents of N, carbohydrates, organic acids, ash, and lipids. Information on the photosynthetical characteristics of *B.* decumbens (i.e., SPE file) was scarce, which meant we used information on the *Brachiaria* genus in general and on C4 plants (tropical grasses). The CUL and ECO files were modified slightly because of the lack of information on photothermal days in the tropics, where hours of light and shade vary little according to season. Where specific parameters were not found for *B.* decumbens in the literature, we used those existing for bahiagrass.

Information on the plant's ecosystem and trial management was obtained from the database of the International Network for the Evaluation of Tropical Pastures (RIEPT, its Spanish acronym). Site selection was based on information available for the climate, soils, and DM production of a range of regions.

The fine tuning of parameters to calibrate the model for *B.* decumbens was done with four data sets:

- El Nus, Department of Antioquia, ICA (National Agricultural Research Program), 1984-1986,
- La Romelia, Department of Caldas, CENICAFE (National Coffee Research Center), 1982-1983,
- Carimagua, Department of Meta, CIAT, 1980-1982, and
- Santander de Quilichao, Department of Cauca, CIAT, 1979-1982.

Validation was done with two additional data sets from:

- El Gigante, Department of Huíla, CENICAFE, 1983-1986, and
- Urrao, Department of Antioquia, Secretariat of Agriculture, 1990-1993.

Water retention and soil conductivity were estimated according to soil texture, apparent density, and organic matter contents, using the Soil Parameters Estimate Program (SoilPar version 1.1; Donatelli et al. 1996, 1997). Solar radiation was estimated according to longitude, latitude, altitude, maximum and minimum temperatures, and rainfall, using the Global Solar Radiation Estimate Model (RadEst version 2.0; Donatelli and Campbell 1998).

The data on DM production was obtained from regional trials of type B of the RIEPT. At each site, a trial was performed where the forage represented the main plot, which itself was divided into four subplots for regrowth ages (at 3, 6, 9, and 12 weeks after the equalization cut), and replicated for maximum and minimum rainfall. Plots were standardized at 15 cm from the soil's surface, taking into account the grass' growth habit and following the methodology proposed by the RIEPT (Toledo and Schultze-Kraft 1982). Using this cutting height enabled us to simulate the growth of that part of the plant, not consumed by the animal, and the reserves of the plant for regrowth. Fertilization was similar for all sites: 22 kg ha^{-1} P (50 kg P_2O_5), 41.5 kg ha^{-1} K (50 kg K2O), 100 kg ha^{-1} N, 20 kg ha^{-1} Mg, and 20 kg ha^{-1} S. The P, Mg, and S fertilizers were incorporated at a 20 cm soil depth during sowing. The N and K fertilizers were fractionated as follows: one-third of the dosage was applied 28 days after sowing, one-third 13 weeks after establishment, and the rest 1 month before the dry season, or during the equalization cut.

Because CROPGRO lacks an option for grazing or cutting, the effect of partial shoot removal was simulated using the insect pest option. A new option MOWE was added to allow us to section the grass to a determined biomass weight. The grass' DM production at 15 cm was obtained in an additional field study, which showed that values ranged from 2000 to 7000 kg ha^{-1}.

The first calibration was made with the "El Nus" data set. According to the ratio between simulated (output files) and observed values, new simulations were made with different values of the parameters, but within the ranges cited in the literature. The same procedure was performed with data from the La Romelia, Carimagua, and Quilichao sites, looking for the best ratio between simulated and observed values for each site added and those already incorporated.

Available N in the plant is an output option of the model; from this value, protein level was calculated. The RIEPT methodology does not generate information about N or crude protein, making it impossible to compare with the simulated values. The new model option was then validated with the data sets from El Gigante and Urrao.

RESULTS AND DISCUSSION

Calibrating the model

Table 1 shows the ranges of the main parameters of the SPE and CUL files used for calibration and the final value used for validation. The most sensitive parameters in the SPE file were those for photosynthesis, respiration, N, leaf area, and leaf specific weight.

The best simulated-to-observed DM ratio was found with 5000 kg ha^{-1} DM as the value of grass production at 15 cm. This value was incorporated in the T file, in the insect pest option. The same value was added to the DM production in the RIEPT data sets, so that both values, simulated and observed, represented the same DM availability at soil level at a given moment. Annual DM production is represented by the integral above 5000 kg ha^{-1}.

Dry matter availability at 6 and 9 weeks at the El Nus, La Romelia, and Quilichao sites are shown in Figure 1. Pasture management in these sites is based on a rest period of 6 to 9 weeks. In contrast, for the Carimagua site, which had different management practices and a prolonged dry season, data for 9 and 12 weeks were used. Simulated data were compared with those obtained in the RIEPT trials for the same numbers of weeks. Figure 1 also shows rainfall data. The agreement between simulated lines and observed points indicates the degree of adjustment that was obtained by calibrating the model.

The number of evaluations (cuttings) depends on the annual distribution of rainfall at each site. In a unimodal distribution, with a prolonged dry season, as in Carimagua and Quilichao, the period between evaluations is wider. In contrast, the El Nus and La Romelia sites had no extensive dry season during the evaluated period, consequently, in the simulated value, there were no days without DM production.

The simulated-to-observed ratios for El Nus and La Romelia were good, being better for the first. At Carimagua, an inexplicable decline in production was observed in the simulated value for day 465 (to 4898 kg ha^{-1} DM). At Quilichao, the model adequately simulated the lack of DM production between day 270 and day 360, and between day 680 and day 790 because of water stress. The simulated data for this site showed that DM production declined to 4896 kg ha^{-1}, as a consequence of a greater than expected “consumption” in the insect pest option near day 100 during the equalization cut.

As a grass quality indicator, Table 2 shows the N values in leaves and stems.

Table 2. Range of upper and lower percentage of simulated N for leaf and stem in *Brachiaria decumbens* grass cut at 3, 6, 9, and 12 weeks at each experimental site used for calibrating the CROPGRO model.

Experimental site in Colombia	Leaf N (%)	Stem N (%)
El Nus	1.84-1.91	0.82-0.86
La Romelia	1.75-2.33	0.78-0.84
Carimagua	1.89-1.95	0.78-0.81
Santander de Quilichao	1.78-1.99	0.81-0.88

Validating the model

Validation showed that the simulated DM production with cutting intervals at 3, 6, 9, or 12 weeks, was, on the average, between 96 and 101% of the observed values for El Gigante (Table 3), and between 82 and 100% for Urrao (Table 4). At the latter site, pasture was established very late in the rainy season, causing the first equalization cut to coincide with a period of drought. The resulting DM production was much lower than the simulated production. But, if the data from the first cutting were excluded, we obtained a tight validation range of 98 to 101% for this experiment also.

For bahiagrass, the average ratio between simulated and observed values at the three sites was only 1.52, ranging between 1.15 and 2.22 (Kelly 1995). This means that the model was significantly more reliable in predicting DM production of *B.* decumbens than for bahiagrass. This result becomes more significant when we consider the wide range of climatic and edaphic conditions for calibration, management with four cutting options, and conditions of maximum and minimum rainfall that were used. The logical structure of the CROPGRO model, together with the quality of the RIEPT database, probably explains the close adjustment.

Table 1. The most sensitive parameters used in the SPE and CUL files of the CROPGRO model for incorporating *Brachiaria decumbens*, compared with the ranges found in the literature, laboratory analyses, and final values used.

Parameter	Definition	Range	Value	References[a]
PARMAX	Light level that gives 67% of the maximum photosynthesis (E m^{-2} d^{-1})	44-173	44	4, 16, **23**, 26, 27, 29, 33, 34, 37, 44, 47, 48, 58
PHTMAX	Photosynthesis with light saturation (g[CH_2O] m^{-2} d^{-1})	28-180	110	4, 9, 15, 16, **26**, 27, 33, 34, 37, 47, 58
KCAN	Light extinction coefficient in the canopy	0.37-0.86	0.86	**46**, 48
CCMP	CO_2 compensation point (mmol[CO_2] mol^{-1}[air])	10-80	10	Average of bahiagrass and soybean
CCMAX	Ratio between photosynthesis with optimal CO_2 and normal CO_2	1.40-2.09	1.9	Average of bahiagrass and soybean
LNREF	N concentration in the leaf for maximum photosynthesis (%)	0.80-3.90	2.60	**1, 4, 6, 19, 20, 24, 25, 36, 40, 50, 54, 55, 57, unpublished data (I. M. Rao)**
PROLFI	Maximum leaf protein concentration (fraction)	0.032-0.39	0.154	**1, 4, 19, 20, 25, 36, 41, 50, 54,** 55, **57, unpublished data (I. M. Rao)**
PROLFG	Normal leaf protein concentration (fraction)	0.032-0.39	0.110	**1, 4, 19, 20, 25, 36, 41, 50, 54, 55, 57, unpublished data (I. M. Rao)**
PROLFF	Minimum leaf protein concentration (fraction)	0.032-0.39	0.074	**1, 4,** 14, **19, 23, 25, 36,** 41, **50, 54, 55, 57, unpublished data (I. M. Rao)**
PROSTI	Maximum stem protein concentration (fraction)	0.019-0.13	0.079	**6, 14, 25, 36, 38, 55**
PROSTG	Normal leaf protein concentration (fraction)	0.019-0.13	0.056	**6, 14, 25, 36, 38, 55**
PROSTF	Minimum leaf protein concentration (fraction)	0.019-0.13	0.041	**6, 14, 25, 36, 38, 55**
PRORTI	Maximum root protein concentration (fraction)	0.0020-0.06	0.050	**38**, unpublished data (I. M. Rao)
PRORTG	Normal root protein concentration (fraction)	0.0020-0.06	0.025	**38**, 45, unpublished data (I. M. Rao)
PRORTF	Minimum root protein concentration (fraction)	0.0020-0.06	0.015	**38, unpublished data (I. M. Rao)**
PCARLF	Leaf cellulose concentration (fraction)	0.23-0.715	0.616	**14, 43, 54, bahiagrass**
PCARST	Stem cellulose concentration (fraction)	0.32-0.715	0.715	14, 54, **bahiagrass**
PCARRT	Root cellulose concentration (fraction)		0.619	**Calculated for sum of components = 1**
CADSTF	Fraction of non-structural carbohydrates stored in stem (fraction)	0.481-0.67	0.58	**17, 50, laboratory samples**
FINREF	Specific leaf area at emergence (cm^2 g^{-1})	76.3-329	207	**8, 57**
SLWSLO	Change of specific leaf weight per unit increase in LAI (g cm^{-2} per LAI unit)	0.0004-0.00071	0.0004	20, **unpublished data (I. M. Rao)**
ALPHL	Non-structural carbohydrates concentration in new leaves (fraction)	0.097-0.20	0.10	**17, 50**
ALPHS	Non-structural carbohydrates concentration in new stems (fraction)	0.115-0.40	0.11	**17, 50**
ALPHR	Non-structural carbohydrates concentration in new roots (fraction)	0.04-0.125	0.072	**38, 42**
RFAC1	Root specific length (cm g^{-1})	738-25549	7893	**10, 40, 41, unpublished data (I. M. Rao)**
LFMAX	Maximum leaf photosynthesis with light saturation, 350 ppm CO_2, 30°C and 21% oxygen (mg [CO_2] m^{-2} s^{-1})	0.62-9.44	2.20	**4, 15, 26, 27, 28, 34, 41, 49, 58**
SLAVR	Specific leaf area under normal conditions (cm^2 g^{-1})	145-227	225	20, **41**

[a] Numbers refer to the references found in "References" at the end of the text. References in bold indicate the paper where the value used in the simulations was found.

Table 3. Observed availability[a] of dry matter in *Brachiaria decumbens* (kg ha^{-1}) at 3, 6, 9, and 12 weeks in El Gigante, Colombia during 1983 to 1986. Results of the CROPGRO validation and the ratios between simulated and observed values.

Week	Eval. period[b]	Obs.	Sim.	Sim/Obs ratio	Week	Eval. period[b]	Obs.	Sim.	Sim/Obs. ratio
3	Max 1	5253	5451	1.04	6	Max 1	5470	5417	0.99
3	Max 1	5460	5524	1.01	6	Max 1	5390	5778	1.07
3	Min 2	5683	5390	0.95	6	Min2	5666	5702	1.01
3	Max 2	5546	5228	0.94	6	Max 2	5676	5411	0.95
3	Max 3	5766	5480	0.95	6	Max 3	5733	5832	1.02
3	Min 3	5593	5107	0.91	6	Min 3	5786	5102	0.88
3	Min 4	5746	5254	0.91	6	Min 4	5620	5085	0.90
3	Max 4	5370	5357	1.00	6	Max 4	5856	5677	0.97
Average				0.96					0.97
9	Max 1	5446	5332	0.98	12	Max 1	5643	5726	1.01
9	Max 1	5480	6072	1.11	12	Max 1	5546	6309	1.14
9	Min 2	5916	5943	1.00	12	Min 2	5983	6166	1.03
9	Max 2	5783	5675	0.98	12	Max 2	6016	6064	1.01
9	Max 3	5800	6074	1.05	12	Max 3	5900	6086	1.03
9	Min 3	5890	5182	0.88	12	Min 3	6000	5302	0.88
9	Min 4	5633	5256	0.93	12	Min 4	5896	5516	0.94
9	Max 4	5836	5673	0.97	12	Max 4	5930	5944	1.00
Average				0.99					1.01
Total average									0.98

[a] Availability of dry matter when pasture is cut at soil level.
[b] Minimum and maximum refer to rainfall; the number corresponds to the sequence of the evaluations carried out.

Table 4. Observed availability[a] of dry matter in *Brachiaria decumbens* (kg ha^{-1}) at 3, 6, 9, and 12 weeks, at Urrao, Colombia during 1990 to 1993. Results of the CROPGRO validation and ratios between simulated and observed values.

Week	Eval. period[b]	Obs.	Sim.	Sim/Obs ratio	Week	Eval. period[b]	Obs.	Sim.	Sim/Obs ratio
3	Min 1	5133	1815	0.35	6	Min 1	5377	2483	0.46
3	Max 1	5564	5258	0.95	6	Max 1	5600	5252	0.94
3	Min 2	5477	5199	0.95	6	Min 2	5470	5207	0.95
3	Max 2	5190	5334	1.03	6	Max 2	5437	5638	1.04
Average				0.82					0.85
9	Min 1	5483	2656	0.48	12	Min 1	5470	5472	1.00
9	Max 1	5540	5247	0.95	12	Max 1	5773	5399	0.94
9	Min 2	5577	5577	1.00	12	Min 2	5547	5787	1.04
9	Max 2	5513	5798	1.05	12	Max 2	5800	5927	1.02
Average				0.87					1.00
Total average									0.84
Total adjusted average[d]									0.99

[a] Availability of dry matter when pasture is cut at soil level.
[b] Minimum and maximum refer to rainfall; the number corresponds to the sequence of the evaluations carried out.
[c] Adjusted average excludes the first values of weeks 3, 6 and 9.

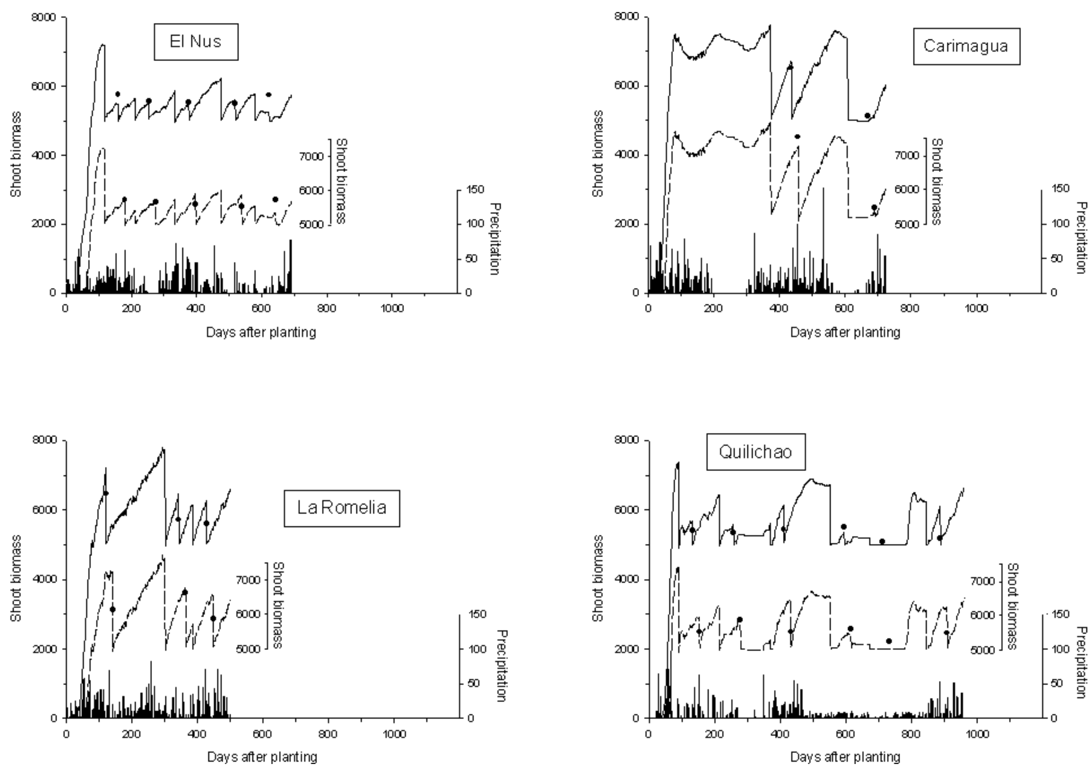

Figure 1. Results of calibrating the CROPGRO model for Brachiaria decumbems at the experimental sites, of El Nus, Carimagua, La Romelia, and Santander de Quilichao. Production cuts (kg/ha) for simulation were at weeks 6 (continuous line) and 9 (discontinuous line) which are compared with the observed values (points). Values for the Carimagua site correspond to weeks 9 and 12 in the simulation. The bar graphs at the lower part of each figure indicate the daily rainfall (mm).

CONCLUSIONS

The results of the validation suggest that the CROPGRO model, as applied to the growth of *B.* decumbens, constitutes a suitable tool for making decisions on establishing and managing this grass and for simulating scenarios of soil use. In practice, the main constraint in using the model is having to ensure the availability of 5000 kg ha^{-1} required for the design of cuttings—in this case at 15 cm above the soil level—or for grazing management. Managing pastures with animals could reduce the biomass to less than 5000 kg ha^{-1}, which, in turn, could affect the grass's capacity to regrow. The decision to use the model to simulate DM production at quantities less than or more than 5000 kg ha^{-1} requires that the user perform new calibrations to reach adequate adjustments.

However, the CROPGRO model is based on a dicotyledonous plant, whereas the grass is monocotyledonous. Knowing the close fit between simulated and observed values, the question remains on how justified would be the investment in creating a model for pastures based on monocotyledons.

Because the data on nitrogen, obtained in the model's output file, were not validated, we recommend caution in using these data, and that this option be first validated and compared with observed data.

CROPGRO can simulate the growth of pastures that have been established for several years. Assuming that the concentration of stems in the base of the plant will increase over time, the reliability of the model in simulating this situation is unknown because the data used both for calibration and validation covers only 4 years.

The incorporation of animals into the DSSAT system has still not been done. Work has advanced in that it had been easy to simulate animal consumption to some extent through the "pest" option. However, the effects of nitrogen recycled through feces and of damage caused by trampling have yet to be incorporated into the model. A new option to include feces as a source of nitrogen is currently being developed (A. J. Gijsman 1999, unpublished data). Future work should focus on developing an option for the model to measure the digestibility of the pasture.

The quality and utility of models depend on the quality of information used in their calibration and on the incorporation of such information into the input files. Although, for this work, the data used from RIEPT contained considerable information, they lacked measurements for daily solar radiation, and for soils; RIEPT characterized only the topsoil layers, whereas the CROPGRO model requires details from across the soil profile.

The experiment stations used in this study, both for calibrating and validating the CROPGRO model, were located in the low latitudes, which limits the use of the model for sites in other latitudes. *Brachiaria decumbens* could be sensitive to photoperiod (J. Miles, personal communication). Future research should therefore include studies to calibrate the model in sites other than in the low latitudes.

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