Calibration and validation of a growth model for alfalfa (Medicago sativa L.)

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ABSTRACT

A model originally developed by McCall and Bishop-Hurley to predict the growth of temperate perennial grasses (Modelo McCall) was modified. The aim was to develop a model capable to describe the aboveground growth of alfalfa pastures (Modelo Alfalfa) subjected to several climate and defoliation conditions. We used winter-active alfalfa pastures growing at a central region of Argentina (cities of Manfredi, Rafaela, Susana, Marcos Juárez and Paraná). Modifications realized at calibration step were made to represent the growth of alfalfa pure stands growing under non limiting conditions (i.e. irrigated and fertilized pastures) and that of pastures subjected to different defoliation frequencies. We modified: 1) the relationship between mean air daily temperature and solar radiation use efficiency (parameter α); 2) the equation taking account the use root reserves during a regrowth; and 3) parameter α to simulate pastures subjected to contrasting defoliation frequencies. At the validation step, we observed that Modelo Alfalfa adequately describe changes in aerial growth associated to variations in both, water availability and defoliation management. It was concluded that the Modelo Alfalfa is capable of representing the variations in growth caused by variations of mains biotic (defoliation) and non-biotic (climate) environmental factors.

Keywords: *Modelo Alfalfa, aerial growth, water availability, defoliation frequency.*

INTRODUCTION

Alfalfa (Medicago sativa) is still the main the main forage species in the country and is the basis of meat and milk production in the Pampas region (Basigalup and Rossanigo, 2007). To have a growth an alfalfa growth model will allow to analyze its productive variability under different growing conditions determined by seasonal and interannual climatic variations.

Also, it is possible to integrate this type of model to broader models in order to analyze the sustainability of milk production systems under different climate and price scenarios.

Currently, a specific dairy project by INTA is developing a model (Litwin and Engler, 2011) based on spreadsheets (Microsoft's Excel program) in order to generate a user-friendly modeling tool to represent milk production systems (SUSTENTAM).

To date, SUSTENTAM uses the data provided by local referents as an estimate of pasture production. The possibility of including a production of pastures submodel would allow to include their production' variability and its impact in dairy systems. This submodel is been developed jointly with a project dedicated to pasture research, also from INTA.

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The goal of this paper is to present the modifications and the results of the adjustments made to develop an alfalfa growth model (hereinafter, Modelo Alfalfa). We worked with a growth model (hereinafter McCall Model) developed in New Zealand for pastures composed mainly of temperate perennial grasses, ryegrass-based (McCall and Bishop-Hurley, 2003).

The McCall Model was designed to explain the spatial (sites) and temporal (years, seasons) variation in the growth of pastures integrated by temperate perennial grasses. The model can be programmed with Excel so it could be easily incorporated by different users, as well as by models that simulate production systems.

The equations of the McCall Model are easy to modify and there is abundant information to adapt them to alfalfa. The good predictability for perennial ryegrass, both in the original model (McCall and Bishop-Hurley, 2003) and in a modified version (Romera et al., 2009) and the simplicity of its operation make its use in other pastures promising.

The input data required by the model are minimal and readily available in terms of pasture (dry green biomass per unit area at the beginning of the regrowth), climate (minimum and maximum daily temperature, rainfall and daily potential evapotranspiration, and daily global radiation) and soil (water storage capacity of the soil, initial water content of the soil).

MATERIALS AND METHODS

Brief description of the original model (McCall Model)

The detailed description of the McCall Model can be found in the original work (McCall and Bishop-Hurley, 2003), so only the most relevant aspects for the development of the Modelo Alfalfa will be briefly presented here.

The abbreviations presented in this work will be the same as those used in the original work.

Basically, the model simulates the new growth from the incident solar radiation (I, MJ / m^2) intercepted by the plant cover. The intercepted proportion of incident solar radiation [c(G)] is a function of a state variable of the pasture, the green biomass expressed as dry matter (G, kg/ha of aerial dry matter).

Then, I is converted to aerial dry biomass through the use efficiency of global solar radiation for gross air growth (parameter α, g/MJ).

A seasonal factor c(G) associated with the vegetative/reproductive state of the pasture (gt), and factors that relate the growth pattern with the average daily air temperature (gT) and with the soil water status (gw). The parameter α is also affected by soil fertility and the forage species that predominates in a pasture at a given site.

McCall and Bishop-Hurley (2003) suggest that for the pastures and soils of New Zealand the parameter α fluctuates between 0.45 and 0.89 g/MJ depending on the soil fertility and the botanical composition of the pasture.

In its original version de model does not have equations that associate variations in the parameter α with variations in soil fertility (eg levels of organic matter, N, P, among others). Authors suggest calibrating the model at each site in which it will be used, and to make the α parameter fluctuate within a range of values identified in the literature (McCall and Bishop-Hurley, 2003).

In addition, there are other parameters mentioned by the authors for calibration. One of them is the phenological development and the relative value of the parameter α in vegetative pastures in relation to those in the reproductive state (v). Another relevant parameter is (gw), which modifies the growth according to the proportion of useful soil water in the depth explored by the roots.

The original model also contemplates the occurrence of senescence (σ), which is a proportion of the green aerial biomass that varies according to the phenological stage, which is higher when the pasture is reproductive.

Thus, the rate of senescence increases when the water content of the soil falls below 20% of useful water. These parameters (v, gw and σ) were not modified to develop the Modelo Alfalfa.

Changes implemented to develop the new model

Three aspects were prioritized for the development of the Modelo Alfalfa. The use efficiency of the global solar radiation for aerial gross growth (parameter α in the original version of the model) was modified, and the values of the gT factor that modify it, that is, the relation of the parameter with the temperature.

The equation that considers the relative importance of the carbon (C) and nitrogen (N) reserves used by the plants during the regrowth was also modified. In the third place, we sought to identify a value of the parameter α to simulate pastures subject to defoliation that contrast in their frequency.

These three aspects were prioritized because of their importance for the growth of forage species and because they are essentially different between alfalfa and temperate perennial grasses. It is worth mentioning that, in this work, an empirical approach was used to represent both the effect of the frequency of defoliation and the effect of plant reserves (C and N) on aerial growth.

The growth factor (gT) in the McCall Model has cardinal temperatures of 4 °C (minimum), 18 °C (optimum) and 35 °C (maximum). This relationship is different in alfalfa. To develop the Modelo Alfalfa a minimum temperature of 5 °C was considered (Thiébeau et al., 2011), as well as an optimum of 25 °C and a maximum of 35 °C. To establish the optimum, we considered that:

i) The optimal growth range reported by Doorenbos and Pruitt (1977) ranges between 25 and 30 °C.

ii) The rate of photosynthesis reached its maximum between 25 ° C and 35 °C (Al-Hamdani and Tood, 1990).

iii) The efficiency of radiation use shows increases up to 26 °C (Collino et al., 2005).

Although the maximum cardinal temperature could be higher than 35 °C we opted for the moment not to modify this value.

The maximum use efficiency value of the photosynthetically active radiation reported for alfalfa in Argentina at the optimum temperature (25 °C) was about 2.5 g/MJ (Mattera et al., 2013). Thus, a value of 1.25 g / Mj was assigned to the parameter α (efficiency of use of global solar radiation).

In grasses, the influence of the C and N content of reserves during regrowth is of little relevance (Schnyder and de Visser, 1999). In order to take into consideration the effect of the reserves, the Model McCall assumes an interception of the radiation of 20% [c(G) = 20] provided that the interception of the radiation (calculated by the model as a function of the green dry aerial biomass) is lower or equal to 20%. In this way, when the intercept is less than or equal to 20%, a growth is tacitly simulated from reserves.

The mobilization of C and N reserves is more important in alfalfa when compared to temperate perennial grasses. Therefore, under good growth conditions, plants resume an active growth from these reserves (Avice et al., 1996) after a cut that practically leaves no remaining foliar area.

To isolate the effect of the C and N reserves, we used data of regrowths under irrigation, and the best fit was sought using values of c(G) between 20% and 60%.

In both in the calibration and in the validation of the Modelo Alfalfa the observed aerial dry biomass values (eg field data) were contrasted with the modeled gross growth value. Senescence was not considered because in the experiments the time interval between defoliation was generally less than 450 accumulated degree days (ADD, base temperature = 5 °C) and therefore the biomass lost by senescence is practically despicable (Brown et al., 2005; Derrick Moot, personal communication, 2014).

Determinations performed prolonged sprouts show that the senescent biomass is null until 350 ADD and reaches values of 7-10% of the total cumulative growth at 700 ADD of the regrowth (Olivo, doctoral work in progress, 2016).

Both the severity and the frequency of the defoliation impact on the harvested crop (Davies, 1988). The effect of frequency is particularly relevant in alfalfa (Smith and Nelson, 1967).

The theoretical optimum moment for defoliation would be when a plant cover reaches the maximum average growth rates (Parsons and Penning, 1988) that correspond approximately to a 90-95% interception of solar radiation.

On the one hand, a value of 1.25 g/Mj was assigned to the α parameter in pastured defoliated at T-95. Since increases in shading levels would produce increases in the radiation use efficiency (Mattera et al., 2013), this value was increased to 1.50 g/Mj for less frequently defoliated pastures (T-95 + 150).

On the other hand, more frequent grazings have reduced the radiation use efficiency (Teixeira et al., 2008), so the parameter α was reduced to 0.7 g / Mj to model very frequently defoliated pastures (T-50).

Data used to calibrate and validate the alfalfa model (Modelo Alfalfa)

In all the analyzed cases the pastures presented an optimum plant coverage (over 90%), a post-cut green initial biomass of 200 kg/ha of dry matter (cutting height = 5 cm) was always considered, and data from cultivars with little winter rest (alfalfa group 9) were used.

The proposed changes to develop the Modelo Alfalfa were calibrated with data from regrowths, in which the accumulation of aerial dry biomass of alfalfa pastures that grew without water limitations (under irrigation) or nutritional limitations (N and P) was followed. This data was obtained at INTA Rafaela, INTA Manfredi and INTA Paraná.

These experiments were conducted on pastures with optimum coverage and strict pest control. In these experiments sequential cuts were made in order to evaluate the accumulation of aerial biomass during each regrowth, in different seasons of the year. When the pastures were not evaluated, they were still defoliated under rotary systems to avoid excessive accumulations of forage.

To calibrate the value of the parameter α according to the frequency of defoliation, we used data from pastures under irrigation from INTA Paraná (Spada et al., 2013) where three cutting frequencies determined by the percentage of intercepted incident radiation (%IR) and accumulated thermal time (accumulated day degrees, base temperature = 5 °C) were evaluated. T-50: defoliated every time the %IR reached 50%; T-95: defoliated every time the %IR reached 95%, and T-95 + 150: once the %IR reached 95% of interception, they were allowed to accumulate 150 degrees day and then they were defoliated.

To validate the Alfalfa Model we used three groups of data from alfalfa that grew under rainfed conditions, with an optimal plant stand. These data were obtained during the same experiments previously described (in the irrigated experiments of the AEFP-2492 project, see section "Changes made to develop the alfalfa model (Modelo Alfalfa)".

In general, the soils and climate in which the experiments were conducted were suitable for the cultivation of alfalfa (eg soils: phosphorus levels > 20 ppm, organic matter > 3%, pH close to neutrality and without limitations for root growth, climate: humid-subhumid temperate, 800-1000 mm annual rainfall, 22-25 °C average daily temperature in summer, 12-14 °C, average daily temperature in winter).

The first group of data corresponded to rainefd biomass accumulation with sequenced cuts within each regrowth, and obtained at INTA Rafaela (31° 11' S, 61° 30' W), INTA Manfredi (31° 41' S; ° 46' W) and INTA Paraná (31° 50' S; 60° 31' W). The second corresponded to the first year of production of six sowings under rainfed conditions in the district of Susana, 10 km away from INTA Rafaela (Berone, 2010). This last group of data was obtained by the trial network of the Chamber of Seed Producers of the Grain Exchange [Cámara de Semilleristas de la Bolsa de Cereales]. This data was included because the importance of having sowings for consecutive years, as because it was near the Rafaela site.

Unlike the first group of data, in this case the cuts are made following phenological criteria (10% of flowering or basal regrowth of 5 cm) without making intermediate biomass evaluations during a regrowth (that is, there is no intermediate evaluation of the biomass between cut and cut defined by the 10% flowering). Thus, we only had the final data of aerial biomass accumulation in each cut. The third group of data corresponded to data obtained under rainfed conditions at INTA Marcos Juárez (32° 36' S, 62° 00' W) where the same defoliation frequencies evaluated in the experiment by Spada et al. (2013) were evaluated.

The data of Marcos Juárez, also obtained in the project AEFP-2492, was used to validate the changes made in the parameter α in order to represent alfalfa pastures (with an adequate stand of plants) subjected to different defoliation frequencies.

Analysis of information

To evaluate the fit between the data from cops and those generated using the model, a visual inspection of the data was first performed with the relationship between the observed values (y axis) and modeled values (X axis) with the original and the modified versions (Piñeiro et al., 2008).

The difference (test t: 0.05) between the observed mean value (OMV) and modeling (MMV) was analyzed. We analyzed the slope, the intercept and the R2 of the relationship between the observed and the modeled values.

Analyzes were performed for individual harvests and when data was available we performed analyzes of accumulated biomass per season (spring, summer, autumn and winter) and per year.

RESULTS

Calibration of the relationship between the parameter α, temperature, and the reserves

Figure 1a shows that, in its original version, the McCall Model significantly underestimated the production of alfalfa, since:

i) It is significantly higher than the observed mean value (OMV) of the modeled mean value (MMV) and

ii) the slope and the intercept of the relationship between the observed and modeled values (X = Y) were, respectively, significantly lower than one and higher than zero (Table 1).

To modify the relationship between temperature and the parameter α without considering the importance of the reserves of C and N during regrowth (version 1 of Table 1) reduced this underestimation. But the significant differences between the OMV and MMV, and both the slope and the intercept of the relationship X = Y remained significantly different from 1 and 0, respectively (Figure 1b and Table 1).

Four versions were analyzed (versions 2 to 5 of Table 1) when considering the effect of the reserves. It was determined that when the interception of the modeled radiation [c(G)] is lower than a certain value, the model assumes said value.

	Original Version (McCall-Model)	Modified versions to develop the Modelo Alfalfa				
		[1]Version 1	Version 2	Version 3	Version 4	Version 5
[2]n	67	67	67	67	67	67
OMV (kg/ha)	1847	1847	1847	1847	1847	1847
MMV (kg/ha)	1145	1470	1626	1763	1887	2034
T-Test	[3]Sig.	Sig.	Sig.	No sig.	No sig.	Sig.
R^2	0,28	0,67	0,70	0,71	0,72	0,72
Intercept	1187 ([4] ≠ 0)	592 (≠ 0)	426 (≠ 0)	296 (≠ 0)	203 (= 0)	131 (= 0)
Slope	0,58 (≠ 1)	0,85 (≠ 1)	0,87 (= 1)	0,88 (= 1)	0,87 (= 1)	0,84 (≠ 1)

Table 1. Calibration. Observed mean value (OMV), modeled mean value (MMV), T-Test significance between OMV and MMV, coefficient of determination (R2), intersect and slope of the analysis between observed and modeled data using the original version (McCall Model) and modified versions to develop the Modelo Alfalfa.

[1]Version 1: only the relation between the parameter α and the temperature was modified. Version 2, 3, 4 and 5: same as version 1, but the use of C and N reserves during the regrowth was contemplated. For this, it was determined that when the interception of the modeled radiation [c(G)] is lower than a certain value, the model assumes said value (Version 2: c(G): 30%, version 3: c(G): 40%, version 4: c(G): 50%, version 5: c(G): 60%).

[2]Data under irrigation and without nitrogen limitation obtained at INTA Manfredi, Paraná and Rafaela.

[3]The acronym Sig. and No sig. denote, respectively, the presence and absence of significant differences (p<0.05) between OMV and MMV.

[4]The symbol ≠ denotes that the intersect and the slope are different (p<0.05) from 0 and 1, respectively. The symbol = shows that the intersect and the slope are equal (p>0.05) to 0 and 1, respectively.

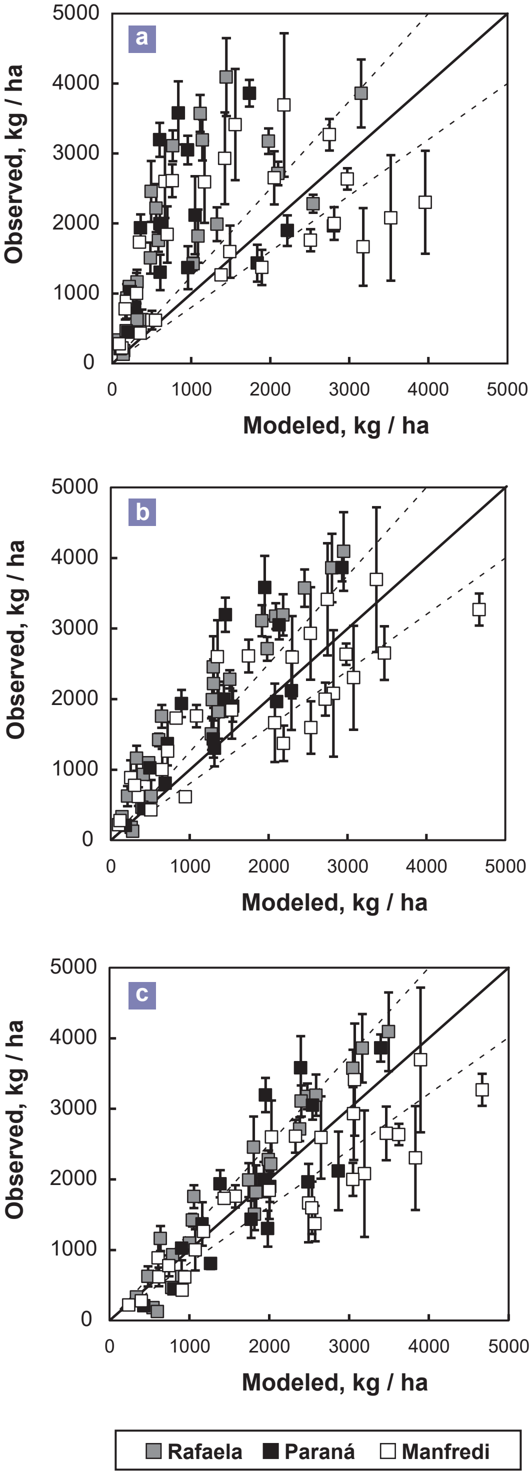

Figure 1. Calibration. Relationship between observed and modeled values using (a) the original version of the model developed by McCall and Bishop-Hurley (2003), (b) the modified version with the new relation of the parameter α with temperature, but without including the modifications for the use of root and crown reserves for growth, and (c) the modified version with the new relation of the parameter α with the temperature, and including the modifications for the use of root and crown reserves for growth. Dotted lines denote a deviation of ± 20% of the line 1:1 where x=y (full line), while the bars show ± 1 standard deviation of the observed values.

The obtained results indicate that version 4, which considers a threshold value of c(G) of 50%, presented the best fit since most of the modeled values were within an acceptable range (± 20% of the observed value observed). The significant differences between OMV and MMV, and between the intercept and the slope of the observed relation disappeared: the modeled were equal to 0 and 1, respectively (Figure 1c and Table 1).

Based on the results obtained in this calibration stage, we determined that the most appropriate version of the Modelo Alfalfa differs from the original version in two aspects:

1) The cardinal temperatures will be 5 °C (minimum), 25 °C (optimum) and 35 °C (maximum) and

2) to consider the greatest importance in the mobilization of the C and N reserves in alfalfa when compared with temperate perennial grasses, an interception of the radiation of 50% is assumed [c(G) = 50] provided that the interception of the radiation (calculated using the model based on the available dry green biomass) is less than or equal to 50%. The adjustments to represent pastures subject to different defoliation and validation frequencies were made using this version 4.

Adjustments in the parameter α to model variations in the defoliation frequency

In this work, adjustments were made a priori in the parameter α associated to the variations in the frequency of defoliation. The goal is to evaluate if it is possible - using this simple method - to properly represent the variations of productivity in pastures subject to different defoliation regimes (Teixeira et al., 2007).

To make these adjustments, the alfalfa production data obtained from INTA Paraná was used. When analyzing the information of the individual harvests, it can be observed that only defoliated pastures at an optimum frequency (T-95) were relatively well represented by the Modelo Alfalfa (Table 2).

Pastures defoliated at a higher (T-50) and lower (T-95 + 150) frequency, when compared to the optimum, were not adequately modeled (Table 2).

By incorporating all the treatments in a single regression, the differences between the different defoliation frequencies were adequately represented by the model (Table 2, Figure 2a). The model improved its performance when the information was analyzed after grouping it seasonally (Table 2, Figure 2b).

Validation

The developed model adequately simulated the rainfed regrowth (Figure 3a, Table 3) and it was not necessary to change the optimal value of the parameter α (1.25 g/MJ). It was necessary to reduce the value of this parameter from 1.25 to 1.00 g/MJ to adequately model the data set for the district Susana, because it overestimated growth.

Modelo Alfalfa: calibration of the model for defoliation frequency								
Statistical	**Individual crops**				**Seasonal**			
	T-50[2]	**T-95**	**T-95+150**	**All**	**T-50**	**T-95**	**T-95+150**	**All**
n[3]	24	15	13	52	7	7	7	21
OMV (kg/ha)	1022	2911	3680	2232	3506	6238	6836	5526
MMV (kg/ha)	1102	2790	3661	2229	3778	5979	6800	5519
T-Test	No Sig.[4]	No sig.	No sig.	No sig.	No sig.	No sig.	No sig.	No sig.
R^2	0,11	0,48	0,10	0,74	0,61	0,93	0,97	0,93
Intercept	685 (≠ 0)[5]	708 (= 0)	2588 (≠ 0)	244 (= 0)	1179 (= 0)	463 (= 0)	- 84 (= 0)	45 (= 0)
Slope	0,31 (≠ 1)	0,79 (= 1)	0,30 (≠ 1)	0,89 (= 1)	0,62 (= 1)	0,97 (= 1)	1,02 (= 1)	0,99 (= 1)

Table 2. Calibration. Observed mean value (OMV), modeled mean value (MMV), T-Test significance between OMV and MMV, coefficient of determination (R2), intersect and slope of the analysis between observed and modeled data using the modified version (Modelo Alfalfa 1) of pastures under different frequencies of defoliation. The result of the analysis for individual harvests and the seasonal harvests (spring, summer, autumn, and winter) is shown.

[1]Modelo Alfalfa: refers to version 4 (see Table 1) in which the cardinal temperatures are: 5 °C (minimum), 25 °C (optimum) and 35 °C (maximum). To contemplate the use of reserves an interception of 50% radiation [c(G) = 50] is assumed, provided that the interception of the radiation (calculated by the model as a function of the available dry green biomass) is less than or equal to 50%.

[2]Three defoliation frequencies: T-50= defoliated each time the %IR reached 50%. T-95= defoliated each time the %IR reached 95%, and T-95 + 150= once the %IR reached 95% of interception, 150 ADD accumulated and then defoliation occurred. To model T-50, T-95 and T-95 + 150, the parameter α in the Modelo Alfalfa was 0.70 g/MJ, 1.25 g/MJ and 1.50 g / MJ, respectively.

[3]Data under irrigation, obtained in INTA Paraná.

[4]The acronym Sig. and No sig. show, respectively, the presence and absence of significant differences ($p<0.05$) between OMV and MMV.

[5]The symbol ≠ denotes that the intersect and the slope are different ($p<0.05$) from 0 and 1, respectively. The symbol = shows that the intersect and the slope are equal ($p>0.05$) to 0 and 1, respectively.

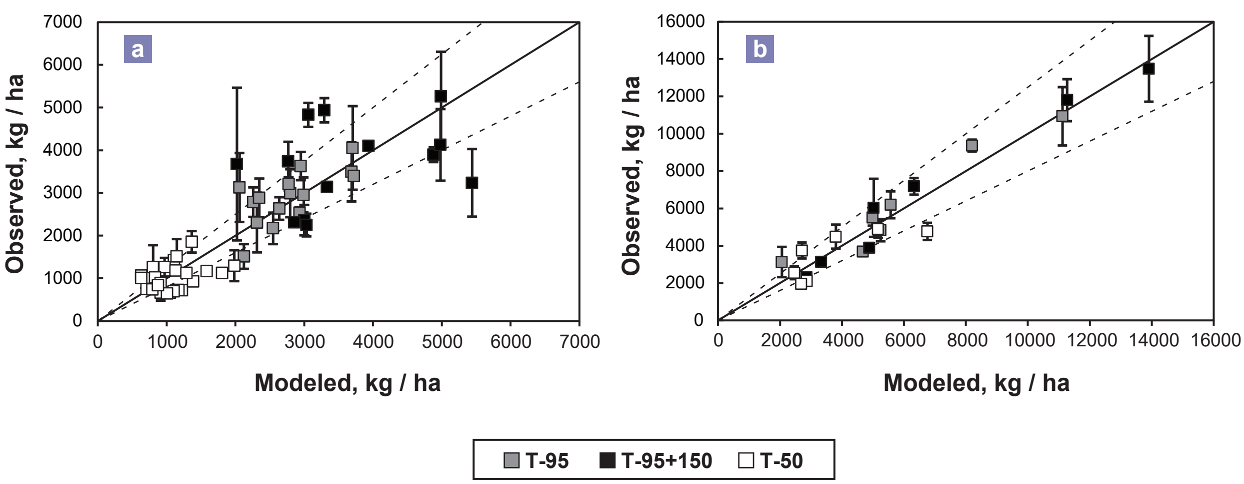

Figure 2. Calibration of the parameter α to model pastures under different frequencies of defoliation. Relationship between observed (obtained under irrigation at INTA Paraná) and modeled values using version 4 of Table 1, where to model T-50 (white squares), T-95 (gray squares) and T-95 + 150 (squares), the α parameter in the Modelo Alfalfa 0.70 g / MJ, 1.25 g / MJ and 1.50 g / MJ, respectively.
(a) Data group of individual cuts. (b) Data group of cuts grouped by season. The dotted lines show a deviation of ±20% of the line 1:1 where x=y (full line), while the bars show ± 1 standard deviation of the observed values.

The fit was not good when the individual harvests were analyzed, but it improved when analyzed at a seasonal time scale (Figures 3b, c, and Table 3).

Finally, the changes made in the value of the parameter α were validated to simulate pastures subjected to contrasting defoliation frequencies. The adjustment was not good when the individual harvests within each defoliation treatment were analyzed (Figure 4a, Table 4).

As in the calibration stage, the result improved when an analysis incorporating all the treatments in a single regression (Table 4) was performed. Although improvements were observed when analyzing the seasonally accumulated

Modelo Alfalfa: evaluation of the model under under rainfed conditions.			
Statisticals	**Statisticals INTA Paraná, Rafaela y Manfredi (Individual crops)**	**Susana (Individual crops)**	**Susana (seasonal accumulated)**
n	67	45	18
OMV (kg/ha)	1318	1702	4255
MMV (kg/ha)	1137	1708	4270
T-Test	Sig.[2]	No sig.	No sig.
R^2	0,80	0,52	0,84
Intercept	162 (= 0)[3]	671 (≠ 0)[3]	537 (= 0)
Slope	1,00 (= 1)	0,60 (≠ 1)	0,87 (= 1)

Tabla 3. Validation. Observed mean value (OMV), modeled mean value (MMV), T-Test significance between OMV and MMV, coefficient of determination (R2), intersect and slope of the analysis between observed and modeled data using the modified version (Modelo Alfalfa 1) of pastures under rainfed conditions at INTA Paraná, Rafaela, Manfredi. Individual harvests were analyzed, while for the district of Susana the results of individual harvests and seasonal accumulates (spring, summer, autumn, and winter) are shown.
[1]Modelo Alfalfa: refers to version 4 (see Table 1) in which the parameter value to the optimal cardinal temperature is 1,25 g/MJ for INTA (Paraná, Manfredi and Rafaela) and 1,0 g/MJ para Susana. Cardinal temperatures are: 5 °C (minimum), 25 °C (optimum) and 35 °C (maximum). To contemplate the use of reserves an interception of 50% radiation [c(G) = 50] is assumed, provided that the interception of the radiation (calculated by the model as a function of the available dry green biomass) is less than or equal to 50%.
[2]The acronym Sig. and No sig. show, respectively, the presence and absence of significant differences ($p<0.05$) between OMV and MMV.
[3]The symbol ≠ denotes that the intersect and the slope are different ($p>0.05$) from 0 and 1, respectively. The symbol = shows that the intersect and the slope are equal ($p>0.05$) to 0 and 1, respectively.

data, it can be observed that the Modelo Alfalfa tends to underestimate productivity at this site, particularly in pastures defoliated with less frequency (Figure 4b, Table 4).

DISCUSSION

As McCall and Bishop-Hurley (2003) stated, “To be useful a model must be able to assist in achieving a stated objective”.

The aim of this work was to develop a model to represent the growth of alfalfa pastures under different environmental conditions and defoliation management. The modifications made to the model originally developed to represent grasslands of perennial ryegrass allowed to adequately represent the growth of alfalfa pastures in different soils, climates, and different defoliation management conditions.

The setting of ecophysiological parameters of the model according to alfalfa significantly improved the modeled result, when compared to the values observed under conditions without water or nutritional limitations (Table 1), that is, potential conditions of each site. However, forage crops, in agreement with the majority of annual crops destined for harvest (eg wheat, corn), present variations in their growth capacity associated with variations in water availability and (macro) nutrients (Sinclair and Rufty, 2012).

The Modelo Alfalfa was able to adequately represent variations due to water availability.

On the one hand, it was able to adequately model the growth of pastures both under irrigation and under rainfed conditions. On the other hand, the irrigated pastures (Table 1) produced more forage than the rainfed pastures (Table 3) and this difference was reflected in the modeled data (compare the OMV of Table 1 versus the OMV of Table 3, and then compare the MMV of version 4 Table 1 with the MMV of Table 3).

As for the variations in nutrient availability, the McCall Model does not have a sub-model of soil fertility, and the authors suggest modifying the parameter α (conversion efficiency of solar radiation) between 0.45 and 0.90 g/MJ (¡McCall and Bishop-Hurley, 2003).

On the one hand, in our opinion alfalfa in Argentina is not usually very limited in terms of macronutrients. Thanks to its ability to fix nitrogen symbiotically, it usually grows with adequate nitrogen availability (Mattera et al., 2012; Sardiña and Barraco, 2013a, b; Sevilla and Pasinato, 2013).

On the other hand, with some exceptions, it is usually used in soils with adequate P levels. It would then be expected that, given the suspicion of lower levels of P in soil, the Modelo Alfalfa can be used simply by reducing the value of the parameter α.

In this regard, although the reasons may not have been related to a low availability of nutrients, in this work it was only necessary to reduce the value of the parameter α (from 1.25 to 1.00 g/MJ) in only one of the evaluated environments (Susana, Table 3) in order to improve the adjustment made by the Modelo Alfalfa.

In the case of the other environments, with defoliated pastures at an optimum frequency in relation to the produc-

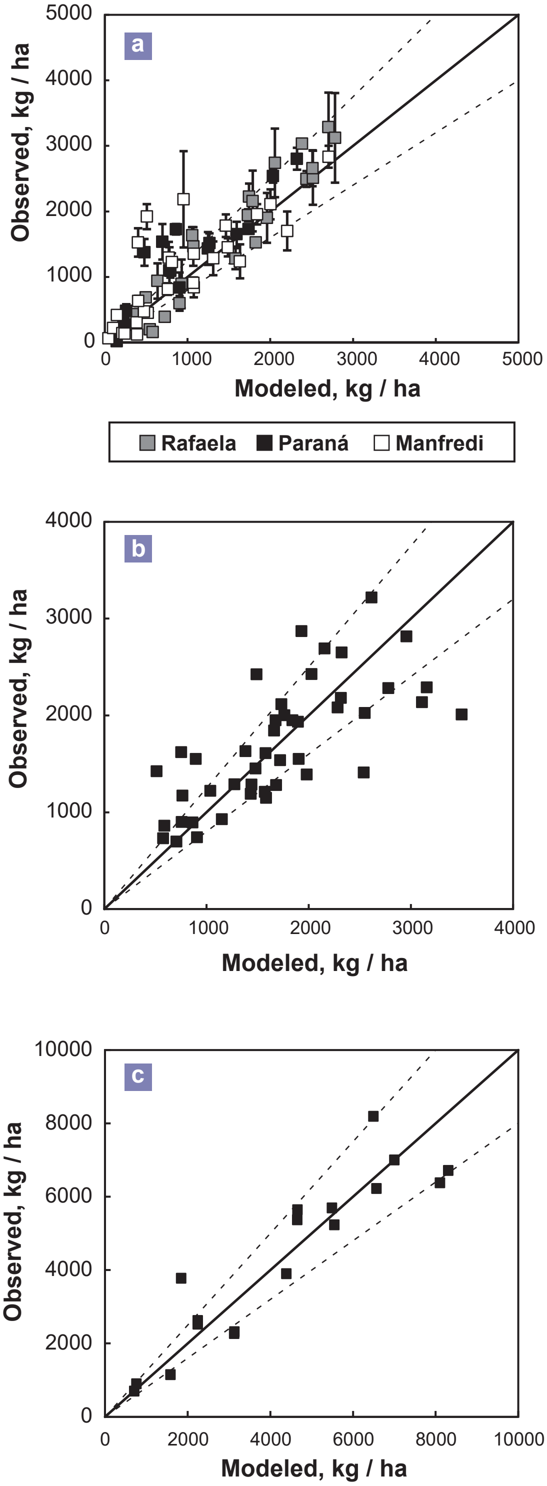

Figure 3. Validation. Relationship between observed and modeled values using the version developed to model the growth of alfalfa (Modelo Alfalfa).
(a) Group of rainfed data obtained in Manfredi, Rafaela and Paraná.
(b) Group of data of individual cuts obtained under rainfed in Susana.
(c) Group of data per station obtained in Susana. The dotted lines show a deviation of ± 20% of the line 1:1 where x=y (full line), while the bars show ± 1 standard deviation of the observed values.

tion, quality and persistence of the alfalfa pastures (Cangiano, 2007) (version 4 of Table 1, and treatment T-95 of Tables 2 and 4), alfalfa growth was adequately represented using the parameter α at its optimal value (1.25 g/MJ).

The good performance of the Modelo Alfalfa should be highlighted to represent, especially at the seasonal scale (eg spring, summer, autumn, and winter) the differences in productivity of pastures under different defoliation frequencies (Tables 2 and 4).

Although the general calibration of the model was good, the validation with the data group of Marcos Juárez presented the tendency to underestimate the productive values. This result may be attributed to the fact that the site has groundwater layers close to the surface that could have contributed with water not considered in the model.

In the future, it would be interesting to develop mechanistic functions that contemplate both the contribution of groundwater and the impact of the frequency of defoliation on the parameter α. To our knowledge, the rest of the models currently used for alfalfa do not have submodels that contemplate these two factors.

Also, the empirical (but based in the literature) modeling of aerial growth in the scenario of changes in the frequency of defoliation does not limit the utility that the model has to fulfill the objective for which it was developed.

Of course, this does not rule out the importance that the Modelo Alfalfa could have in the future development of a general relationship that associates variations in RUE with variations in frequency of defoliation.

On the one hand, as it is demonstrated in the present work, the Modelo Alfalfa reflects, at least at the seasonal scale, the productive differences of pastures defoliated with different frequency. We understand that this is a significant aspect and a remarkable contribution. For example, this will allow to analyze - at the level of system modeling - the result of contrasting strategies for the management of alfalfa pastures in different systems, avoiding (or complementing) very expensive and long-lasting experiments. Thus, to have this tool will allow to evaluate in a short time and at low cost (via modeling) the response of production systems to management alternatives.

On the other hand, in order to conduct this analysis it is necessary to incorporate a submodel into the Modelo Alfalfa because because pastures defoliated at a higher frequency tend to offer less forage quantity but with higher quality (Cangiano, 2007) - when compared to less frequent defoliated pastures.

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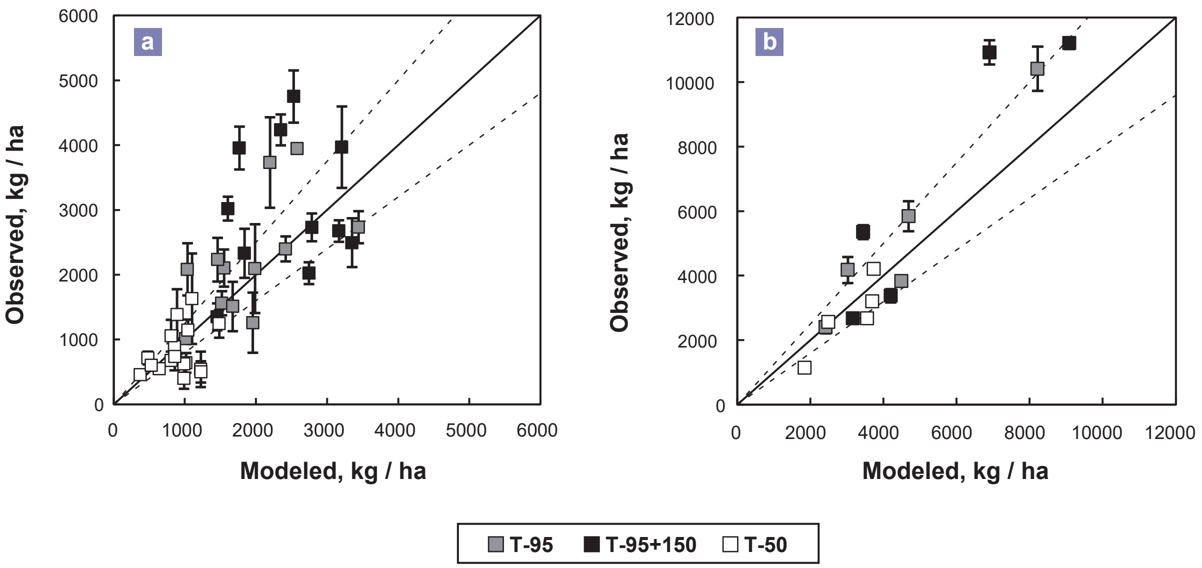

Figure 4. Validation of changes made to the parameter α to model different defoliation frequencies. Relationship between observed (obtained under rainfed conditions at INTA Marcos Juárez) and modeled values using the version 4 of Table 1, where to model T-50 (white boxes), T-95 (gray boxes) and T-95 + 150 (black boxes), the α parameter in the Modelo Alfalfa was 0.70 g/MJ, 1.25 g/MJ and 1.50 g/MJ, respectively.
(a) Group of data of individual cuts.
(b) Group of cut data grouped by season. The dotted lines show a deviation of ±20% of the line 1:1 where x=y (full line), while the bars show ± 1 standard deviation of the observed values.

Modelo Alfalfa: evaluation of the model under different defoliation frequencies

Statisticals	Individual crops				Seasonal			
	T-50[2]	T-95	T-95+150	All	T-50	T-95	T-95+150	All
n[3]	17	12	11	40	5	5	5	15
OMV (kg/ha)	810	2222	3048	1849	2756	5332	6706	4931
MMV (kg/ha)	902	1903	2437	1624	3065	4569	5361	4332
T-Test	No Sig.[4]	No sig.	No sig.	No sig.	No sig.	No sig.	No sig.	No sig.
R^2	0,12	0,36	0,02	0,57	0,75	0,92	0,85	0,89
Intercept	430 (= 0)[5]	741 (= 0)	2485 (= 0)	102 (= 0)	- 737 (= 0)	- 687 (= 0)	- 1224 (= 0)	- 1407 (≠ 0)
Slope	0,42 (= 1)	0,78 (= 1)	0,23 (= 1)	1,08 (= 1)	1,14 (= 1)	1,32 (= 1)	1,48 (= 1)	1,46 (≠ 1)

Table 4. Validation. Observed mean value (OMV), modeled mean value (MMV), T-Test significance between OMV and MMV, coefficient of determination (R2), intersect and slope of the analysis between observed and modeled data using the modified version (Modelo Alfalfa 1) of pastures subject to different defoliation frequencies. Results for individual crops and seasonal accumulates (spring, summer, autumn, and winter) are shown.

[1]Modelo Alfalfa: refers to version 4 (see Table 1) in which the cardinal temperatures are: 5 °C (minimum), 25 °C (optimum) and 35 °C (maximum). To contemplate the use of reserves an interception of 50% radiation [c(G) = 50] is assumed, provided that the interception of the radiation (calculated by the model as a function of the available dry green biomass) is less than or equal to 50%.

[2]Three defoliation frequencies: T-50= defoliated each time the %IR reached 50%. T-95= defoliated each time the %IR reached 95%, and T-95 + 150= once the %IR reached 95% of interception, 150 ADD accumulated and then defoliation occurred. To model T-50, T-95 and T-95 + 150, the parameter α in the Modelo Alfalfa was 0.70 g/MJ, 1.25 g/MJ and 1.50 g/MJ, respectively.

[3]Rainfed data, obtained at INTA Marcos Juárez.

[4]The acronym Sig. and No sig. show, respectively, the presence and absence of significant differences ($p<0.05$) between OMV and MMV.

[5]The symbol ≠ denotes that the intersect and the slope are different ($p>0.05$) from 0 and 1, respectively. The symbol = shows that the intersect and the slope are equal ($p>0.05$) to 0 and 1, respectively.

ability of bovine milk production systems, and PE-1126073: Eco-efficient and low-carbon pastures in livestock).

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